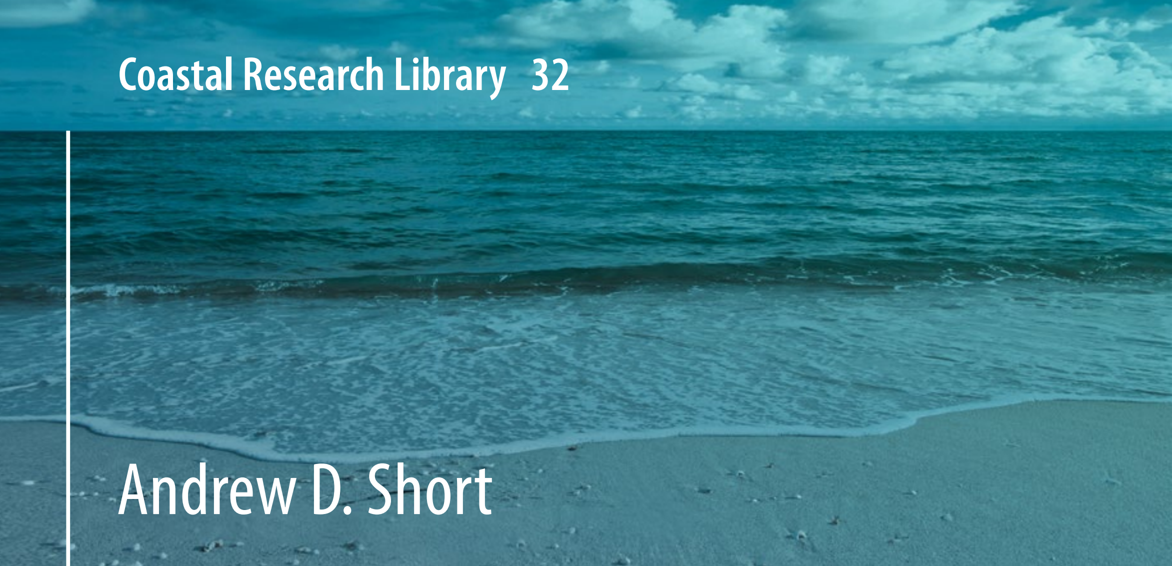

Coastal Research Library 32

Andrew D. Short

Australian Coastal Systems

Beaches, Barriers and Sediment Compartments

Springer

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Volume 32

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To all who have worked and published on the Australian coast

Foreword

The initial idea for a comprehensive coverage of the Australian coast using the sediment compartment approach emerged during the period when the Australian Government had a Department of Climate Change. Between 2008 and 2012, a range of coastal initiatives emerged involving federal and state agencies, Commonwealth Scientific and Industrial Research Organisation (CSIRO), consultants, universities and local government. There was a concerted effort to look at different ways the nation could approach coastal adaptation issues associated with the new climate era. Geoscience Australia initially took a lead role in examining basic characteristics that constitute the framework for studying different types of coastal settings. In 2011, the Government established a National Coast and Climate Change Council to look further at ways all the work supported by the Department, including that by Geoscience Australia, could facilitate action to manage those built and natural assets under threat from forces of climate change. This Council produced a number of recommendations, one of which was accepted by the incoming federal government in 2013, namely, to undertake a national coastal sediment compartment study.

As part of the extended arrangements to support the National Climate Change Adaptation Research Facility (NCCARF) based at Griffith University, funds were made available to undertake a detailed study of sediment compartments covering some 35,000 km of the Australian coast. This project was part of CoastAdapt and was embedded into its Shoreline Explorer module. A small team of coastal 'experts' was engaged to review literature and data and use their own field knowledge to subdivide, describe and forecast potential change at a scale referred to as secondary compartments. This concept of primary, secondary and tertiary compartments fitted into a broader hierarchical division of the entire coast. It was an enormous continental scale effort that now requires more detailed analysis at both regional and local scales. Andy Short in this book has taken up this challenge.

Australia is blessed with an amazing variety of coastal systems reflecting in the first instance its geological history and then its various geographical settings. Our geomorphological knowledge of the coast is sufficiently mature to enable those involved in science, policy and management to understand how these systems have responded over time to different sea levels, climatic conditions, habitat change and human impact. Much has been written, and much more work will be undertaken to address future problems of shoreline change, inundation of low-lying lands and adverse impacts on human settlements and infrastructure. Andy Short has played a major role in developing this knowledge base, and in this book, we have a foundation for further exploring and addressing all those vital issues that we confront around our coast.

Former Chair, National Coast and Climate Change Council Bruce Thom
Sydney, NSW, Australia

Preface

The Australia coast is long, highly variable and for the most part uninhabited, with most of the population located along the central-southeast and southwest leaving vast areas in between with few or no people. Forty percent of the 11,000 plus beaches have no access, and many have no formal name with the same applying to many of its headlands and rocky points and tidal creeks. What this indicates is that while parts of the coast are well-known, densely populated and highly developed, the majority is not. What this also means is that while there is considerable attention directed to the populated parts of the coast, most Australian's know little about their vast coast, other than it is large. However, all parts of the Australian coast whether it be Bondi, Surfers Paradise or the Eighty Mile Beach are a vital part of our national boundary, and all have and are responding to a range of processes that daily deliver waves, tides and sand to continue the ongoing evolution of the shoreline, and all are potential sites for future development. Parts of the coast that were until recently remote, inaccessible and undeveloped are now seeing development ranging from major ports to tourist resorts. If we are to effectively manage Australia's large coastline and be prepared for the future, we need to know the nature of the entire coast, the processes it faces and how these have shaped its past, present and future. The future will be increasingly compromised by the ongoing pressure to develop more of the coast at a time when climate change is delivering rising sea levels, changing wave climates, coastal inundation and recession. To help address these issues, we need to know about its nature, geology, geomorphology, ecology, dynamics and change both now and into the future.

I have had the opportunity to visit the entire coast and have attempted to read all that has been written about its physical systems and have used this knowledge to write this book. It is but a first step in documenting the entire Australian coast and what we know about it, which, while extending to 1000 pages, 550 figures and over 1000 references, is still not very much. There is a huge amount of work to do to achieve the level of detailed knowledge required for each individual coastal sediment compartment if we are to effectively understand and manage its behaviour. Hopefully, this book will serve as reference and in some cases a starting point for ongoing research and application.

This book is intended for all those who are personally and professionally interested in the coast; for students, educators, coastal scientists, engineers, consultants and managers and all levels of government involved with the coast; and for anyone who wants to know more about any part of our vast coastline.

Moruya Heads, NSW, Australia Andrew D. Short

Acknowledgements

This book is about recording what we know about the Australian coast: its beaches, barriers and sediment compartments in 2019. It is based on the author's own investigations and experience of the entire coast and the work of all those other coastal scientists and engineers who have contributed to our knowledge of the coast. The book has utilised throughout the framework developed by the Australian Coastal Sediment Compartment Project. All those involved in the project and its development are also acknowledged. This includes at Geoscience Australia: F Howard, Martyn Hazelwood, A McPherson, D Moore, Scott Nichol, Tony Nicholas and D Owens; at the National Climate Change Adaption Research Facility: David Rissik; the coastal 'expert team' of Bruce Thom, Ian Eliot, Matt Eliot, Nick Harvey, Chris Sharples and Colin Woodroffe; and the two teams at Damara in Western Australia (Tanya Stul, Ian Eliot, Matt Eliot, Bob Gozzard) and at the Water Research Laboratory in New South Wales (A Mariani, Francois Flocard, James Carley, Chris Drummond, N Guerry, Angus Gordon, Ron Cox, Ian Turner), who respectively undertook the west and east coast sediment compartment case studies. In addition to those mentioned above, I would particularly like to acknowledge the work and publications of the following which I have found most useful in writing this book: Tony Belperio, Eric Bird, Tom Boreen, Bob Bourman, Ron Boyd, Anne Brearley, Brendan Brooke, John Chappell, Lindsay Collins, Claire Courtney, Peter Cowell, Jack Davies, Peter Flood, Doug Fotheringham, Shari Gallop, Bob Galloway, Edmund Gill, Ian Goodwin, Angus Gordon, Vic Gostin, John Hails, Dave Hanslow, Mitch Harley, Ernest Hodgkin, Peter Harris, Andrew Heap, Mark Hemer, Patrick Hesp, David Hopley, John Hudson, Noel James, Joe Jennings, Brian Jones, Mike Kinsela, Brian Lees, Brian Logan, Doug Lord, Marc Marsden, Gerd Masselink, Kathleen McInnes, Tom Mortlock, Colin Murray-Wallace, Jonathan Nott, Tom Oliver, Dean Patterson, Chari Pattiaratchi, Phillip Playford, Ken Pye, Skip Rhodes, Peter Riedel, Peter Roy, Peta Sandertson, DJ Searle, Tom Shand, Jamie Shulmeister, Vic Semeniuk, Craig Sloss, Reg Sprigg, Toru Tamura, Sira Tecchiato, Rodger Tomlinson, Rob Tucker, Ian Turner, John Veevers, Richard Whitlow, Eric Wolanski, and Don Wright.

All of the above have worked in collaboration with many others who are also acknowledged.

While I have attempted to find and include all the relevant and up-to-date literature, there will be some that has not come to my attention. In my searching, I have found 50 years of reading the literature, Research Gate and Google all very useful, but no doubt some important works will have eluded my searching, my apologies to those I may have missed.

I would also like to especially acknowledge Bruce Thom, who gets part of the blame for me starting this book but also for critical early advice and agreeing to write the Foreword, and also Brendan Brooke for his early critical advice.

Likewise, I would like to acknowledge my wife Julia, who put up with me spending 2 years in ‘the office’ when there were better things and jobs to do ‘outside’.

I would again like to thank Charles W Finkl, Series Editor of the Coastal Research Library, for suggesting and then encouraging me to undertake this book, and at Springer Petra Van Steenbergen for once again organising the contract and always being available for advice and direction, and finally to the Springer editorial and production team at SPi Global, co-ordinated by Solomon George and managed by Ramkumar Rathika who transformed the manuscript into this book. Sincere thanks to all.

Contents to Volume 1

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Abbreviations and Units

ABSAMP	Australian Beach Safety and Management Program
ACSCP	Australian Coastal Sediment Compartments Project
ARI	annual return interval
GBR	Great Barrier Reef
GAB	Great Australian Bight
EAC	East Australian Current
ECC	east coast cyclones
ENSO	El Nino-Southern Oscillation
FTD	flood tide delta
GPR	ground-penetrating radar
ICOL	intermittently closed and open coastal lagoon
IPO	Interdecadal Pacific Oscillation
ka	thousand years ago
Ma	million years ago
M	million
MSLP	mean sea-level pressure
NCCARF	National Climate Change Adaptation Research Facility
PC	primary compartment
PMT	postglacial marine transgression (Holocene sea-level rise)
RI	return interval (years)
RTR	relative tide range
SAM	Southern Annular Mode
SC	secondary compartment
SOI	Southern Oscillation Index
SSB	shelf sand body
SST	sea surface temperature
SLR	sea-level rise
STR	subtropical ridge
TC	tertiary compartment
TL	thermoluminescence

Locations

QLD	Queensland
NSW	New South Wales
VIC	Victoria
TAS	Tasmania
SA	South Australia
WA	Western Australia
NT	Northern Territory
The Bight	Great Australian Bight
The Gulf	Gulf of Carpentaria
The gulfs	South Australia gulfs

Sediment Compartments

PC	primary compartment
SC	secondary compartment
TC	tertiary compartment

Beach Types and States

BS	beach state	
WD	wave-dominated	
TM	tide-modified	
TD	tide-dominated	
Wave-dominated (WD)		
	D	dissipative
	TBT	longshore bar and trough
	RBB	rhythmic bar and beach
	TBR	transverse bar and rip
	LTT	low tide terrace
	R	reflective
Tide-modified (TM)		
	R+LTT	reflective + low tide terrace
	R+LTR	reflective + low tide rips
	UD	ultradissipative
Tide-dominated (TD)		
	B+RSR	beach + ridged sand flats
	B+SF	beach + sand flats
	B+TSF	beach + tidal sand flats
	B+TMF	beach + tidal mud flats
Others		
	R+RF	reflective + rock flats
	R+CF	reflective + coral (reef) flats

Symbols

crenulation ratio = shoreline distance/direct distance

H_o	deepwater wave height
H_s	significant wave height (height of 1/3 highest waves)
H_{max}	maximum wave height (height of 5% highest waves)
H_b	breaker wave height
kt	kilotonnes (1000 tonnes)
$M\ m^3$	barrier volume, M = million
$m^3\ m^{-1}$	barrier volume per meter of beach
T	wave period
T_p	peak wave period
$TWh\ yr^{-1}$	terawatt hours per year
W_s	sediment fall velocity ($m\ s^{-1}$)
σ	standard deviation
Ω	dimensionless fall velocity
^{o}	degree
μm	microns
‰	parts per thousand
$\approx$	approximately
δ’	embaymentisation parameter

Chapter 1
The Australian Coast: Introduction

Abstract The 30,000-km-long Australian coast surrounds the world's oldest, flattest and driest continent with aspects of the continent reflected in the nature of the coast. Being a continent it is also surrounded by three oceans and several seas which deliver waves, tides and sediment to build beaches and barrier systems which occupy half the coast, together with estuaries, deltas and rocky shore. The geology ranges from ancient cratons in the west and centre to more recent oregons across the eastern third and a series of sedimentary basins resulting from buckling during the continent's northward drifting. Coastal processes can be divided into a northern coast dominated by meso to mega-tides, low sea waves and southeast trade winds and a southern coast with micro-tides, exposed to moderate to high swell and west through south winds. The waves, tides and sediments combine to produce a range of beach types and states that have distinct regional variation linked to the coastal processes. Likewise, the coastal barriers vary considerably around the coast with regional variation in nature, extent and volume. The coast is divided into a hierarchy of provinces, divisions, regions and primary and secondary sediment compartments, which are used as the framework for this book. This chapter reviews the coastal processes that operate around the coast and range of coastal systems they produce.

Keywords Australian coast · Geology · Climate · Coastal processes · Beaches · Barriers · Estuaries

1.1 Introduction

The Australian coast was occupied by indigenous people during and following the Holocene rise in sea level that flooded the continental shelf and coastal valleys and formed the present coast about 7 ka. However, it has only been in more recent times that it has been comprehensively mapped and then investigated. The mapping of the coast began with the Dutch in 1606 taking another 200 years before Flinders, in 1814, produced the first comprehensive description and map of the Australian coast and for the first time called the continent 'Australia'. The scientific investigation of the coast waited another century before geologists and geographers began taking an

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interest in the nature and dynamics of parts of the coast. And now another century later, we are finally getting an understating of the entire coast – both its physical systems, which will be the topic of this book, and its rich and varied ecosystems. At the same time, there has been a 'sea change' with the coastal zone becoming an increasingly preferred place to live, work and recreate, as well as attract tourists. This pressure is being expressed in a wide range of ways from an increasing number and size of commercial ports and boating marinas, increasing number of coastal tourist resorts even in remote locations, upgrading of coastal access and the growth and spread of coastal cities, towns and communities. All of this has led to a substantial and rapidly increasing coastal population, development and usage. This has now been coupled with the challenges of the coastal impacts of climate change. The coast is caught between our rush to live and build there and our need to stop, reassess and perhaps in places retreat in the face of present and future environmental impacts. Major decisions are being made right around the coast as how best to accommodate our desire and in fact need to utilise this great resource – our coast – while ensuring it is utilised sustainably and in a way that maximises the maintenance of the natural coastal systems and minimises the adverse impacts of our presence. This book is aimed at contributing to this discussion by encapsulating what we presently know about the physical nature of the coast and particularly its sedimentary systems that comprise about half the coast in the form of beach, dunes, barriers, deltas and estuarine shores.

The overall aim of this book is to provide the reader with an understanding of the physical nature of the entire Australian coast and its regions, as well as sufficient information to understand the coast at a regional level. The book is written for coastal professionals – scientists, engineers and managers – as well as students learning about our great coast and for the public who wish to know more about the coast that you find on the coffee table and in tourist brochures. The book uses the results of the Australian Coastal Sediment Compartments (ACSC) project (Thom et al. 2018) to divide the coast into a hierarchy of provinces, divisions, regions and compartments, the details of which are presented in Sect. 1.7. The book is divided into the northern tropical province and the southern temperate province, with the provinces roughly divided by the Tropic of Capricorn with boundaries located at Exmouth Gulf in the west and Hervey Bay-Fraser Island in the east. Within these two provinces, the coast is divided into seven divisions based on general location and orientation, then into 23 regions based on local geology and into 102 primary compartments (PC) based on prominent boundaries, followed by 354 secondary compartments (SC), which have an average length of 85 km and each of which is described to some degree in this book. Within each compartment the book describes the nature of the coast, its beaches and barrier systems and other major coastal systems such as estuaries and deltas, together with the modes of sediment transport and area and volume of Holocene beach and dune deposits. The book does not go however into the details of the as yet unmapped ~1000 tertiary compartments (TC), which may be as small as a single beach.

Chapters 1–15 cover the tropical northern coast from Exmouth Gulf in the west around the top to Hervey Bay in the east. They provide an introduction to the entire coast: its geology, climate and coastal and oceanographic processes (Chap. 1) and the northern tropical province (Chap. 2). This is followed by the coastal geology, processes, beach and barrier systems of the northwest (Chaps. 3 and 4), the Kimberley-Territory (Chaps. 5, 6, 7 and 8), the Gulf of Carpentaria (Chaps. 9, 10, 11 and 12) and the northeast (Chaps. 13, 14 and 15) divisions and their 9 regions and 37 PCs and 126 SCs. Chapters 16–33 cover the temperate southern half of the coast from Fraser Island around to the Exmouth Peninsula. It commences with an introduction to the southern temperate province (Chap. 16) followed by the southeast division (Chaps. 17, 18, 19, 20 and 21) and then the great southern (Chaps. 22, 23, 24, 25, 26, 27, 28, 29 and 30) and the southwest (Chaps. 31, 32 and 33) divisions and their 14 regions and 65 primary compartments and 228 secondary compartments. It finished with Chap. 34 that presents an overview and review of the coast and its status and future.

1.2 The Coast

The Australian coast surrounds an entire continent and is exposed to three of the world's major oceans, their waves and tide regimes. Its 30,000 km of open coast shoreline is a rich tapestry of sandy beaches, rocky shores, mangrove-lined tidal flats and fringing coral reefs that extends between 9–43°S latitude (Fig. 1.1) and ranges in climate from tropical to temperate and from humid to arid. Its beaches are a mix of quartz (silica) grains derived from erosion of the land and carbonate detritus produced by marine organisms. The sand ranges in colour from pure white to yellow to brown together with some pink, green and black and in size from fine sand to boulders, each colour and size indicative of the source(s) of the material. This seeming diversity does however have much structure and organisation, particularly over smaller sections where common geology, sediments, waves, winds, tides and biota may produce a range of similar beach and coastal systems. There are 10,796 mainland beaches around Australia, occupying half of the coast. They range from small pockets of sand to the three longest beaches each more than 200 km in length, while the types of beach range from high energy southern Australia beaches with persistent swell and 0.5-km-wide surf zones to the quiet tide-dominated beaches with kilometre-wide sand flats of the north. Likewise, the rocky sections contain every rock type from porous limestone to sedimentary and metasedimentary rocks to igneous basalt and resilient granite, while the mangroves, non-existent in Tasmania, grow to tall, kilometre-wide forests on the northern shores. This book is about this coast – all of it. It does however focus on the physical nature of the coast, its coastal processes, geology and sedimentary systems particularly the beaches, dunes and barrier systems that make up much of the open coast, together with reference to the estuarine and deltaic systems. The focus is on the evolution of these systems, their present nature and likely impacts of climate change based on our present knowledge of the coast.

While Australia may be the world's oldest continent, the coast is young and dynamic. Most of the coast formed when rising sea level flooded the continental

Fig. 1.1 Map of Australia showing some of the major coastal locations and rivers discussed in this book. (Source: Short and Woodroffe 2009)

shelf and came to rest at its present level about 7 ka, called the postglacial marine transgression (PMT). The sea-level rise and accompanying waves and tides immediately set to work modifying the coast – flooding the continental shelf and eroding rocky shores to form sea cliffs and rock platforms, moving into larger coastal rivers and valleys to form estuaries and bays and sweeping sand shoreward from the flooded continental shelf to be deposited where space was available as over 10,000 beach and dune systems, which now occupy about half the coast, the remainder predominately rocky shore. At the same time, the rivers and streams continued to flow to the coast depositing mud, sand and gravel to begin infilling the estuaries and in places build deltas and supply sand directly to the shore to build more beaches and dunes. As sea level stabilised, the newly flooded coast and bays provided a nutrient-rich, shallow habitat for a wide range of flora and fauna including salt marshes, mangroves, seagrass meadows and coral and algal reefs. These marine ecosystems and their carbonate detritus have also supplied about half the sand to build the beaches and coastal dunes. Across the north the warm seawater has interacted with the carbonate-rich beach sand to cement the beaches forming hard beachrock, while across the semi-arid south and west, the carbonate-rich sand dunes have been slowly turned into dunerock. Now more than 7000 years since sea level first lapped at our present shoreline, the coast reflects the interaction of all these physical, biological and chemical processes. In order to understand and appreciate any part of the Australian coast, all these factors must be taken into account to see how they have interacted over time to form the wide range of coastal types and systems around the continent and how each still influences the coastal behaviour today.

1.2.1 Dimensions and Classification

The actual length of the Australian coast is an ongoing debate. In this book the length of the open Australian mainland coast including Tasmania is based on Galloway and Bahr (1979) and is taken as 30,270 km. However, the length of the coast depends on how it is measured. Galloway used an inlet-bay closure width of 1 km, not measuring any shoreline within bays with an entrance narrower than 1 km, such as Sydney Harbour. Also, in the predigital age, Galloway and Bahr used topographic maps to plot the coast, which will inherently decrease the accuracy of the measure. As you decrease the closure width, the amount of coast located in bays and estuaries will increase, and so too will the overall length of the coast, with it increasing to 60,630 km with a 0.1 km closure width but only 24,330 km with a 100 km closure. Likewise, by using digital measures of the coast, a much higher order of accuracy and detail and length can be obtained. For this reason, a range of measures have been published, including 25,000 km (*The World Factbook*), 60,000 km (Geoscience Australia) and 66,500 km (www.wikipedia.org). It can, however, easily reach 120,000 km if all estuaries, tidal creeks and smaller indentations are included. In addition, when the hundreds of islands are included the coast length will grow accordingly, with Galloway and Bahr (1979) and Galloway (1982) counting 11,600 islands of which 6096 with an area > 0.8 ha have a total shoreline length of 21,300 km. This book will stick with the ~30,000 km as it provides a good measure of the 'open' coast, avoiding many of the smaller estuaries and bays. While these estuarine systems are an extremely important component of the coast, they are not covered in any detail in this book for two reasons – first, this book wishes to focus on the open coast, and second, a separate book would be required to do justice to the hundreds of Australia's estuarine systems (see Bucher and Saenger 1991).

The classification of the Australian coast commenced with Davies (1977) who used climate to divide the coast between Exmouth Gulf and Hervey Bay into the tropical north coast and warm temperate south coast and then into four 'provinces': the tropical arid northwest, tropical humid north-northeast, warm temperate humid southeast and warm temperate arid south. He also noted that each 'province' had characteristic wave energy, tide range and nearshore gradients together with beach-barrier types. Finally, he mapped the extent of coral reefs, mangroves, dunerock and their reefs and plotted major river discharge, providing the first first-pass assessment of the entire coast. The following year, Bird (1978) divided the coast into 19 coastal sediment systems based on the nature and source of sediments, and Gill (1982) identified seven coastal types based on a combination of climate, geomorphology and sediment type. Galloway et al. (1980) was the first to systematically map the landform types (mud flats, mangroves, sand and dunes) based on 10-km-long by 3-km-wide sectors around the entire coast. They then calculated the area of each landform type per 600-km-long coastal segments, which were then tallied by state and for Australia.

As more detailed information has become available on the nature of the coast and its various systems, the coast has been classified according to the estuaries (Bucher and Saenger 1991; Heap et al. 2001), beaches (Short 2006a), barriers (Short 2010b) and shoreline type and stability (Sharples et al. 2009), while Griffin et al. (2010) and Hazelwood et al. (2013) developed a 'national coastal geomorphology' framework to provide a consistent geomorphic classification of Australian coastal landform types. Geoscience Australia's OzCoasts site (http://www.ozcoasts.gov.au/index.jsp) provides a range of information about the coast, its estuaries, deltas, beaches and habitats. Finally, the Australian Coastal Sediment Compartments project (http://coastadapt.com.au/coastadapt-interactive-map; Thom et al. 2018) mapped a hierarchy of sediment compartments around the entire coast which is used as a framework for this book and is discussed in more detail in Sect. 1.7.

1.3 Geology

1.3.1 Geological Evolution

The size, extent and shape of the Australian coast are a product of its geology and its geological evolution with the geology or bedrock forming the continental shelf and exposed as rocky shore along approximately half the coastline. Erosion of the hinterland bedrock has also supplied terrigenous sediment to the coast and shelf via the vast network of rivers and creeks. As a consequence there is considerable geological inheritance embedded in the present coast and shelf which expresses itself directly in the form of continental shelf, the rocky shore, headlands, reefs and drowned valleys and indirectly in its influence on coastal process including waves, tide and longshore transport. At a mesoscale Porter-Smith and McKinlay (2012) quantified the Australian coast and shelf based on its shelf morphology, rugosity (topographic unevenness), geology and lithology which were correlated with wave and tidal power. They found that the coast was straighter where the lithology was homogenous, compared to mixed lithologies, concluding that lithology determines the coastal complexity signature with wave energy providing a secondary mechanism and geological inheritance having a major influence in the variability of coastal complexity. On the shelf Brooke et al. (2017) identified a range of drowned coastal features (palaeoshorelines) spread across the shelf with concentrations around 30–40 m and 50–60 m depth, remnants of periods of lower sea levels.

The Australian continent consists of two major geologic components. The western and central region is part of the Australia craton, which includes the ancient Pilbara-Yilgarn Craton in the west, the uplifted Kimberley Basin and Arunta craton

Fig. 1.2 The Australian continent is composed of the large Australia craton which was unified by 1800 Ma and a younger series of oregons (Kanmantoo, Lachlan and New England fold belts) which accreted the eastern third of the continent by 200 Ma. (Source: Short and Woodroffe 2009)

in the north and the Gawler Craton in the south, all of which were merged into the great Australia Craton by 1800 Ma (Fig. 1.2). This was followed by successive episodes of mountain building (oregons) associated with the Tasman Fold Belt (400 Ma) and Lachlan Fold Belt (200 Ma), which formed the eastern third of the continent when it was part of the great Gondwanaland supercontinent, centred on Antarctica. Then about 154 Ma, rifting began with Australia separating from Gondwanaland, starting in the northwest, forming the Western Australian coast and working counter-clockwise around the coast, finally breaking away from Antarctica about 100 Ma. It then began drifting north about 43 Ma forming the southern Australian coast and gradually opening up the Southern Ocean. This was followed by rifting in the Tasman Sea (85–60 Ma) which separated the New Zealand-Chatham Rise from southeastern Australia opening up the Tasman Sea and forming the southeast Australian coast between southeast Queensland and Tasmania and, finally, rifting in the northeast (55–50 Ma) that opened up the Coral Sea and formed the northeast coast. Both rifting events also uplifted and formed the eastern highlands that parallel the coast from north Queensland to western Victoria.

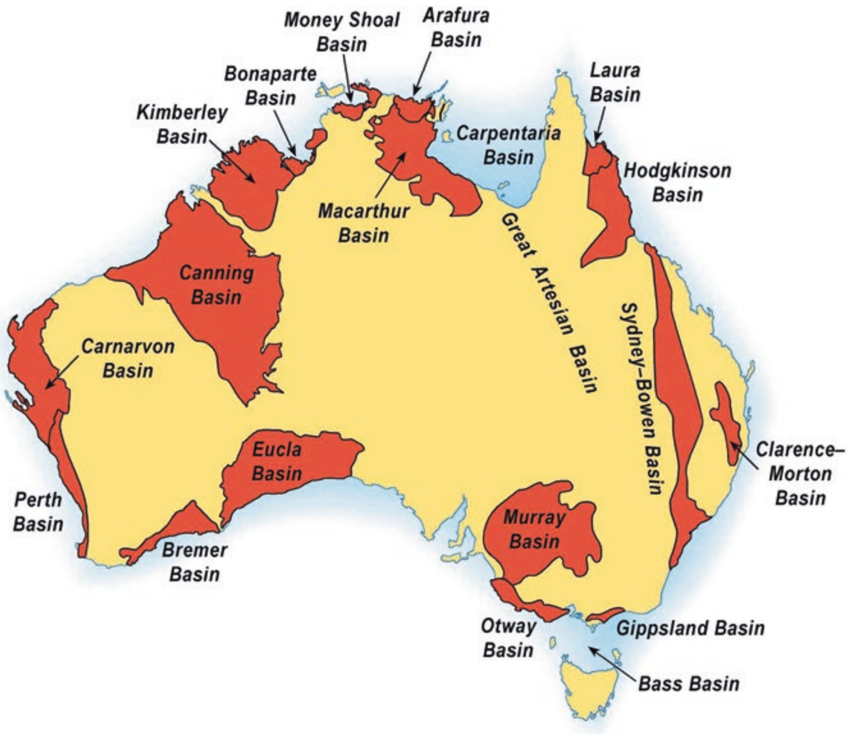


Fig. 1.3 Australia's coastal sedimentary basins. (Source: Short and Woodroffe 2009)

The northward migration of the continent caused regional buckling around its perimeter leading to the formation of a series of shallow coastal basins (Gippsland, Bass, Otway, Murray, Nullabor, Perth, Carnarvon, Canning, Bonaparte, Arafura and Carpentaria; Fig. 1.3). Once formed the basins began infilling with terrigenous and/or marine sediments, and most were subsequently uplifted, with only parts of the Gippsland and entire Bass basins still submerged. Today these basins occupy approximately half the Australian coast and are the site of the longest beach systems and generally lower lying, lower gradient coastal hinterland.

1.3.2 Coastal Geology

The geology of the coast depends on its nature and evolution and ranges from ancient 3500 Ma old granites to recent sediments. In general, the rocks of the Australian craton are old (>1800 Ma) and heavily metamorphosed, apart from the younger rocks found within the sedimentary basins. The basins generally have younger (<100 Ma) horizontally bedded sedimentary rocks, while the intervening cratons and fold belts have older often heavily metamorphosed metasedimentary and igneous rocks, including granites and basalts. For a more detailed description of Australia's geology, see Johnson (2004), and for regional geologies, see Day et al. (1975) for Queensland, Scheibner and Basden (1996) for NSW, Birch (2003) for Victoria, Burrett and Martin (1989) for Tasmania, Drexel and Preiss (1995) for South Australia and Geological Survey of Western Australia (1990) for Western Australia.

Australia's coastal geology is therefore a product of its geological evolution over the past 3500 Ma and includes the role of plate tectonics in forming the actual coast and sea-level fluctuations, which determine the location of the shoreline. Today approximately half the coast is bedrock, forming rocky sections, as well as individual headlands, bluffs, cliffs, platforms, reefs and islands, while sandy beaches make up most of the other half wherever accommodation space is available. Australian beaches average just 1.37 km in length, with most bordered by bedrock headlands and underlain by bedrock. Furthermore, approximately half the beach sand is quartz or siliceous sand grains ultimately derived from erosion of the hinterland granites and sandstones. Therefore, the geology of the coast and the hinterland plays a major role in both the nature of the rocky coast and the intervening beach systems.

1.4 Climate

1.4.1 Air Masses and Pressure Systems

Australia's climate is controlled by its tropical to mid-latitude location and surrounding oceans, which combine with its size and flatness to dictate the prevailing air masses and the associated pressure systems. Table 1.1 lists the air masses, their source-location, characteristics and typical weather, and Fig. 1.4 shows the seasonal pressure systems, the dominance of the sub-tropical high and seasonal penetration of humid maritime air masses onto the continent. The continent's size and sub-tropical location result in the sub-tropical high-pressure system residing over the continent year round, centred at 36°S in summer and 30°S in winter. The highs bring dry stable conditions to the interior year-round and the north in the winter. Rainfall is delivered by the humid maritime air masses (Table 1.1 and Fig. 1.4) that reside over the surrounding oceans and seas and periodically penetrating the continent bringing rain and some snow. The northwest monsoons (Em) bring summer rain across the north; the trades (pTm) deliver rain to the northeast coast year-round peaking during summer; and the westerlies (Sm and NPm) and their associated fronts bring frontal rain to the south coast, particularly during winter (Fig. 1.5b). The dominating high maintains a dry interior and central west coast, restricting rainfall to the coastal fringe in the north, east and parts of the south (Fig. 1.5a, b).

During *summer* the high is centred at 32°S permitting two heat lows to form over the Pilbara and Cloncurry regions (~20°S). These link to form the equatorial low

Table 1.1 Australian air masses: sources, characteristics and weather

Code	Air mass	Source	Characteristics	Weather-region
NPm	Modified polar maritime	Southern Ocean 55–68°S	Cold, moist, unstable	Cold fronts to southern Aust and NZ
Sm	Southern maritime	Southern Ocean 35–55 °S	Cool, moist, unstable low, stable aloft	Cool, moist cloudy – S Aust
tTm	Tropical maritime Tasman	North Tasman Sea	Warm, unstable, moist to high levels	Warm, cloudy, drizzly – E Aust
pTm	Tropical maritime acific	Tropical western Pacific	Warm, unstable, moist	Heavy rain and tropical cyclones – N QLD
iTm	Tropical maritime Indian	Eastern Indian Ocean	Warm, unstable, moist	Rain to NW Aust
Em	Equatorial maritime	Seas north of Australia	Very warm, unstable, moist	Summer monsoon in N Aust
Tc	Tropical continental	Central Australia	Very hot, dry and unstable in summer, cooler in winter	Hot, dry, cloudless to northern (winter) and Central Aust
sTc	Sub-tropical continental	South Central Australia	Warm dry, dominates in winter	Warm and dry in south Central Aust (winter)

Source: Sturman and Tapper (1996, p. 121–123)

and are the site of the Intertropical Convergence Zone (ITCZ). The low draws in warm humid air from the north, converging on the ITCZ, which arrives as the summer northwest monsoon (Em, Table 1.1), commonly known as 'the wet'. The monsoons deliver humid conditions and convectional rain across the north between December and May (Figs. 1.4b and 1.5a). On the south side of the ITCZ, the anticyclonic high delivers the southeast trades which bring summer orographic rain to the east Queensland coast but inland move as a dry wind across the continent flowing offshore as hot dry winds in the west. The ITCZ is also responsible for the initiation of tropical cyclones in the northeast Indian Ocean/Arafura Sea (iTm), the Gulf of Carpentaria and the Coral Sea (pTm) as discussed in Sect. 1.4.2.

In the south the high dominates the climate keeping the subpolar lows and their frontal rain well south of the continent, with only Tasmania receiving substantial summer rain from this source. In the southeast however, east coast lows (tTm) can form throughout the year and deliver cyclonic conditions including periodic heavy rain and flooding, strong winds and high seas along the southeast coast.

During winter the equatorial low and ITCZ move to the northern hemisphere, and the high shifts north to 30°S. The high delivers trade winds across northern Australia which on the east coast bring some winter rain to the northeast coastal fringe. However, for the rest of the north, the trades deliver dry winter conditions, including the northern and northwest coasts where the trades flow offshore. In the

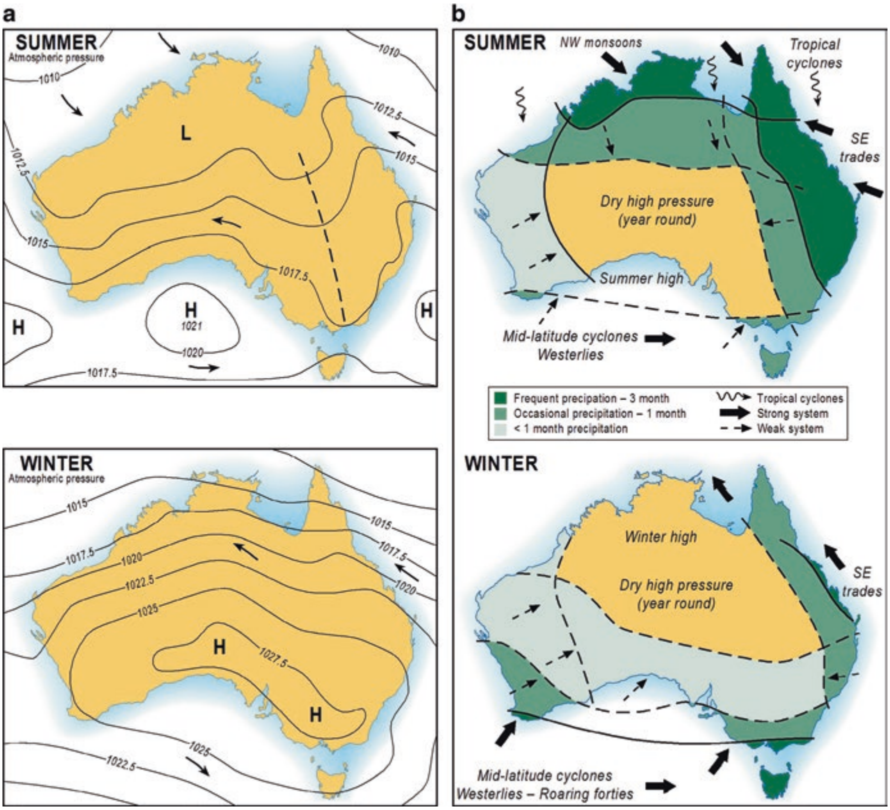


Fig. 1.4 (**a**) Australia's dominant summer and winter pressure systems and (**b**) the timing and extent of onshore maritime flowing into the Australian continent, bringing seasonal precipitation. (Source: Short and Woodroffe 2009)

south the subpolar lows shift closer to the coast and between the slowly migrating high-pressure systems can penetrate the continent bringing winter frontal and orographic rain (Sm and NPm; Fig. 1.5b) to the southwest and across southern South Australia, Victoria, Tasmania and southern NSW, while east coast lows can also deliver winter rain to the southeast coast.

Temperatures are controlled by latitude, with generally hot summer conditions across the north and centre and with warm but milder conditions across the south. During summer the mean maximum along the north coast ranges from 30 to 40 °C with the temperatures increasing southward to peak in the lower Gulf of Carpentaria (Fig. 1.5c). During winter temperatures range from the mid-20s on the eastern Cape York Peninsula to mid-30s increasing both northward and to the west (Fig. 1.15d). In the south summer temperatures are mild to warm (18–28 °C), while during winter they are cool to cold (15–20 °C). Frosts are rare at the coast, and snow only falls in higher southeast alpine regions.

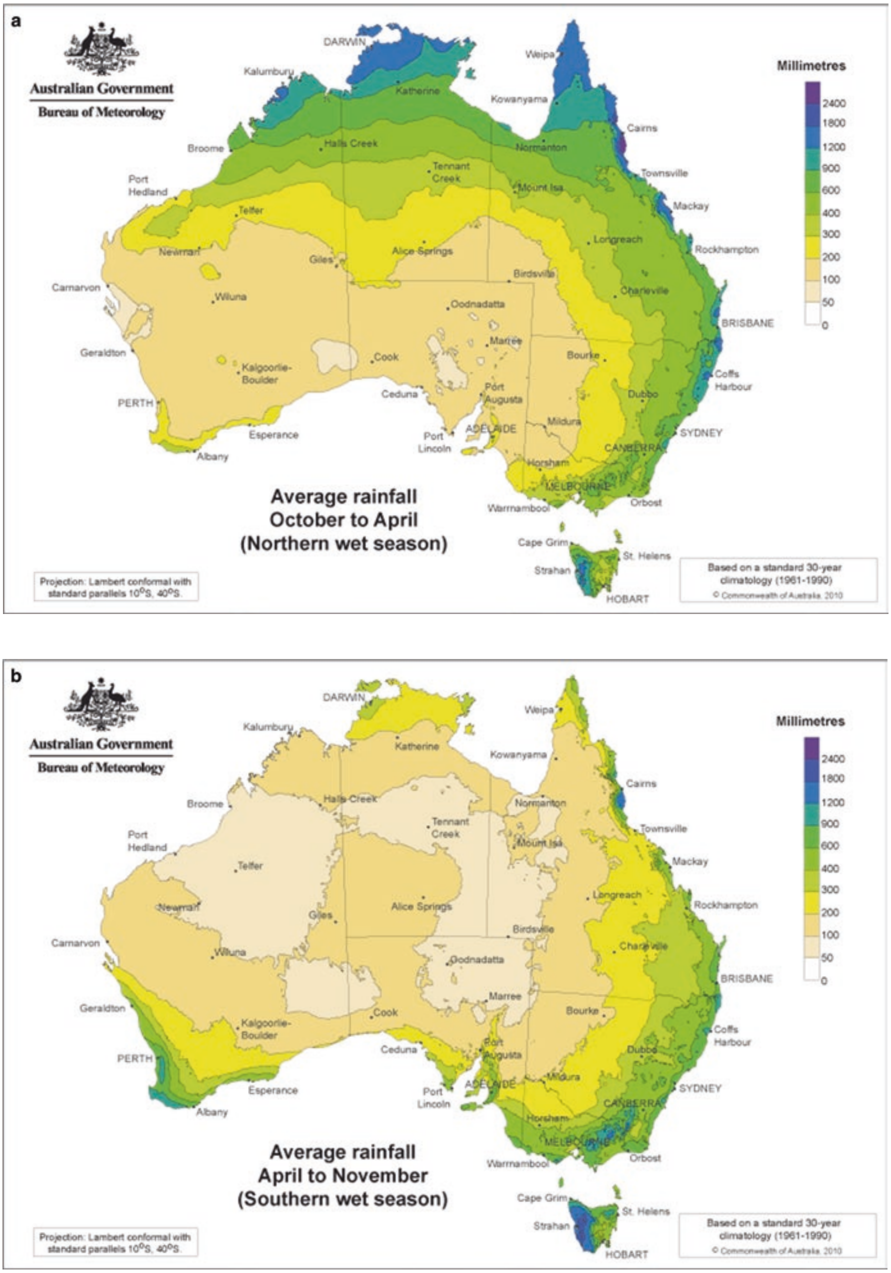
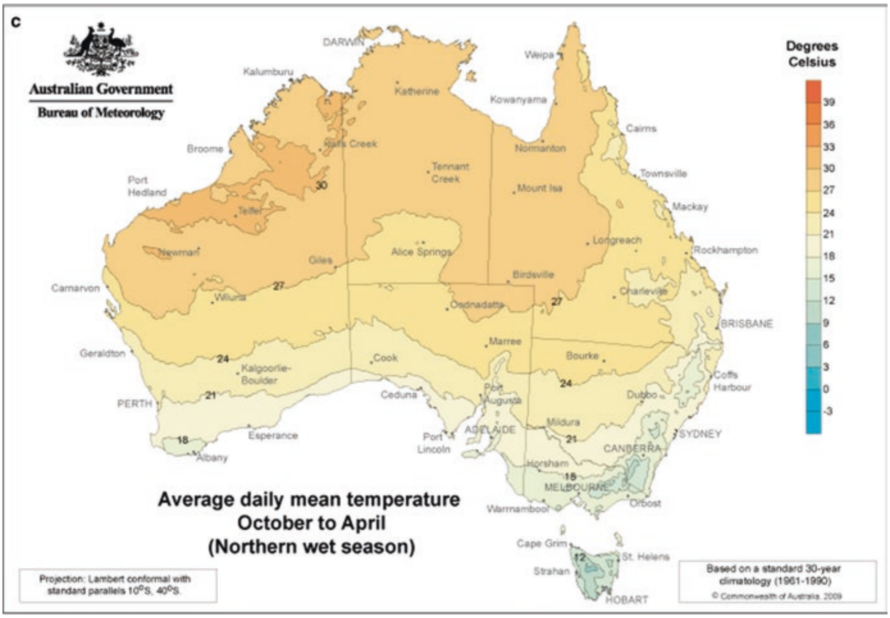


Fig. 1.5 Australia's summer (**a**) and winter (**b**) rainfall and summer (**c**) and winter (**d**) mean daily temperature. (Source: Bureau of Meteorology)



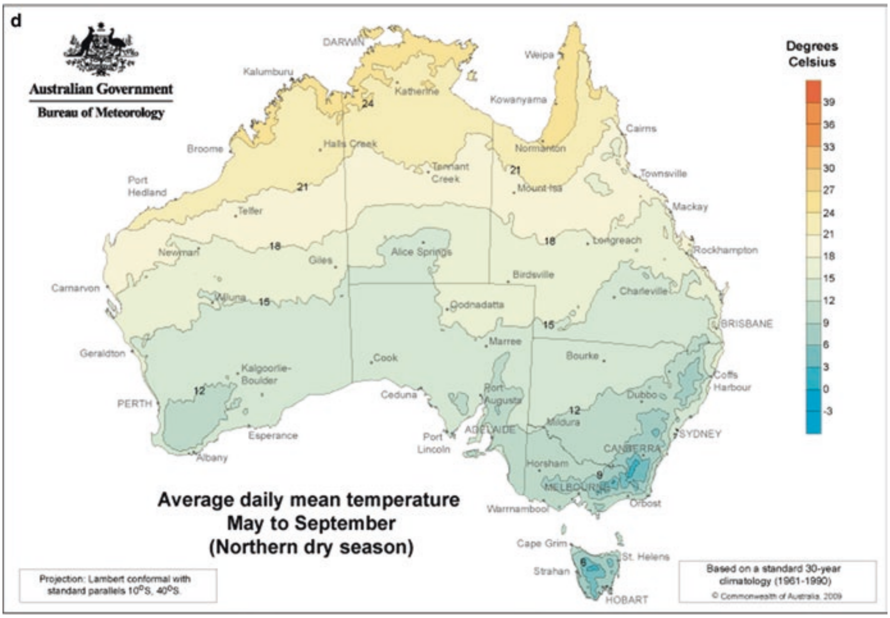


Fig. 1.5 (continued)

1.4.2 Tropical Cyclones

Tropical cyclones (TCs) require three major elements for their formation: warm moist rising air, a disturbance to initiate circular air flow and sufficient Coriolis effect to maintain and enhance the circular flow. For this reason, they only form over warm tropical seas and oceans (<26.5 °C) more than 5° from the equator and under the ITCZ. The ITCZ is where the northwest monsoons meet the easterly trades; the two opposing warm winds converge and rise to form the equatorial low-pressure system, while the Coriolis deflection spirals the air inwards at low levels and outwards at high levels to provide the structure of the cyclone. As the moist air cools and condenses at higher altitudes, it releases the latent heat that drives the cyclone and the moisture that fall as rain. TCs by definition are a rotational low-pressure system of tropical origin with a mean wind speed of at least 63 km h^{-1}. They are graded into five categories based on their strongest gusts, which can reach over 280 km h^{-1} (Bureau of Meteorology).

In the Australian region, TCs form between 10 and 20°S over the Indian Ocean-Timor Sea, the Gulf of Carpentaria and Coral Sea. Once formed, they tend to travel west and curve to the south (driven by the trade winds and Coriolis effect) and can impact the entire northern Australian coast (Fig. 1.6c). They tend to occur between November and April with a pronounced later summer peak when the oceans are warmest (Fig. 1.6b). They are most prevalent off the northwest Western Australian coast where they tend to make landfall between Port Hedland and Onslow, centred on 20°S (Fig. 1.6c). In the Gulf of Carpentaria, they tend to move south crossing the southern Gulf coast, while in the Coral Sea, they can land between Cape York and Brisbane, with 40% landing north of Cooktown and 60% landing between Cooktown and Mackay, with broad maxima either side of Cairns (Fig. 1.6c). Therefore, most tropical cyclones land south of Broome in the west, in the southern gulf, and south of Cooktown in the east, with much of the Kimberley, Northern Territory and Cape York coast receiving a lesser impact. This is because all of the northern coast lie between 9° and 18°S, while the cyclones tend to be generated between 15° and 20°S where the Coriolis effect is stronger and tend to make landfall further south, thereby usually missing much of the northern coast. This does not mean these areas are free of tropical cyclones as evidenced by Cyclone Tracy at Darwin in 1975 and Cyclone Ingrid in 2005, which hit the northern Kimberley coast. When tropical cyclones do make landfall, they are usually accompanied by very strong winds, heavy rain, coastal flooding, high seas and storm surges, all of which can have a devastating impact on the coast through wind damage, river flooding, sea-level inundation and wave erosion and overwashing. While tropical cyclones have a low frequency of occurrence and impact at any particular location, the results of their impact can persist for long periods, resulting in the formation and preservation of tropical cyclone-generated coastal features, including cheniers, cobble and boulder beach ridges, overwash chutes and elevated storm deposits (see Nott 2006).

1.4.3 Wind

Australia's wind systems are associated with the great anticyclonic gyre that moves around the sub-tropical high and the surrounding maritime air masses and their pressure systems (Table 1.1). There are two seasonal wind systems in northern Australia: the southeast trade winds and the northwest monsoons. The trades are of

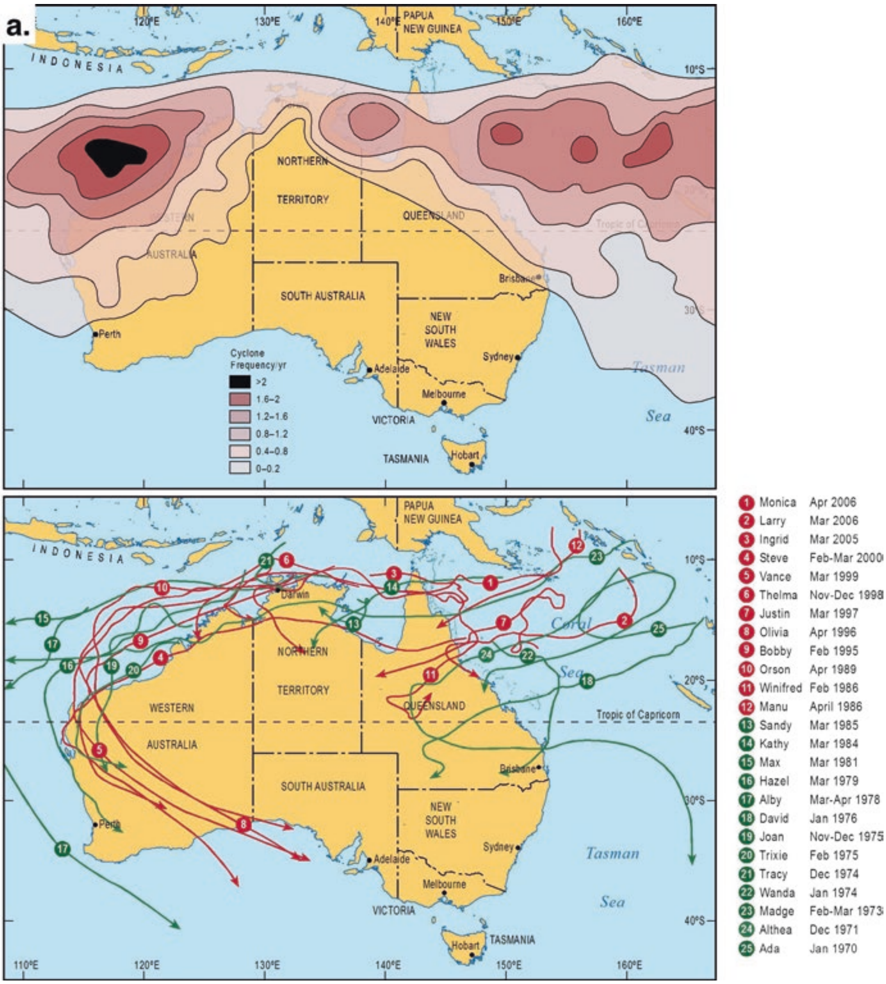
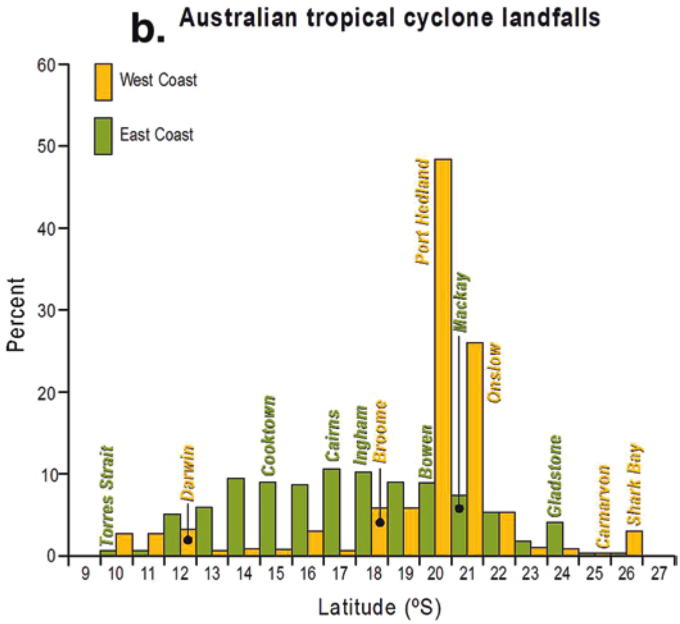


Fig. 1.6 (**a**) Annual frequency of tropical cyclones across northern Australia (top) and location, tracks and landfall of some of the more damaging cyclones in western and eastern Australia between 1970 and 2006. Notice most trend west and then south in a counter-clockwise trajectory and usually dissipate when they move over land (lower); (**b**) latitude of tropical cyclone landfall in Western Australia (green) and Queensland (yellow). Note the peak in the west in the Pilbara region (20°S), the greater spread down the Queensland coast, and the fact that none land north of 10°S; and (**c**) average number of tropical cyclones per month forming off northern Australia. (Source: Short and Woodroffe 2009)



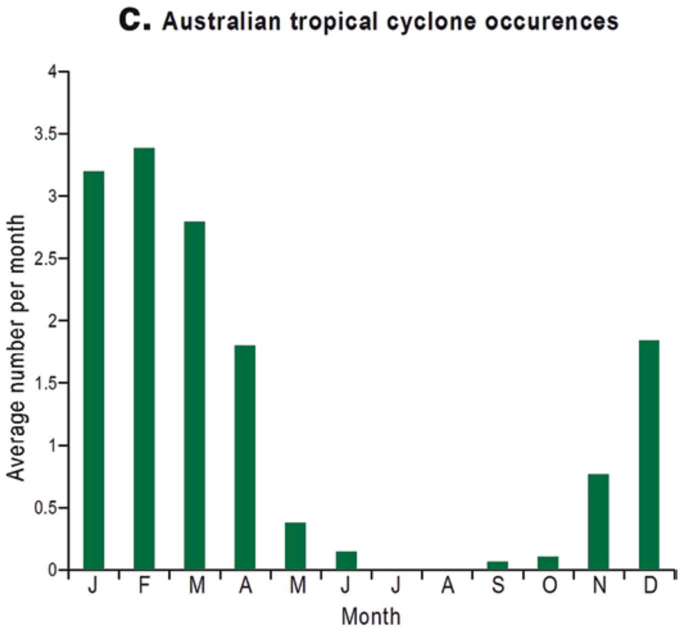


Fig. 1.6 (continued)

moderate velocity and blow year-round with higher velocities during winter between April and November. Figure 1.7 shows the winter wind roses with a dominance of east to southeast winds right around the north coast. The trades remain persistent in direction but fluctuate in velocity with the passage of the highs across Australia, tending to be strongest when the highs are centred on Australia producing a strong ridge of pressure and wind along their eastern-northern side. During the summer period, the northwest monsoons bring light to moderate west to northwest winds to the west and north coast, but they do not penetrate across Cape York Peninsula, with light to moderate velocity eastern winds dominating the eastern cape coast (Fig. 1.7).

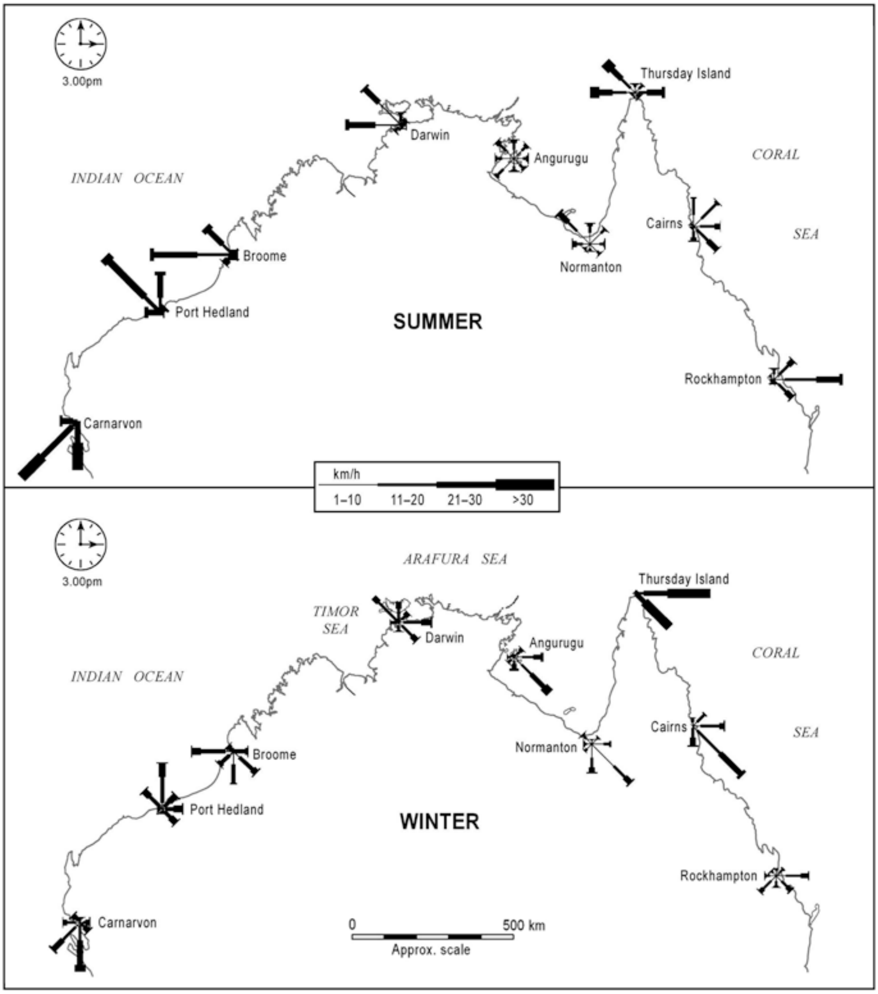


Fig. 1.7 Wind roses for 3 pm summer with monsoonal westerly winds dominating and winter with the southeast trades dominating

Southern Australia is dominated by a generally westerly flow of air associated with the regular west to east passage of subpolar low-pressure systems generally moving south of the continent. As the lows and their fronts pass across southern Australia, they bring stronger westerly to southerly winds. When the lows pass and the high re-establishes itself, the winds shift to lighter easterlies.

Sea breeze systems. Coastal sea and land breezes are associated with the highs and particularly warmer summer weather. The sea breeze results from the daily warming of the coastal land surface. As the air above the land warms up during the morning, it beings to rise. As the morning temperature increases and more air rises, it is replaced by air moving in from above the adjacent, but relatively cooler, coastal ocean waters. Consequently, a local circulation cell is initiated, resulting in the cooler onshore sea breeze replacing the hotter land air. The sea breeze usually arises in the mid- to late morning and brings onshore winds and generally cooler conditions to the coastal fringe. At night and in the early morning hours, the reverse can occur; the land cools rapidly, while over the relatively warmer ocean, air begins to rise, which is in turn replaced by the cooler air from the land, called a land breeze. This produces a light offshore breeze, more common on clear, still mornings.

The direction and strength of the sea breeze varies around the coast depending on coastal orientation and the Coriolis effect, being generally northeasterly in the east, southerly in the south, southwesterly in the west and northwesterly in the north. The winds also generate local seas and bring cooler maritime air to the hotter land surface thereby moderating summer temperatures by as much as several degrees.

1.4.4 Climate Types

The aggregate of Australia's weather and climate can be expressed as climate types. The Köppen climate classification for Australia (Fig. 1.8) illustrates Australia's climate types. The tropical north ranges from hot desert (BWh) and hot semi-arid (BSh) in the northwest through to savannah (Aw) across the monsoonal north coast. On the northeast coast, the onshore trade winds bring additional rain with a strip of monsoonal (Aw) along the Cairns coast, grading to humid sub-tropical (Cwa) and Cfa along the central-southeast Queensland coast. In the temperate south, the climate is humid sub-tropical (Cfa) in northern NSW, grading to cooler oceanic (Cfb) from Sydney south into Victoria and Tasmania. Across the south coast where summers are dry and winter rain dominates, the warm summer Mediterranean (Csb) dominates the more humid southern coast from western Victoria and across the South Australian coast to Streaky Bay, with a drier cool semi-arid (BSk) across the Great Australian Bight. In the southwest there is a gradation as rainfall decreases and temperatures increase from warm summer Mediterranean (Csb) at Cape Leeuwin to hot summer Mediterranean (Csa) along the Perth coast to hot semi-arid (BSh) at Shark Bay and hot desert (BWh) north into the Pilbara.

A more specific assessment of the climate in each of the tropical and temperate provinces and the seven divisions is provided in the following chapters.

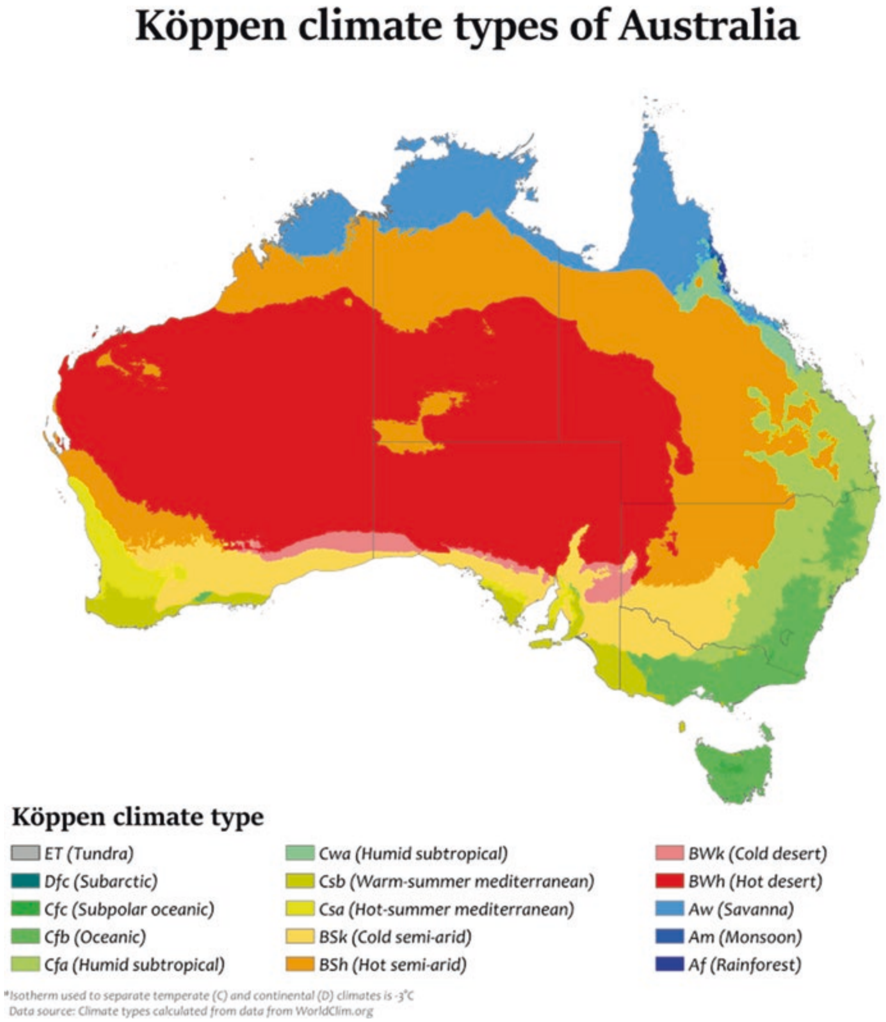


Fig. 1.8 Australia climate types based on a modified Köppen classification scheme. (Source: Bureau of Meteorology)

The Australia distribution of major river catchments and their rivers is a function of the geology, topography and precipitation. Figure 1.9 shows the major Australia river catchments and their regional distribution. When compared to the rainfall pattern (Fig. 1.5) and climate types (Fig. 1.8), there is a high degree of correlation between the humid north, east, southeast and southwest coasts and the location of the catchments. The central west rivers are located in an arid climate but feed by periodic tropical cyclone, while the arid Bight has no drainage, a fact assisted by the limestone geology of the Eucla Basin. The rivers are critical to the supply of terrigenous sediment to the coast as well as the denudation and formation of coastal valleys and embayments. Their nature, input and impact of the coast will be discussed in the following chapters.

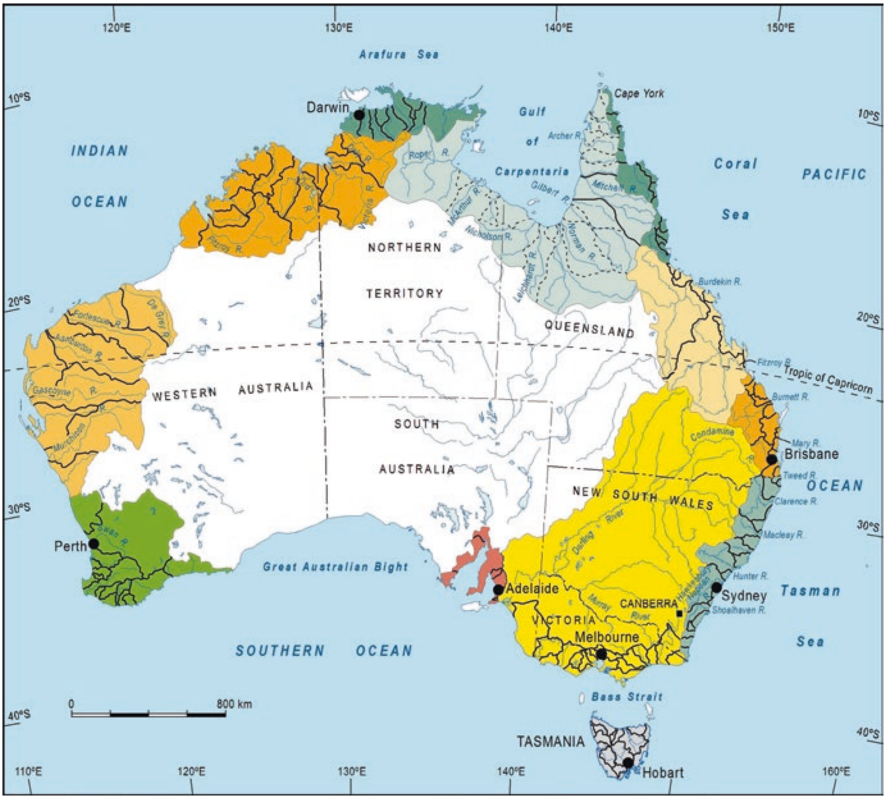


Fig. 1.9 Major Australian coastal catchment boundaries (black solid and dotted lines) and some of the larger rivers (named). Much of Central Australia drains internally and the Great Australian Bight and Eighty Mile Beach coasts have no drainage. (Source: Short and Woodroffe 2009)

1.5 Coastal Sediments and Processes

1.5.1 Sediments

Beach sediment around the Australian coast is predominately fine to medium sand, with an overall mean size of 0.4 mm (σ = 0.4 mm) (Short 2006a). However, the composition is climatically determined, with quartz-rich sand dominating the humid Cape York Peninsula and entire east coast and the humid southwestern tip, while carbonate-rich sand dominates the south and west coasts, with the Kimberley and NT coast having a mix of both quartz and carbonate (Fig. 1.10). Also as will be seen in Sect. 1.6.1, the size is also to an extent process determined, with the lower-wave energy northern Australian beaches tending to have coarser material compared to the higher-energy southern beaches. Details of regional and PC sand characteristics are provided in the relevant chapters.

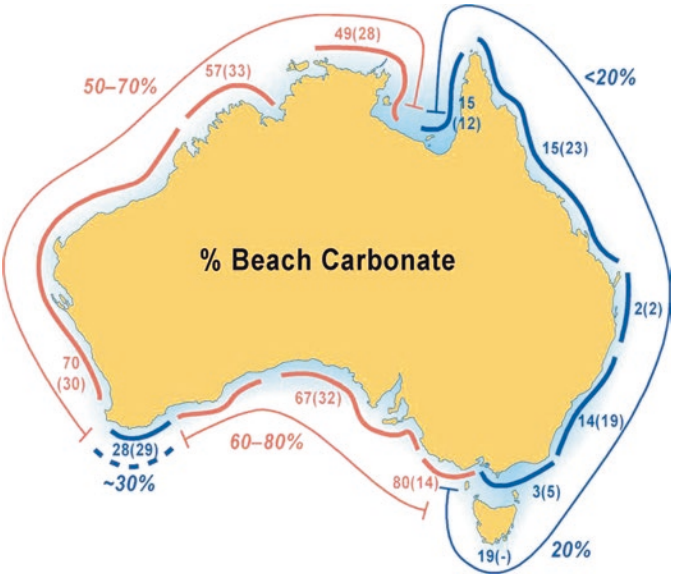


Fig. 1.10 Percentage of carbonate beach sand around the Australian coast. Most of the remainder of the sand is terrigenous quartz grains. Numbers indicate percentage with the standard deviation in brackets. (Source: Short and Woodroffe 2009)

The Australian continent is affected by its climate, which controls temperature, and delivers precipitation and winds, all of which in combination with gravity and biota act on the surface to slowly erode and transport material via rivers to the coast. Because of the great age of the Australian continent and lack of mountain building in the past 60 Ma, it has been eroded down to the lowest, flattest continent on Earth. At the coast the continent is exposed to the additional processes derived from the ocean, particularly waves and tides, but also wind, water temperature and chemistry and biota. All of these act on the coast to erode, transport and deposit sediments and to build and erode coastal landforms. This section briefly examines the major processes that act on the Australian coast.

1.5.2 Waves

Ocean waves are the major source of energy around the southern Australian coast and a major contributor to the northern coast. Figure 1.11 illustrates the global deep-water wave height occurring 10, 50 and 90% of the time. The world's highest and most persistent waves occur south of Australia and deliver year-round moderate to high southerly swell and seas to the entire southern coast. At Cape Sorrel (43°S) on Tasmania's west coast, the waves average 3 m year-round with a period of 12–13 s, with an average H_{max} of 5 m.

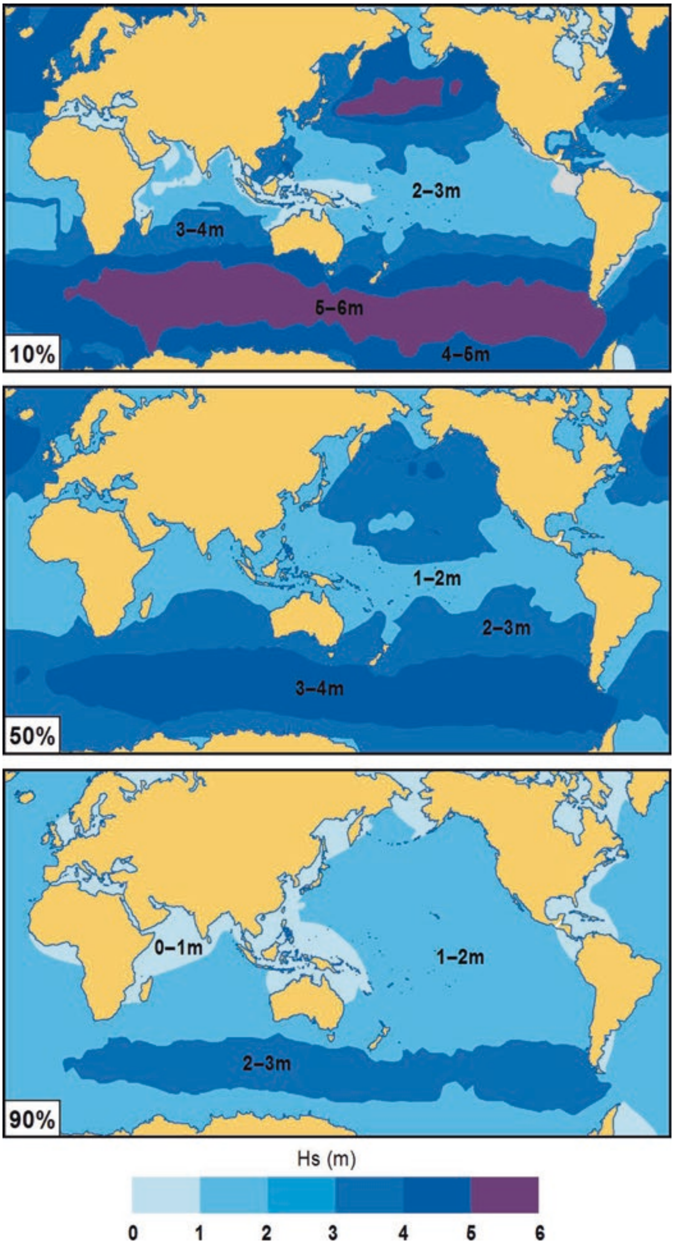


Fig. 1.11 Global deepwater wave climate showing location and percent of time given wave heights are reached. (Source: Short and Woodroffe 2009)

Young (1999) found that the Southern Ocean has the consistently highest wave on Earth due to the high wind velocities, rather than the long fetch. He found they are highest in June–July averaging 5 m and lowest in November–January (3 m) with a westerly direction. As they travel north, they gradually decrease in height averaging 2.6 m at Cape du Couedic (36°S), dropping to 2.2 m by Perth (32°S). These predominately southwesterly waves have to refract to reach the southeast coast and in doing so decrease further in height, arriving as a southeast swell averaging 1.6 m at Sydney (34°S) and 1.2 m at Stradbroke Island (27°S). On the south-central west coast, inshore calcarenite reefs and further north fringing coral reefs lower wave height substantially (<1 m) along the coast north of Perth, up to the Exmouth Peninsula.

Additional waves are generated on the southeast coast by tropical cyclones, east coast lows and onshore high-pressure winds including northeast sea breezes. See Short and Trenaman (1992) for a detailed description of the Sydney wave climate and Shand et al. (2010) for the NSW wave climate. Across the southern coast, additional waves come from the onshore summer sea breezes, while on the southwest coast, the southwest sea breezes are particularly intense and in sheltered locations can be the dominant wave source. Overall the southern coast has a moderate to high deepwater wave climate, while the southeast coast has a more moderate wave height. Breaker wave height is highly variable around the coast as it depends on orientation, degree of sheltering from headlands and the nearshore topography which will attenuate and refract waves, with breaker waves ranging from 100% to 0% of the deepwater wave height.

Northern Australia, as indicated by Fig. 1.11, is exposed to lower deepwater waves and consequently has a much lower energy wave climate. Waves are derived from four sources across the north. First are the persistent southeast trade winds which bring short seas (H_o = 1–1.5 m, T = 3.5 s) to the east coast (inside the Great Barrier Reef lagoon) and to east-facing sections of the north coast like east Arnhem Land. Elsewhere they blow offshore. Next is the summer northwest monsoon, which delivers low to moderate winds and associated low seas (H_o < 1 m, T = 3–5 s). Also during summer, the afternoon sea breezes will deliver short choppy seas, with direction ranging from northeast on east-facing shores to northwest on west-facing shores. Finally, occasional summer TCs can generate high seas and swell, together with storm surges in the vicinity of the landfalls (see Fig. 1.6). While TCs can be extremely damaging when they occur, because of their low frequency of occurrence, they make little impact on the annual wave climate, though they can imprint themselves on the short- and longer-term beach and coastal morphology, as will be discussed in the following chapters.

Hemer et al. (2017) quantified and mapped wave energy around Australia based on observational data, in situ buoys, satellite altimetry and wave hindcasting. As Fig. 1.12a clearly shows, the southwest and southern coast receive the greatest level of wave energy, which decreases up the southeast coast and is lowest across the entire northern coast. They found that annual mean wave energy was an order of

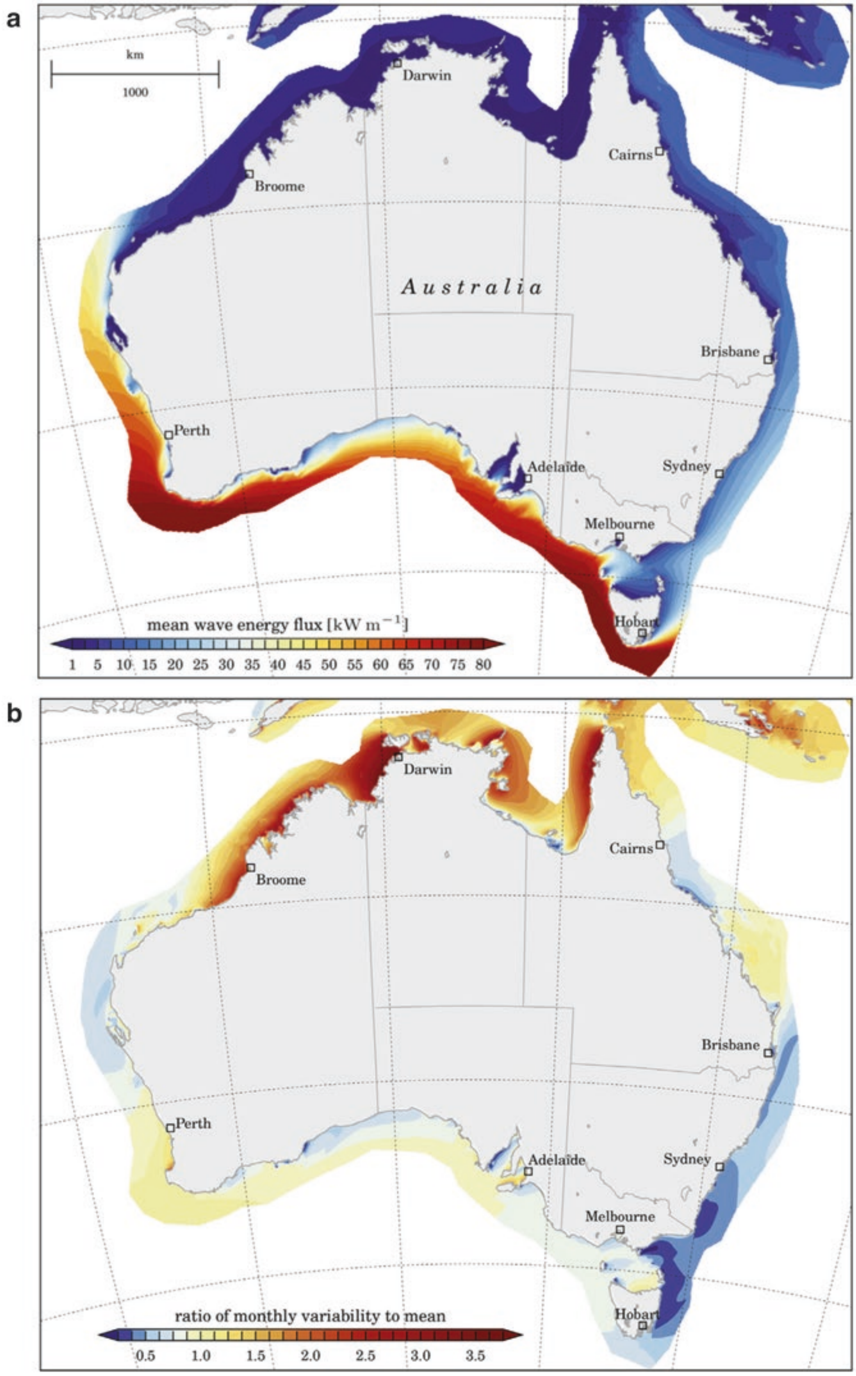


Fig. 1.12 (**a**) Mean wave energy flux (kW m^{-1}) for the Australian coastal region and (**b**) monthly variability in mean wave energy flux. (Source: Hemer et al. 2017)

magnitude higher along the southwest-south coast, compared to northern Australia, with the highest energy along the southwest coast (710 TWh year^{-1}) and the lowest in the Northern Territory (17 TWh year^{-1}). The monthly variation in energy flux (Fig. 1.12b) indicates that there is little monthly seasonal variation in wave energy around the entire swell-dominated southern and trade wind-dominated northeast coasts, with monthly (seasonal) variation greatest along the monsoonal northwest and north coast.

Porter-Smith et al. (2004) used H_s and T and tidal current speed to predict sediment mobilisation on the Australian continental shelf. They found that mobilisation by waves occurred on ~31% and tides on ~41% of the continental shelf, with waves off the Otway coast able to mobilise very fine sand (0.1 mm) to a depth of 142 m. Based on their results they defined six shelf regions of relative wave and tidal energy: zero (no-mobility); waves-only, wave-dominated, mixed, tide-dominated and tides-only (Fig. 1.13).

In summary, Australia can be divided into a low wave energy northern coast and northern province and a moderate to high wave energy southern coast and province. For more detailed descriptions of the Australian and regional wave climates, see Laughlin (1997) and Hemer et al. (2017) for all of Australia and Short (1996, 2000, 2001, 2005, 2006b, 2006c, 2007) for the respective states/territory.

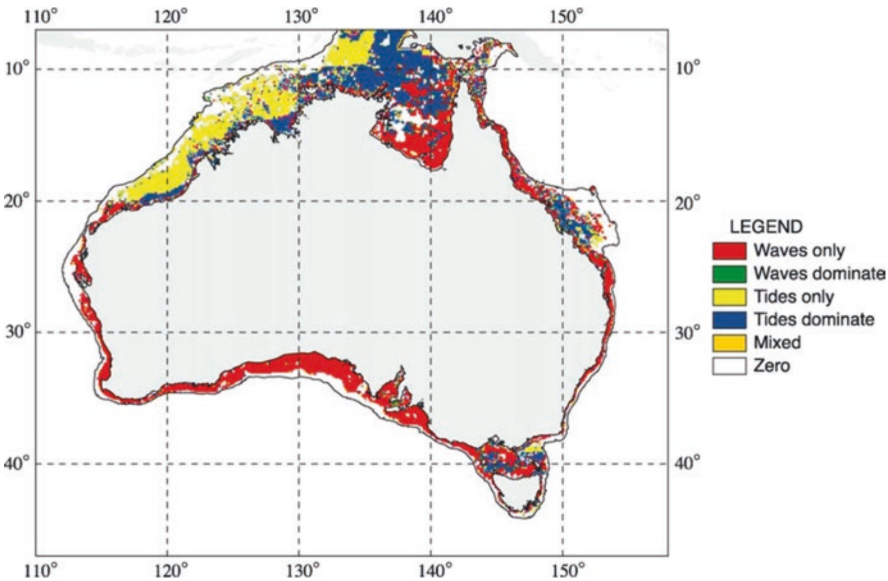


Fig. 1.13 Continental shelf regions based on the ratio of wave and tidal exceedance estimates for observed grain size. (From: Porter-Smith et al. 2004)

1.5.3 Storm Surges

Storm surges are elevated sea levels resulting from strong winds and low barometric pressure. While they can occur right around the Australian coast, they are highest where winds are strongest and the pressure lowest and are enhanced by wide shallow nearshore shelves and will be potentially more damaging in micro-tidal areas. Nelson (1975) found that the highest recorded surges where in Bathurst Bay, QLD (13.7 m); Cossack, WA (9.2 m); Yammadery Bank, WA (7.6 m); and Groote Eylandt, NT (6.6 m), all located in northern Australia.

Silvester and Mitchell (1977) likewise found that the highest surges reaching several metres occur across northern Australia (Northern Territory, Gulf of Carpentaria and east Queensland), whereas across southern Australia, they are less than 2 m except in the South Australian gulfs where they can reach 4 m. Hopley and Harvey (1978) also found that the area of highest storm surge risk is in the southern Gulf of Carpentaria and Groote Eylandt both areas of shallow shelf and micro-tides exposed to intense TCs. Starting in the west, they found that southwest WA has a low risk; the major TC belt between Broome and Carnarvon has moderate to high risk, reduced somewhat by the high tide range, while between Broome and Arnhem Land, there was moderate risk again reduced by the higher tide ranges; down the northeast Queensland coast (Cape York to Hinchinbrook Island), the risk is low in the north and moderate in the south, also moderated by meso-tides, while the central Queensland coast (Whitsundays to Sandy Cape) has a high frequency of TCs but the surge risk is reduced by the meso-macro-tides; and in south Queensland, the risk is low. Low surges occur around the micro-tidal southern Australian coast, but the risk is generally low. These findings are supported by Haigh et al. (2012) who modelled extreme water levels around the Australian coast and found at a 1:100 year return interval (Fig. 1.14), they range from 5 to 6 m in the northwest and Gulf to less than 2 m around southern Australia. Hopley and Harvey concluded that on a global scale the risk is low to moderate with the higher tides providing a buffer around much of northern Australia.

1.5.4 Tides

Australian mean spring tide range is illustrated in Fig. 1.15. It shows the predominance of meso- (2–4 m), macro- (4–8 m) and mega (>8 m)-tide ranges across northern Australia and generally micro-tides (<2 m) across the south, apart from Bass Strait and the South Australian gulfs where they reach up to 3 m. The variation in tide range and time of arrival around the coast is a product of the five tidal systems that generate the tides around the coast, as well as the shelf and coastal morphology that interacts with and modifies the tidal waves as they travel across the shelf to reach the shore. The first comprehensive overview of Australian tides was undertaken by Easton (1970) who plotted the tidal systems round the entire coast.

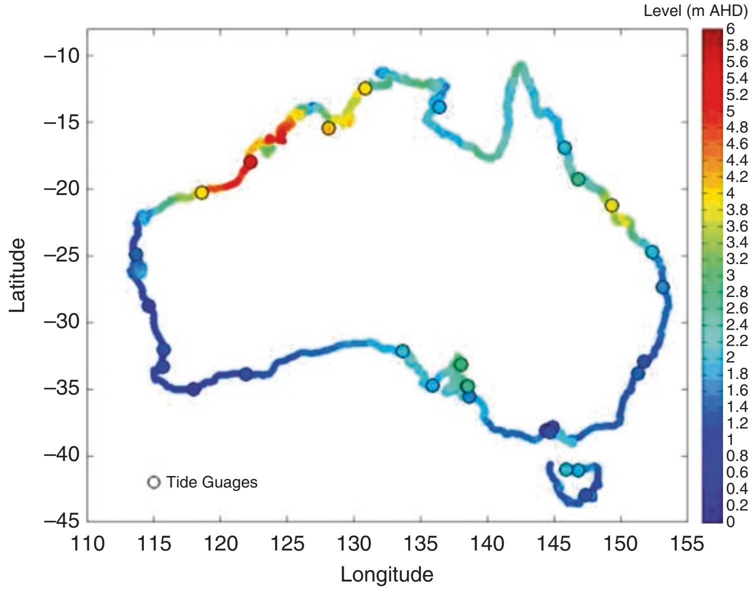


Fig. 1.14 100-year extreme water levels modelled by Haigh et al. (2012)

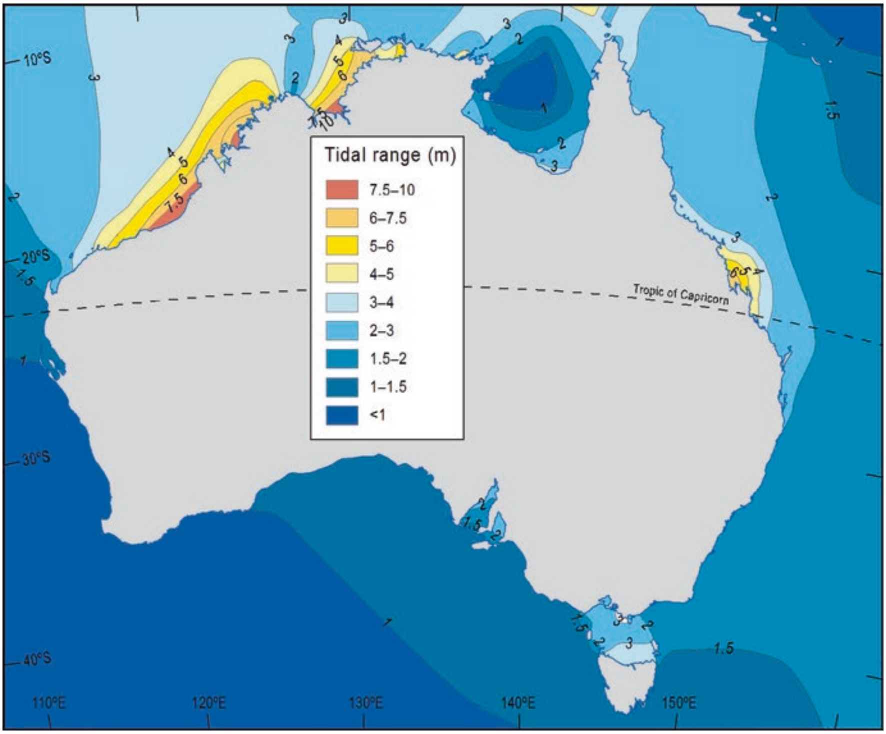


Fig. 1.15 Spring tide range around the Australian coast. (Source: Short and Woodroffe 2009)

On the northern coast, the tidal wave is associated with a system centred off the southwest tip of the continent. The wave travels quickly up the west coast delivering micro-tides as far as Exmouth. As it passes Exmouth Gulf and moves up the Pilbara and then Kimberley coast, it encounters an increasingly wide shallow continental shelf, which shoals, slows and amplifies the tide at the coast, the tide range progressively increasing northwards to reach 6 m at Port Hedland and 9 m at Broome, where it arrives 1 h after Perth. The tide is further amplified by embayment resonance in King Sound (Derby 11 m) and Cambridge Gulf (Wyndham 8 m) where it arrives 10 hours after Perth. As it slowly moves across the top of Australia, the height ranges between 3 and 7 m across the Northern Territory coast. It encounters two smaller tidal systems in the Arafura Sea and as it moves into the Gulf of Carpentaria in drops to between 2 and 4 m. Meanwhile the entire east coast is receiving its tides from a large system located southwest of New Zealand. This wave reaches the southeast coast essentially simultaneously bringing micro-tides to the entire coast between Hobart and Fraser Island. As it moves up the Queensland coast, inside the Great Barrier Reef (GBR) lagoon, it is slowed and amplified across the shallow shelf, averaging 2–3.5 m. It is further amplified by the convergence of two tidal waves as it moves into Broad Sound reaching 8 m and through Torres Strait where it reaches 3.5 m.

The southern coast receives micro-tides, with two areas of meso-tides. The spring tide range averages 1.3 m along the NSW coast, 0.5–2 m along the open Victoria coast, 1.1–1.6 m along the east and west Tasmanian coasts and 1.1–1.6 m on the open South Australian coast. The lowest tides (0.8–1 m) occur along the south and southwest coast of Western Australia. There are in addition two areas of tidal amplification in Bass Strait and the South Australian gulfs. In Tasmania the tidal wave travels clockwise around the coast and as it moves into Bass Strait from the west encounters the shallow seabed, which both slows and amplifies the tide reaching 2–3 m and peaking at 3.9 m at Launceston. At the same time, another part of the tidal wave is entering Bass Strait from the east; this is also slowed and amplified reaching 2.7 m on Flinders Island. In Gulf St Vincent and Spencer Gulf, the wave slows and is amplified as it travels up the gulfs, peaking at 2.9 m at Ardrossan and 3.2 m at Port Augusta. For a more detailed description of the tidal regimes, see Easton (1970) and Laughlin (1997) for all of Australia and Short (1996, 2000, 2001, 2005, 2006b, 2006c, 2007) for the respective states/territory. Homes (1989) describes the network of tidal stations now operating around the Australian coast and their role in recoding changes in sea level.

1.5.5 Tsunami

Tsunamis can impact the entire Australian coast (Fig. 1.16), as by their nature once generated they can travel virtually throughout an entire ocean basin and into adjoining oceans. The east coast of Australia receives tsunami waves generated in the Pacific basin from locations such as Alaska and Chile. Fortunately, they are usually small (<1 m) when they reach the Australian coast and usually do little damage.

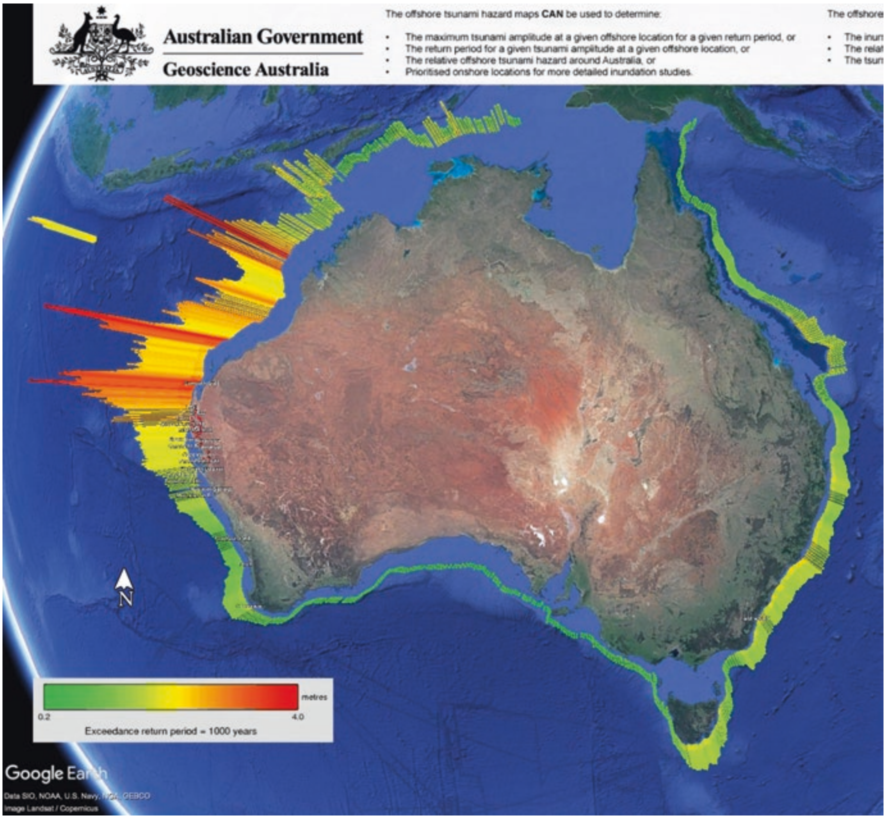


Fig. 1.16 Probability of tsunami height around the Australian coast with a 1:1000 year return period. (Source: Geoscience Australia and Google Earth) (http://www.ga.gov.au/scientific-topics/hazards/tsunami/australia)

Australia's biggest risk is the northwest coast, which is exposed to tsunami generated in the nearby Indonesian archipelago, like the 2004 Aceh tsunami. Tsunami run-up of up to several metres has been recorded along this coast. In general, however, most of Australia and particularly the populated southeast regions have a low tsunami risk (Courtney et al. 2012). For more information on tsunami, see http://www.bom.gov.au/tsunami/.

1.5.6 Oceanography

The Australian coast is surrounded by the Pacific, Southern and Indian oceans and across the top the Timor and Arafura seas and the Gulf of Carpentaria. The seas and oceans are both heated by the sun and moved by the winds, resulting in a latitudinal gradation in ocean temperature and in ocean circulation.

In the Australian region, summer sea surface temperatures range from 30 °C along the north coast to the mid-20s by the mid-coasts to 18–20 °C across the south coast. During winter these drop to mid-20s across the north coast, ~20 °C by the mid-coasts and 12–16 °C across the south coast (Fig. 1.17). On both the east and west coasts, a coastal boundary current (East Australia Current (EAC) and the Leeuwin Current) drives warmer water south along the coast, extending the warmers waters further south than would otherwise occur. For this reason, Australia has the world's most poleward coral reef systems located on Lord Howe Island (31.6°S) and Houtman Abrolhos (29°S).

Ocean circulation around Australia is part of larger circulation taking place in the surrounding oceans. In the Pacific Ocean, the South Equatorial Current travels in equatorial latitudes east to west right across the Pacific. When it reaches northern Australia it is deflected south along the east coast as a western boundary current to form the warm EAC. The EAC flows down the Queensland coast (outside the GBR) though receiving warm water from the GBR lagoon and then breaks into a series of eddies off the central-southern New South Wales (NSW) coast and tracks towards New Zealand (Fig. 1.18). Across the north water flows down through the Indonesian archipelago and through the Arafura and Timor seas to pool in the northeast Indian Ocean off northwest Australia. This warm water then moves down the west coast as an eastern boundary current, called the Leeuwin Current. It brings warm water to the southwest coast, resulting in the world's most poleward coral reefs at Ningaloo and the Houtman Abrolhos. It then rounds Cape Leeuwin breaking into a series of eddies as it travels east across the bottom of Australia to ultimately reach Bass Strait and Tasmania. Further south the cold Antarctic Circumpolar Current travels continuously from west to east well south of the continent.

All oceans and seas contain dissolved salts derived over hundreds of millions of years from the erosion of land surfaces. Chlorine and sodium dominate and, together with several other minerals, account for the dissolved 'salt'. The salts are well-mixed and globally average 35 parts per thousand (‰), increasing slightly into the dry sub-tropics and decreasing slightly in the wetter mid-latitudes. In the Australian region, salinity averages 35‰, except in estuaries where it may be reduced by dilution by freshwater or increased in large bays by excessive evaporation, as in southern Shark Bay where it can reach 70‰ and the South Australian gulf where it can reach 42‰ in Gulf St Vincent and 45‰ in Spencer Gulf.

1.6 Australian Coastal Systems

The Australian open coast is a mixture of rocky and sandy shore, the latter often backed by coastal dune and barrier systems, together with sections of mangrove-lined tidal flats and numerous bays, estuaries and deltas. In addition, extensive areas of sandy shore have been cemented into beachrock and dunerock (beach and dune calcarenite), while salt marshes, mangroves, seagrass meadows and coral-algal reefs fringe large sections of the coast. In order to understand and manage the coast,

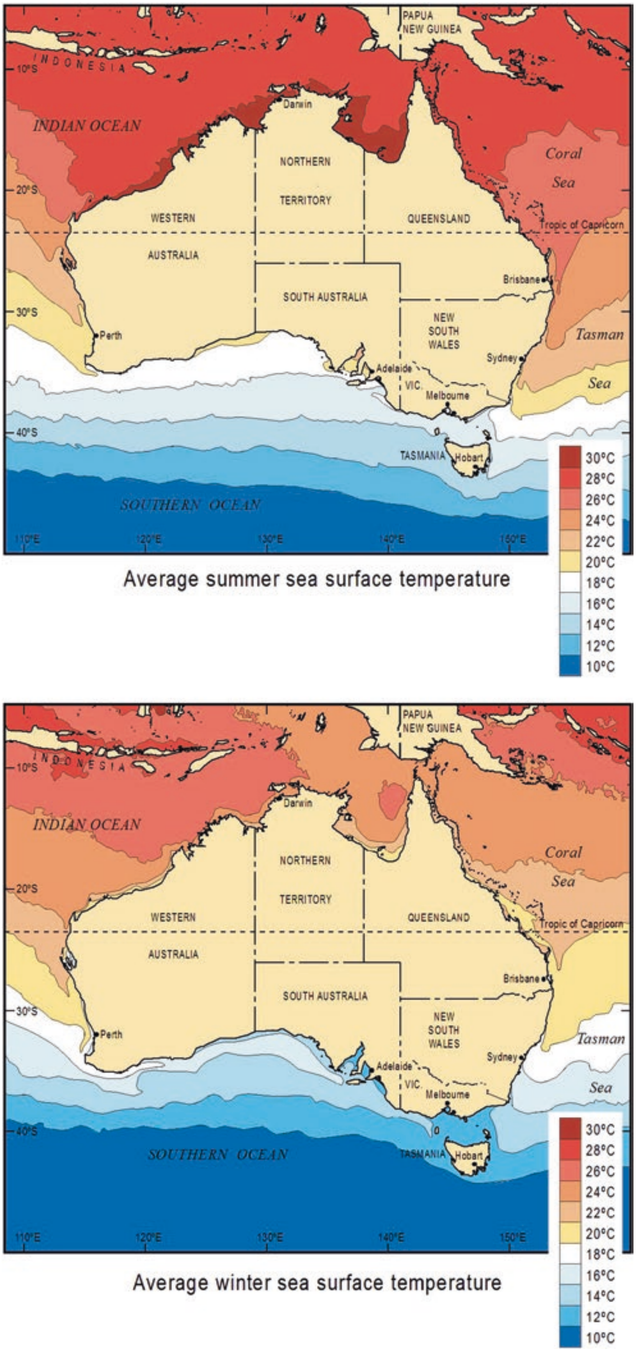


Fig. 1.17 Average ocean surface temperature around Australia in summer (top) and winter (bottom). (Source: Short and Woodroffe 2009)

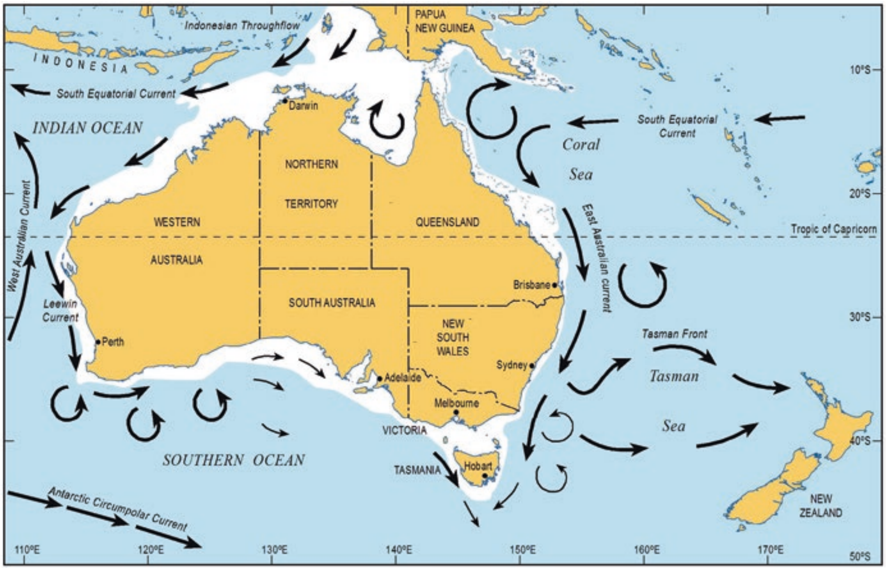


Fig. 1.18 Generalised ocean circulation around Australia. (Source: Short and Woodroffe 2009)

we need to know about the nature and dynamics of each of these systems and their interactions within the broader coastal zone.

The scientific investigation of the Australian coast began sporadically in the nineteenth century when scientists like Darwin and Dana reported on observations made of parts of the coast. The coast, and particularly its beaches, received very little scientific attention until the beginning of the twentieth century when reports on the impact of a series of damaging storms were published. It is not the purpose of this book to review the history of scientific investigation of the coast; rather it is to bring the existing knowledge together in one book. For a review of Australian coastal studies up to the 1980s, see Thom (1974, 1984) and Thom and Short's 'Australian coastal geomorphology 1984–2004' (Thom and Short 2006). For regional studies and description of parts of the coast, see Chapman et al. (1982) for NSW, Bird (1993) for the Victorian coast, Brearley (2005) for the southwest of Western Australia, Hopley et al. (2007) for the Great Barrier Reef and Bourman et al. (2016) for South Australia. For studies focusing more on coastal systems, see Galloway et al. (1980) for an overview of Australia's coastal land types. Bucher and Saenger (1991) and Heap et al. (2001) for estuarine systems, Short (2006a, b, c) for beach systems, Short (2010b) for barriers and Short and Woodroffe (2009) for an overview of Australia's coastal systems, including an overview of rocky coasts. For detailed descriptions of the beaches of each state/territory, see Short (1996, 2000, 2001, 2005, 2006b, c, 2007). Information on Australian beach and estuarine systems is also available online at http://www.ozcoasts.gov.au/coastal/smartline.jsp#1 and for beaches on the iPhone 'Beachsafe' app.

1.6.1 Beach Systems

The Australian open mainland coast has 10,796 predominately sandy beaches that occupy just under half of the open coast (14,686 km, 48.5%) and have an average length of 1.37 km (Short 2006a). These beach systems are the most dominant landform type around the coast and also the most dynamic, responding to changing waves, tides and sediment budgets. Short (2006a) and Short and Woodroffe (2009) summarise the results of the Australian Beach Safety and Management Program (ABSAMP) which documented all Australian beaches, their location, physical characteristics, beach type and state and associated physical hazards. The following briefly outlines the types of beaches found around the coast beginning with some definitions:

Beach – wave-deposited accumulations of sediment (sand-boulders) at the shoreline.

Embayed beach – a beach located between two boundaries where normal circulation gives way to cellular circulation at the boundaries and under increasing wave height. Can be defined morphodynamically by the embaymentisation parameter (δ') > 19

$$S' = S^2 / 100 C_l H_b$$

where S = shoreline length, C_l = chords length and H_b = breaker wave height, and morphometrically by the embayment morphometric parameter $\gamma e = a/\sqrt{Ae}$ where a = indentation (midpoint of headland width to backbeach boundary), Ae = embayment area (Fellowes et al. 2019)

Pocket beach – a beach located between two boundaries where cellular circulation dominates the beach morphodynamics and the $\delta' < 8$.

Note: a beach with a δ' between 9 and 19 is regarded as transitional between a pocket and embayed beach with elements of both.

Swash aligned – a beach plan form aligned to the dominant wave crests, which arrive parallel to shore.

Drift aligned – a beach where the dominant wave arrived at an angle to the shore inducing longshore transport (also called littoral drift).

Longshore transport – the movement of sediment along a coast by waves and currents. On sandy beaches most transport takes place in the breaker zone, also known as *littoral drift*.

Tides can be also classified into four range categories (Davies 1973, 1980; Levoy et al. 2000):

Micro < 2 m range.
Meso 2–4 m
Macro 4–8 m
Mega >8 m.

Table 1.2 List of the 4 beach types and 15 beach states and some of their environmental characteristics

No.	Abbreviation	Beach state	RTR[a]	Ω	H_b (m)
Wave-dominated (WD)					
1	*D*	Dissipative	*<1*	*>6*	*>2*
2	*LBT*	Longshore bar and trough		*~5*	*1.5–02*
3	*RBB*	Rhythmic bar and beach	*<3*	*~4*	*>1.5*
4	*TBR*	Transverse bar and rip	*<3*	*~3*	*~1.5*
5	*LTT*	Low tide terrace	*<3*	*~2*	*~1*
6	*R*	Reflective	*<3*	*~1*	*<1*
Tide-modified (TM)					
7	*R+LTT*	Reflective + low tide terrace	*3~10*	*~1*	*<1*
8	*R+LTR*	Reflective + low tide bar and rips	*3~10*	*~3*	*~1*
9	*UD*	Ultradissipative	*3~10*	*~5*	*~1*
Tide-dominated (TD)					
10	*B+RSF*	Beach[b] + ridged sand flats	*~10~50*	*<1*	*<0.5*
11	*B + SF*	Beach + sand flats	*~10~50*	*<1*	*<0.3*
12	*B + TSF*	Beach + tidal sand flats	*~10~50*	*<1*	*<0.2*
13	*B + TMF*	Beach + tidal mud flats	*~10~50*	*<1*	*<0.2*
*Rock/reef flats**					
14	*R + RF*	Reflective + rock flats	–	–	–
15	*R + CF*	Reflective + coral reef flats	–	–	–

[a]All boundaries for RTR, Ω and H_b are soft and provide a general indication only

[b]'Beach' indicates a very low energy strip of high tide sand with insufficient energy for wave reflection

[c]Rock and reef fronted beaches form independently of RTR, Ω and H_b

All beaches are a product of waves, tide and sediment and can be classified by combinations of these three variables. Based on wave height and tide range alone, beaches can be classified into three types, wave-dominated (WD), tide-modified (TM) and tide-dominated (TD), using the relative tide range (RTR), where

$$\mathrm{RTR} = \mathrm{TR} / H_b$$

where TR is the mean spring tide range and H_b the breaker wave height (Masselink and Short 1993). When RTR < 3, beaches are WD; from ~3 to 10, they are TM; and from 10 to ~50, they are TD, beyond which tidal flats prevail. Within each type there are several beach states, which are quantified using the dimensionless fall velocity (Ω), which includes the above parameters plus sand size and wave period:

$$\Omega = H_b / W_s T$$

where W_s is sediment fall velocity (m s^{-1}) and T is wave period (s) (Gourlay 1968). Table 1.2 lists the 4 beach types and 15 beach states together with their RTR, Ω and H_b.

Figure 1.19a illustrates the actual range in these parameters based on all Australian beaches. WD beaches (#1–6) are exposed to higher waves (0.5–2.5 m)

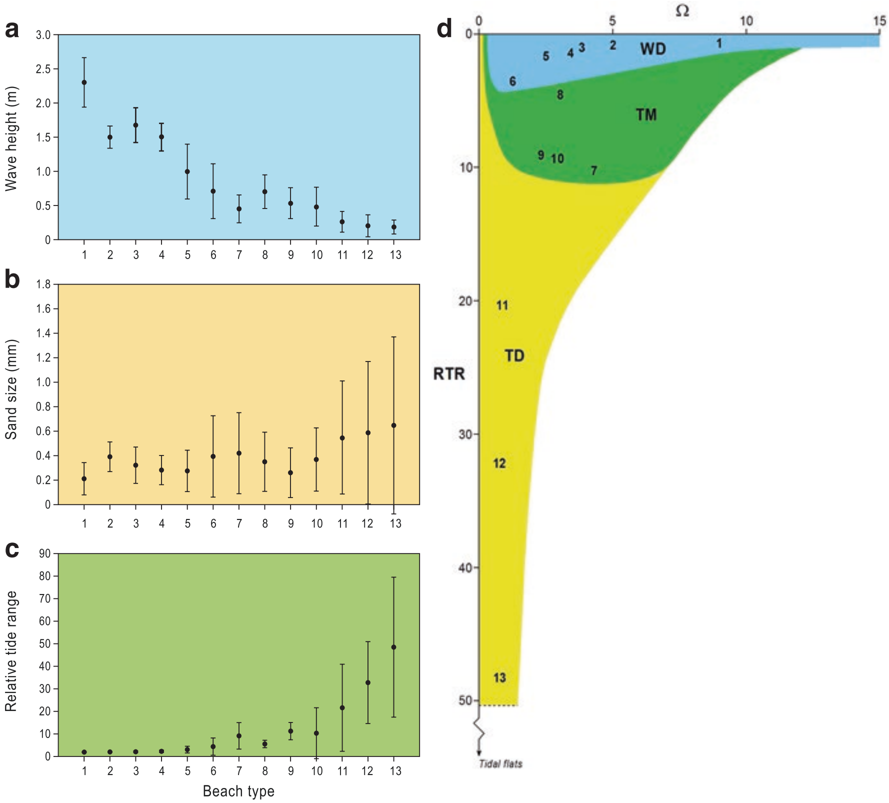


Fig. 1.19 (**a**) Relationship between Australian beach states (1–13) and (**a**) wave height H_b(m); (**b**) sand size (mm); and (**c**) RTR. Error bars represent standard deviation. See Table 1.2 for definition of beach states. (Modified from Short and Woodroffe 2009) (**d**) distribution of Australian beach types (WD, TM, TD) and states (#1–13) based on Ω and RTR. (Source: Short and Jackson 2013)

and are generally composed of reasonably well-sorted fine-medium (0.2–0.4 mm) sand, with a low RTR (<3). TM beaches (#7–9) have lower waves (0.5–0.75 m), RTR between 3 and 10 and slightly coarser (fine to medium, mean = 0.4 mm) sand. TD (#10–13) beaches have very low waves (<0.5 m) and RTR increasing from 10 to 50+ and are composed of poorly sorted coarser (mean = 0.6 mm), often shelly, sand. The R + RF and R + CF are, respectively, geologically and biologically controlled and independent of RTR, Ω and H_b.

Figure 1.19b plots the location of the three beach types (WD, TM and TD) and their 13 beach states (#1–13) with respect to RTR and Ω. The horizontal Ω axis can be read as increasing H_b and/or decreasing sand size, while the vertical RTR axis represents increasing TR and/or decreasing H_b. The WD beaches have the highest waves, finer sand and lowest tides, while the TD beaches have the lowest waves, highest tides and coarsest sands, with TM located in between. It should be noted that wave or tide dominance is relative and as indicated in the figure TD beaches can

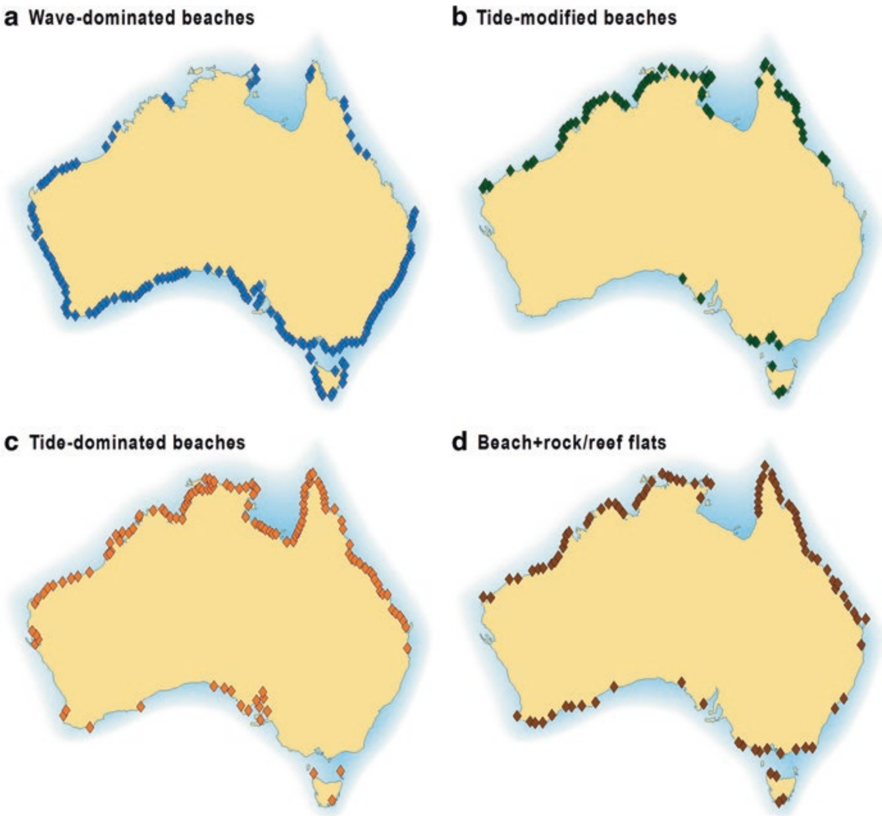


Fig. 1.20 Generalised distribution of (**a**) wave-dominated, (**b**) tide-modified, (**c**) tide-dominated and (**d**) beaches with rock/reef flats around Australia. (Source: Short and Woodroffe 2009)

occur in areas of low micro-tides where waves are extremely low and WD beaches in areas of meso- and higher tides where waves are sufficiently high; it's a matter of the relative contribution of each, not their absolute value, hence the use of RTR. It should also be stressed that the plots are for Australian beaches and wave climates and that in other regions these values and the nature of some of the TM and TD beach states may vary, as indicated by Scott et al. (2011) for meso/mega-tidal UK beaches.

Figure 1.20 plots the general distribution of the four beach types around Australia, and Table 1.3 listed the beach types and states (number and length) by state. WD beaches are located predominately around the southern half of the continent where higher waves and micro-tides prevail, with WD in northern Australia located on sections of coast well exposed to the trade wind wave conditions like northeast Arnhem Land and parts of east Queensland. TM and TD beaches predominate across the northern half of the continent where meso/mega-tides and low waves prevail and in some southern locations, such as the South Australian gulfs and northern Tasmania,

Table 1.3 Australia beach types and state (a) number of beaches and (b) beach length (km). (Modified from Short 2006a)

		(a)									(b)								
	Beach states[a]	QLD	NSW	VIC	TAS	SA	WA	NT	Total	%	QLD	NSW	VIC	TAS	SA	WA	NT	Total	%
WD																			
1	D	0	0	0	0	14	4	0	18	0.2	0	0	0	0	270	8	0	278	1.9
2	LBT	0	0	0	0	7	1	0	8	0.1	0	0	0	0	15	3	0	18	0.1
3	RBB	7	73	83	2	33	81	0	279	2.6	112	183	280	0	91	134	0	800	5.4
4	TBR	34	237	170	193	159	221	14	1028	9.6	241	525	353	259	288	660	45	2370	16.1
5	LTT	13	195	116	174	164	241	28	931	8.7	97	200	125	135	203	595	50	1405	9.6
6	R	40	216	153	786	571	843	61	2670	25.0	75	67	73	407	354	1053	34	2062	14.0
TM																			
7	R + LTT	478	0	32	28	42	60	114	754	7.1	792	0	19	17	45	50	182	1105	7.5
8	R + LTR	127	0	0	1	2	8	41	179	1.7	570	0	0	0	16	10	61	658	4.5
9	UD	95	0	0	8	0	66	11	180	1.7	201	0	0	16	0	350	58	625	4.3
TD																			
10	B + RSF	195	0	0	33	29	35	98	390	3.7	482	0	0	18	44	38	306	887	6.0
11	B + SF	485	0	72	35	364	743	437	2136	20	751	0	119	22	517	749	503	2641	18.0
12	B + TSF	87	0	0	2	69	552	127	837	7.8	111	0	0	3	177	411	141	843	5.7
13	B + TMF	12	0	0	0	0	110	120	242	2.3	57	0	0	0	0	54	172	283	1.9
14	R + RF	57	0	66	7	0	247	402	779	7.3	24	0	20	1	0	192	314	551	3.3
15	R + CF	20	0	0	0	0	199	35	254	2.4	13	0	0	0	0	92	36	142	1.0
	Total	1650	721	692	1269	1454	3411	1488	10,685	100	3525	974	989	878	2020	4398	1902	14,686	100.0
										mean (km)	2.14	1.35	1.43	0.69	1.39	1.29	1.28	1.37	

[a]See Figs. 1.21 and 1.23 for illustrations of beach states 1–15

which have similar conditions. The R + RF can occur anywhere rock flats front a sandy beach, while the R + CF occur only in the tropical north where fringing coral reefs front the beach. All Australian beaches can be classified into one of these 4 types and 15 states. The following section briefly describes each beach type and state for the Australian open coast. For more detailed descriptions, see Short (1999, Short 2006a), Short and Woodroffe (2009) and http://www.ozcoasts.gov.au/conceptual_mods/science_models.jsp#beach.

Table 1.3 indicates that the most common WD beach state by number is the low energy R (25%), followed by TBR (9.6%) and LTT (8.7%), with the TD dominated by B + TSF (20%). However, by length, the generally longer TBR (2.3 km and 16%) dominates over the shorter R (0.77 km and 14%) and LTT (1.5 km, 9.6%), while the TD B + SF remains dominant (1.3 km, 18%) in its domain. The most dominant TM beach by number and length is the R + LTT (7%). As would be expected, the WD beaches dominate the southern states including the southern half of WA and SE QLD, with the TM and TD occurring primarily in the northern states (northern WA, NT and QLD), together with significant numbers in the sheltered micro-tidal southeast TAS bays and meso-tidal northern TAS coast and the sheltered meso-tidal SA gulfs.

Wave-dominated (WD)beaches occur in areas of higher waves (0.5–2.5 m, T ~ 8–14 s) and generally micro-tides. They consist of six beach states. At the high energy end of the spectrum is the high energy multi-bar *dissipative* (D) with waves averaging 2.5 m and breaking across a broad dissipative multi-bar surf zone up to 500 m wide composed of fine sand (mean = 0.2 mm) (Figs. 1.21 and 1.22a). Four intermediate beaches occupy the middle of the WD spectrum, each typified by cellular rip current circulation with sand ranging from 0.3 to 0.4 mm. With slightly lower waves (2–2.5 m) or coarser sand, the *longshore bar and trough* (LBT) prevails with an outer bar separated from the beach by a wide deep trough containing rip current circulation (Figs. 1.21 and 1.22b). The *rhythmic bar and beach* (RBB) occurs as waves decreases (1.5–2 m) the bar moves shoreward generating prominent rip current circulation and wave refraction within the surf zone leading to the formation of a highly rhythmic shoreline, with megacusps protruding seaward in lee of the shoaler bars and embayments in lee of the deeper rip channels (Figs. 1.21 and 1.22c). As waves drop to about 1.5 m, the bars weld to the shore at the megacusp horns forming the *transverse bar and rip* (TBR) state, with shallow transverse bars adjacent to deeper rip channels and pronounced segregated rip current circulation (Figs. 1.21 and 1.22d). As waves decrease to 1 m, the bar continues to move shoreward, and the rip channels begin to infill forming *the low tide terrace* (LTT), with a welded low tide bar possibly cut by small remnant rip channels (Figs. 1.21 and 1.22e). Finally, when waves drop below 1 m, the bar moves up onto the beach forming a prominent series of high tide beach cusps which can infill to form a straight berm with a steep *reflective* (R) beach face, composed of coarser sand (mean = 0.4 mm) with waves surging over the base of the beach (the step) with no bar or surf zone (Figs. 1.21 and 1.22f). The range in grain size with WD beach state is in agreement with Klein et al. (2005).

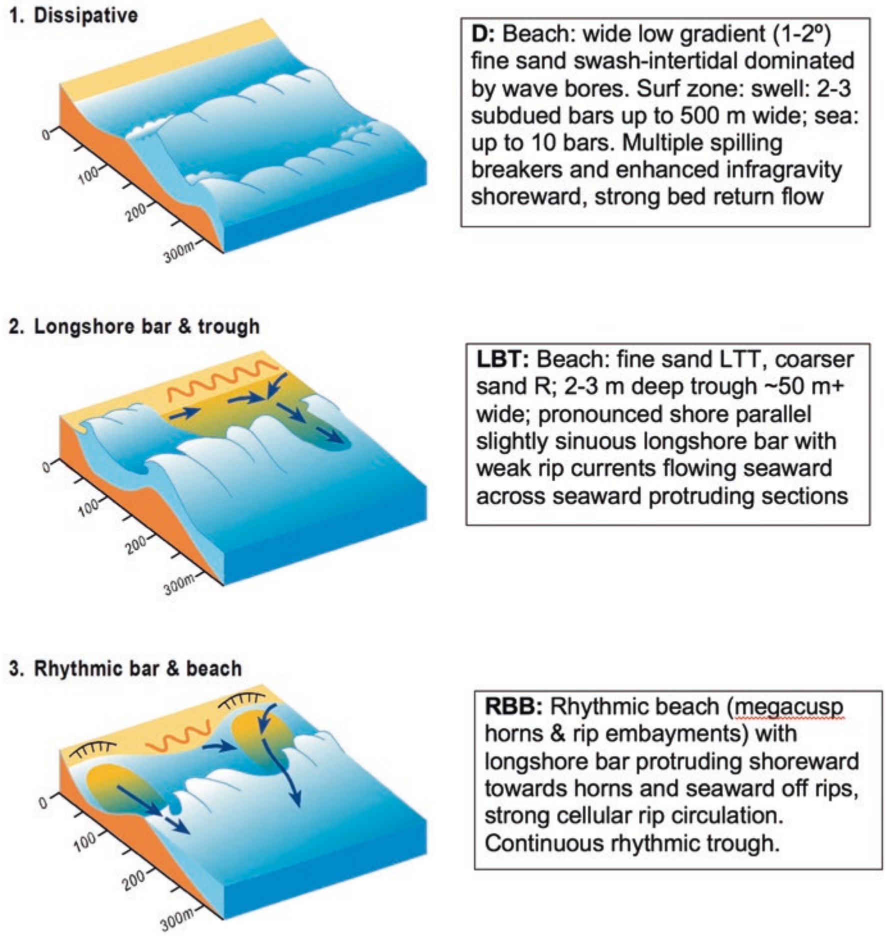


Fig. 1.21 The six wave-dominated beach states. (Source: Short and Woodroffe 2009)

Beach Number

All images of Australian beaches provided in this book are labelled by their State initials and beach number, as shown in Fig. 1.22a–f. Full description of all Australian beaches is available on a State by State basis in Short (1996, 2000, 2001, 2005, 2006b, cand 2007) where each beach is identified by its State and a unique number, e.g. QLD 1471, VIC 55, WA 2537.

Beach rips, *topographic rips* and *megarips. Beach rip* currents are narrow currents that flow seaward across the surf zone and dissipate seaward of the surf zone. They are a mechanism for returning seaward water brought shoreward by breaking

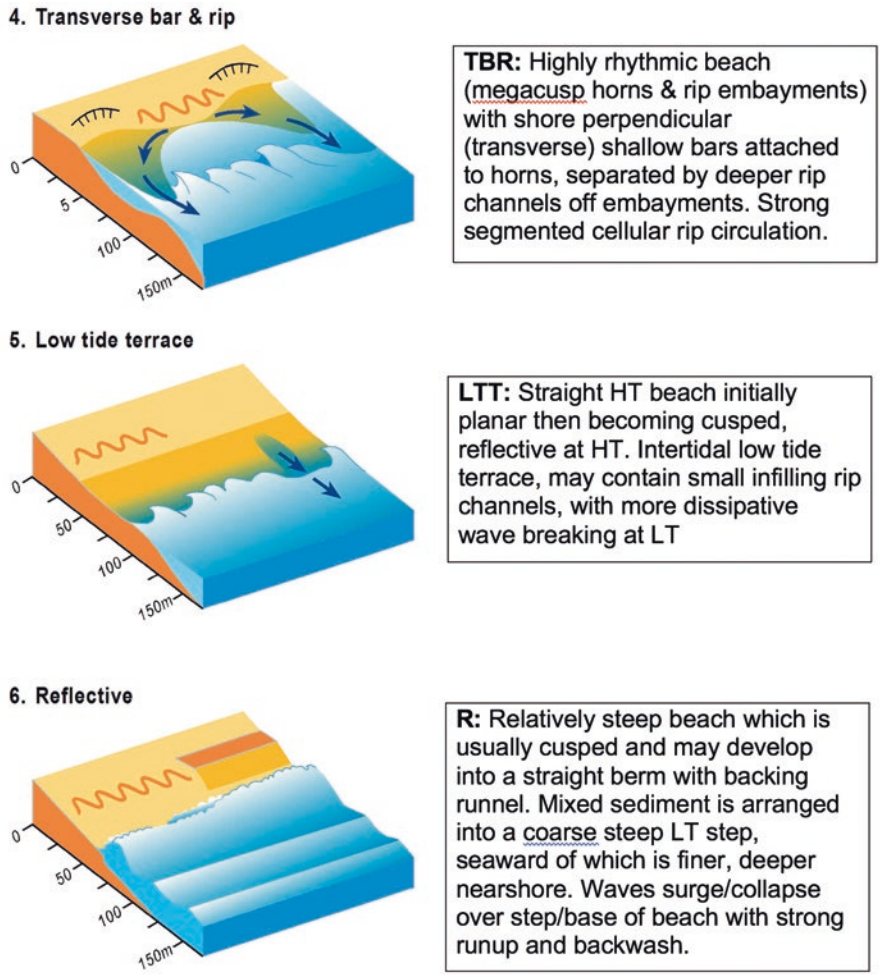


Fig. 1.21 (continued)

waves. The breaking waves and wave bores move shoreward and then at the shoreline generate currents that flow along the beach as a *feeder current*. The rip is usually fed by two narrow converging rip feeder currents, which flow close to shore then converge (usually in a rip embayment) and flow seaward as the narrow rip current. The rip usually has velocities between 0.5 and 1.5 m s^{-1} and usually, but not always, flows in a deeper *rip channel*. Seaward of the surf zone it usually spirals and dissipates as a *rip head*. Rip currents and their cellular circulation are a component of all intermediate beaches. *Rip spacing* is a function of wave height and period and surf zone gradient and is usually regular alongshore. Spacing can range from 50 m on short period (<5 s) sea-dominated beaches to 500 m on high energy long period (~15 s) swell-dominated beaches (Short and Brander 1999). Beach rips can also be

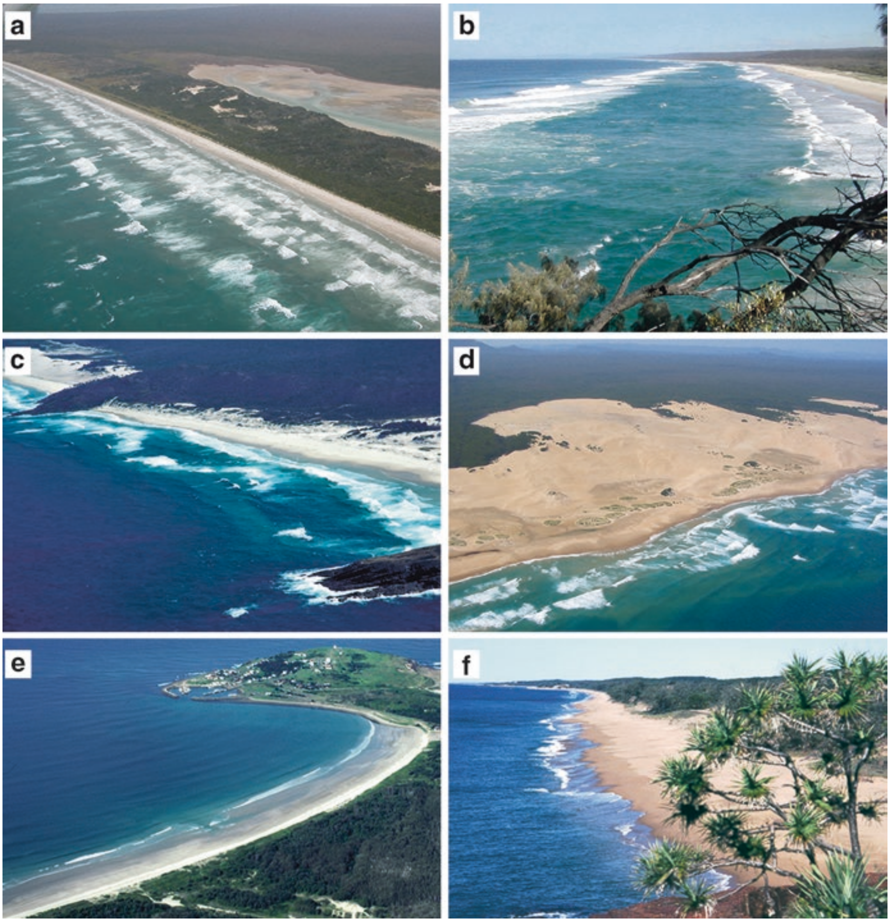


Fig. 1.22 Wave-dominated beaches: (**a**) dissipative beach at Back Banks beach, Robbins Island, TAS (RI 4); (**b**) longshore and wide deep trough at Point Lookout, QLD (QLD 1588); (**c**) rhythmic bar and beach at Treachery Beach, NSW (NSW 219); (**d**) transverse bars attached to the shore and deep rip channels, at Lagoon River beach, W TAS (TAS 825); (**e**) low tide terrace, Crowdy Head, NSW (NSW 184); and (**f**) steep reflective beach at Round Hill, QLD (QLD 1471). (Photos: AD Short)

classified into erosional (or free) rips and accretionary (or fixed) rips (see Short (1999) for a full description).

Topographic rip currents occur where a rip feeder and/or longshore current is deflected seaward against an object or structure such as a headland, groyne, rocks and reefs. Because these currents are often constricted by the obstacle, they tend to flow faster (>1.5 m s^{-1}) and combined with wave breaking/turbulence around the structure scour a deeper channel and flow further seaward. They are also known as *headland* and *boundary*rips (Brander and Scott 2016).

Megarips are large-scale topographic rips that occur in association with high wave conditions (>3 m) on embayed beaches and where a large obstacle obstructs surf zone circulation. Megarips may occupy an entire embayment with their location a function of wave direction and embayment shape, usually flowing out against a boundary, or may exit from the centre of larger embayments. They flow seaward as strong (2–3 m s^{-1}) current that can erode and transport large volumes of sand and carry it >1 km seaward depositing it in deep water. They are one of the major causes of severe erosion on exposed embayed beaches.

Tide-modified (TM)beaches prevail across northern Australia (Fig. 1.20b) in areas of meso- to mega-tide ranges exposed to moderate waves (Fig. 1.19a). They have an RTR between 3 and ~10, with wave height usually between 0.5 and 1 m (Fig. 1.19b). They require sufficient wave energy to generate rip circulation and rhythmic bar (but not beach) morphology and high tide beach cusps. There are three TM beach states (see 7–9, Fig. 1.23), which represent the reflective to dissipative spectrum and range from the lower energy reflective plus low tide terrace (R + LTT) to the higher energy ultradissipative (UD).

The *reflective plus low tide terrace* (R + LTT) beach is typified by a steep R high tide beach, often composed of coarser sand, usually with multiple sets of beach cusps spaced vertically down the beach face (produced during high tide at different states in the tidal cycle), an abrupt change in slope at the base of the beach, where the water table exits, fronted by a wide (50–200 m) (often finer sand) LTT (Figs. 1.23, 1.24a). At low tide waves break across the terrace dissipating their energy, while at high tide, they pass unbroken across the terrace to surge up and reflect off the high tide beach face generating the high tide cusps. The intermediate state is represented by the *reflective plus low tide bar and rips* (R + LTR). This usually receives higher waves (~1 m) and may have finer sand. The high tide beach is similar to the R + LTT with a steeper beach face with cusps, while the low tide bar may extend further seawards (100–300 m). The distinguishing feature is the presence of rhythmic bar and rip channels located along the low tide seaward edge of the bar (Figs. 1.23 and 1.24b). The bar may be detached (LBT-RBB) or attached (TBR-LTT). The low tide waves break on the outer bar generating the bar and rip circulation and morphology. At high tide the waves pass unbroken over these features (and the rip circulation ceases) and finally break by surging up the high tide beach. The high tide beach remains straight, as the rhythmic low tide morphology is disconnected from the high tide beach by 10's to 100 m of intertidal sand, and thereby unable to imprint itself on the high tide morphodynamics. The *ultradissipative* (UD) beach represents the dissipative highest energy TM beach and also has the highest waves (>1 m) and finest sand. It consists of a wide (200–500 m), low gradient concave essentially featureless beach, with a slightly steeper high tide beach usually containing high tide cusps (Figs. 1.23 and 1.24c). The beach is extremely dissipative at low to mid tide, becoming more reflective at high tide.

Tide-dominated (TD)beaches occur in areas of low waves (<0.5 m) and higher tides, with the RTR ranging from ~10 to 50 and more (Fig. 1.19). They are the most common beach type across northern Australia (Fig.1.20c) and consist of four states ranging from the higher energy beach plus ridged sand flats (B + RSF) to the lowest energy beach plus tidal mud flats (B + TMF) (see 10–13, Fig. 1.23). Each is characterised by a low often shelly high tide beach and wide intertidal flats. The high tide

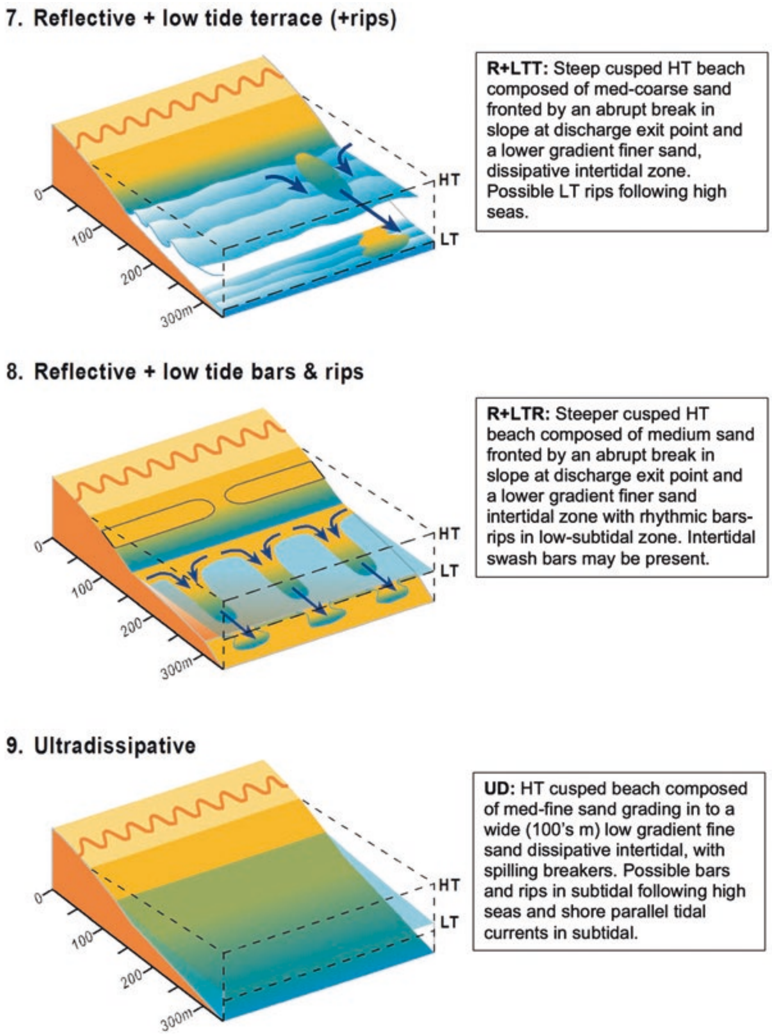


Fig. 1.23 The three tide-modified beach states (7–9), four tide-dominated states (10–13) and two rock/reef flats beaches (14 and 15). (From Short 2006a, b, c)

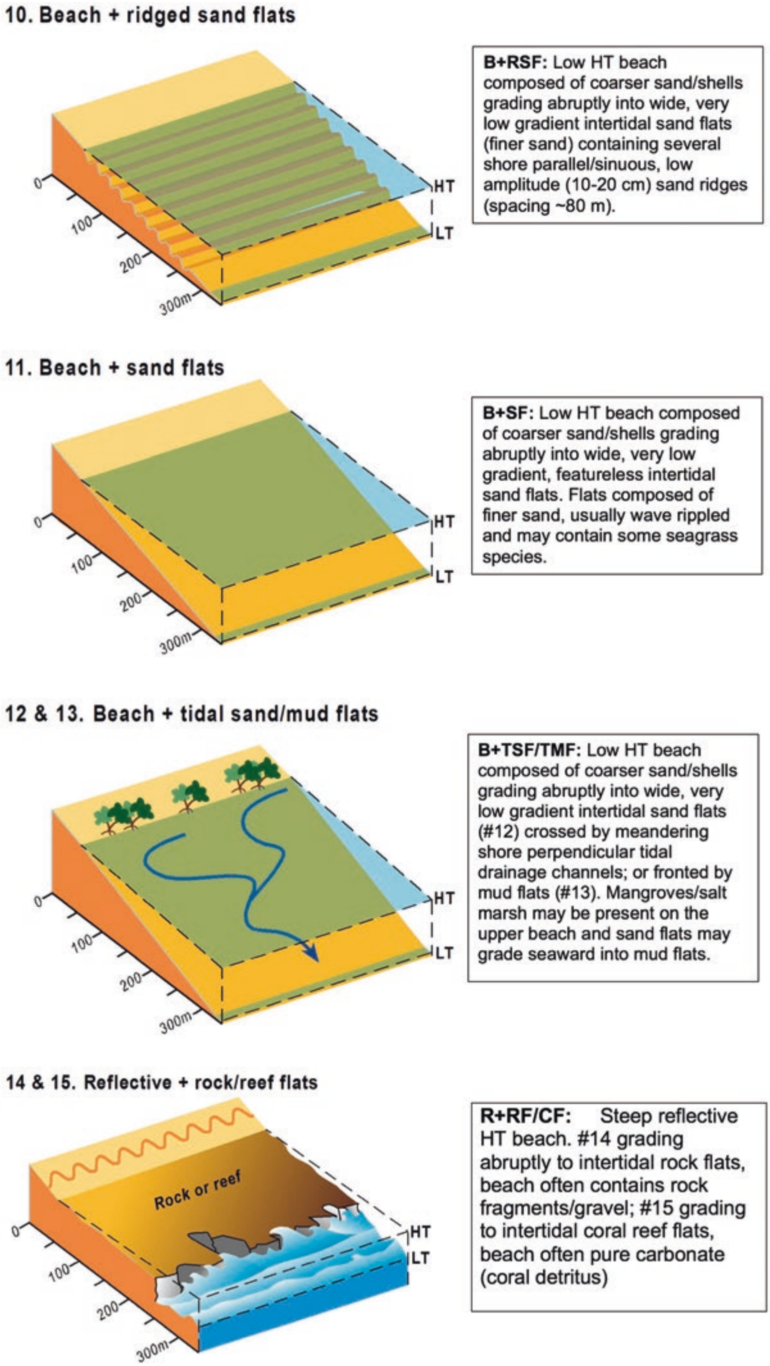


Fig. 1.23 (continued)

Fig. 1.24 Tide-modified beaches: (**a**) steep reflective cusped high tide beach and low tide terrace at Bramston Beach, QLD (QLD 755); (**b**) reflective beach and low tide rip channels at Mission Beach, QLD (QLD 784); and (**c**) ultradissipative beach at Mulambin, QLD (QLD 1370). (Photos: AD Short)

beach is called a 'beach', rather than a reflective beach, because there is usually insufficient wave energy for wave reflection to imprint cusps on the high tide beach. Rather the high tide beach tends to be low, narrow and composed of coarse poorly sorted material including carbonate detritus (shells and shell grit) and often crenulate alongshore. The highest energy TD beach is the *beach plus ridged sand flats* (B + RSR) which receives waves averaging 0.5 m and has an RTR ~ 9. It consists of the high tide beach and intertidal sand flats averaging 600 m in width which have low, equally spaced sand ridges on their surface, the ridges averaging about 80 m in spacing and 5–10 cm in height (all dimensions relate to Australian beaches as provided by Short 2006a; Fig. 1.25a). The ridges are apparently produced by the breaking waves as they move across the flats on a rising tide. As wave energy drops and RTR increases (~ 20), there is a shift to the beach plus sand flats (*B* + *SF*), which is similar to the RSR, except that the flats are flat, wide (average 300 m) and essentially featureless (Fig. 1.25b), apart from wave and current ripples. As wave height drops further and RTR continues to increase, the final two states are reached. The

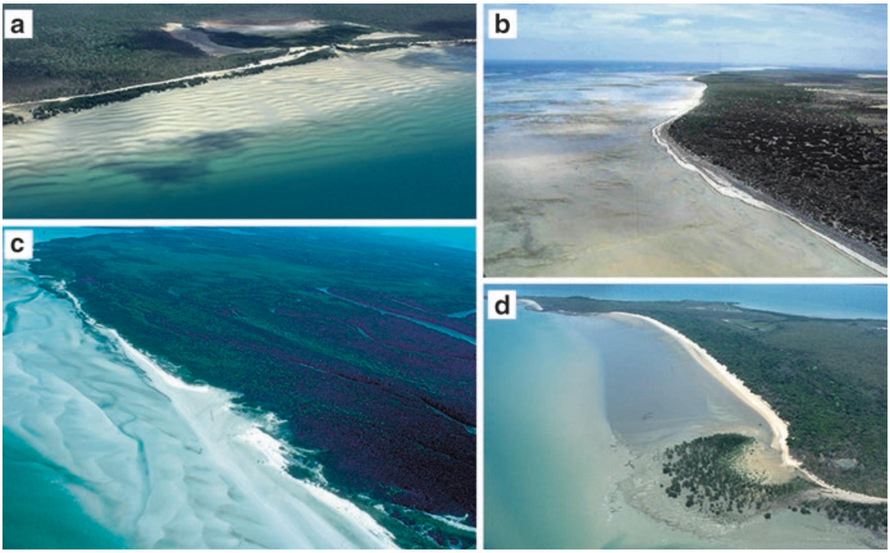


Fig. 1.25 Tide-dominated beaches: (**a**) mangrove fringed high tide beach and 18 ridged sand flats at Wurgurlu Bay, NT (NT 175); (**b**) beach and featureless sand flats at Shoalwater Pt, SA (SA 614); (**c**) beach and tide-dominated sand flats at Kennedy Inlet, QLD (QLD 230); and (**d**) high tide sand beach and mud flats at Hut Pt, NT, bordered by mangroves (NT 104). (Photos: AD Short)

beach plus tidal sand flats (B + TSF) receives waves averaging ~0.16 m and has an RTR of ~32. It has the low energy high tide beach, with the sand flats averaging 350 m in width, with the flats reworked by tidal currents into a tidal drainage pattern containing drainage channels and shoals (Fig. 1.25c). The final beach state is the *beach plus tidal mud flats* (B + TMF), which receives low waves (~0.16) and has the highest RTR (~50) and consists of an often steep shell-rich high tide beach, fronted by intertidal mud flats averaging 500 m in width, which may or may not have tidal drainage patterns (Fig. 1.25d). In addition, on some beach, inner tidal sand flats merge seaward into tidal mud flats, and any of these TD beach types may occur in association with mangroves, particularly in northern Australia.

Rock/Reef Flat (R + RF/CF)Beaches.

The final two beach states are independent of waves and tides, as they depend on geology and biology (see 14 and 15, Fig. 1.23). The *reflective plus intertidal rock flats* (R + RF) occur where a sandy beach is deposited in lee of intertidal rock flats (Fig. 1.26a). It consists of the usually steep, reflective cusped, high tide beach, fronted by intertidal rock flats that average 270 m in width. The high tide beach is only active at high tide, while at low tide waves break heavily on the outer end of the flats only breaking across the flats during mid to high tide. The *reflective plus intertidal coral reef flats* (R + CF) occur across the tropical north of Australia where coral reefs fringe the shore (Fig. 1.26b, c). In many locations, particularly in embayments, the reef flats are backed by steep, coarse-grained, carbonate-rich high tide beaches. The reef flats average 300 m in width but can reach up to 2000 m.

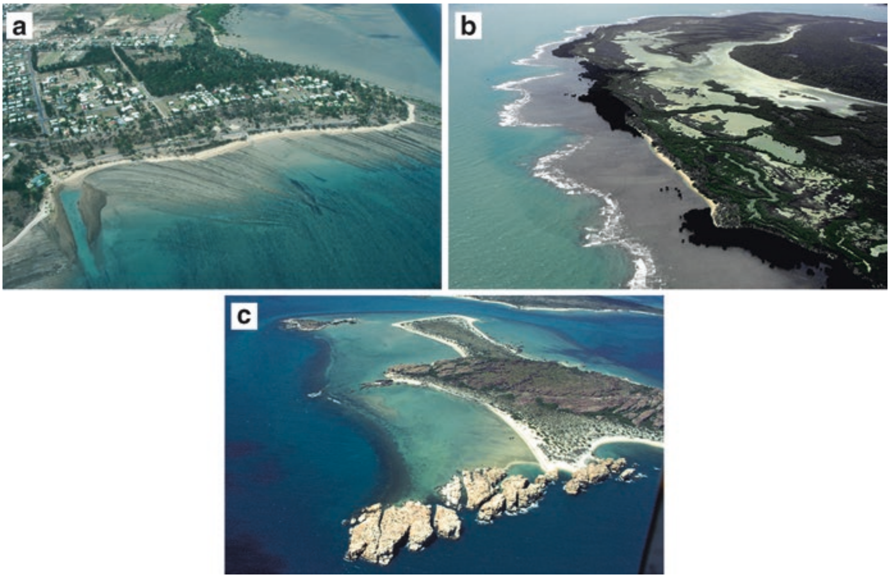


Fig. 1.26 (**a**) High tide beach fronted by intertidal rock flats at Pt Vernon, QLD (QLD 1522); (**b**) beach fringed by mangroves and fronted by fringing coral reefs on the northeast tip of Melville Is, NT (MI 113); and (**c**) fringing coral reefs surround much of Mugwana Is, NT (adjacent to northwest Groote Eylandt). (Photos: AD Short)

The 4 beach types and 15 beach states described above permit the classification of all Australian beaches. While there is broad regional coherence in the beach types, considerable local variation in both beach type and state can occur in association with spatial variation in wave and sediment conditions. For a detailed State by State/Territory description of every Australian beach, see Short (1996, 2000, 2001, 2005, 2006b, c, 2007). Descriptions and photos of most beaches are also contained in the free iPhone app 'Beachsafe' produced by Surf Life Saving Australia.

1.6.2 Sand Origins and Transport

Australian beaches for the most part consist of unconsolidated fine to medium through coarse sand. This sand is usually composed of quartz (silica) gains or carbonate detritus, with lesser regional percentage of lithics including heavy minerals (Fig. 1.10). The quartz sand is ultimately derived from erosion of the hinterland, particularly granite, some metasedimentary and all sandstone rocks. It is transported to the coast by rivers and then transported, and being highly resilient is reworked many times, along the coast. Veevers (2015) calculated that some of the extremely resilient heavy mineral sand grains on the NSW-southeast Queensland coast date back 500–700 Ma, with their origin in the granite belt of the Lachlan Fold Belt. At the other end of the scale is the carbonate detritus being produced by modern organisms. The carbonate is derived from three main sources – in the south the inner continental shelf biota (James and Bone 2010) and seagrass meadows (Belperio et al. 1988; Short 2002, 2013) and in the north from fringing coral reefs.

Fine to medium sand can be readily eroded by waves and transported and deposited elsewhere by wave, tidal currents and wind, within or beyond the beach system. As a consequence, beaches respond to changing wave and tide conditions by transporting sand on, off and along-shore depending on conditions and once on the beach and can be transported inland by strong winds. The following section looks briefly at some of the ways beaches respond and how sand can be transported within and beyond beach systems via wave-, tide- and wind-driven sand transport.

A beach's *sediment budget* is the sum of all the sources of sediment, including longshore, offshore, fluvial, carbonate production and beach nourishment, less all the losses to sand dunes, offshore, longshore, extraction, etc. The budget may be positive, balanced or negative, leading, respectively, to accreting, stable or receding shorelines. Sediment budgets are very difficult to calculate, and usually at best a conceptual budget may be developed based on the location and nature of the beach system and the longer-term behaviour of the shoreline. Short (2010b) provides an approximate onshore sand budget for the Australian coast, as well as some of its major coastal depositional centres. In Sect. 1.7 the coast will be divided into sediment compartments based on the sediment compartment concept developed by Davies (1974) and more recently enhanced by Thom et al. (2018).

Beach oscillation refers to the periodic erosion of beaches by larger waves and their recovery during the following periods of lower waves, i.e. beach erosion and recovery. Beach oscillation is a common phenomenon on beaches exposed to periods of higher and lower waves. It occurs regularly around much of the southern Australian coast and seasonally on northern Australian beaches. During high waves and storm conditions, the shoreline may in a few hours to days retreat several to tens of metres (e.g. see Thom and Hall 1991; Harley et al. 2017) and then recover over a period of days to months during the ensuing lower waves. A beach may oscillate tens of metres but still maintain a stable long-term shoreline position if the sediment budget is stable, the beach being in a state of dynamic equilibrium. This implies when sand is eroded from the beach it stays within the sediment compartment and ultimately returns to the shore. The amount of sand eroded by major wave events is called the *storm demand*. During a major storm event, it can range from a few tens of metres to over 200 m^3 m^{-1} of beach (Gordon 1987; Harley et al. 2017). It represents the amount of sand needed to be eroded and transported into and beyond the surf zone to build bars and widen the surf zone in order to help dissipate the impact of the larger waves on the shoreline. The storm demand is used to map the extent of potential beach erosion that is then used in coastal zoning and planning to establish erosion hazard zones and buffer zones and determine setback distances. Therefore, knowledge of beach oscillation and storm demand is essential for developing meaningful beach management and avoiding placing property and infrastructure at risk (see, e.g. OEH 2018).

Beach accretion and recession. *Beach accretion* refers to the net accretion or building out of a beach and shoreline in response to a long-term positive sediment budget. Many beach systems accreted during and following the stabilisation of sea level about 6.5 ka, building out when there was a massive positive sediment budget. These beaches built seaward from between tens of metres up to several kilometres as regressive beach and foredune ridge plains (see, e.g. Thom et al. 1981; Murray-Wallace et al. 2002; Oliver et al. 2015, 2017). *Beach recession* refers to the net retreat of the beach and shoreline owing to a negative long-term sediment supply. Many once accreting beaches are now receding owing to a shift in the sediment budget from positive to negative. Beach systems may therefore be stable (balance sediment budget), receding (negative budget) or accreting (positive budget). For this reason knowledge of the tertiary sediment compartments and beach sediment budget is critical for understanding longer-term beach behaviour and is now a central component of coastal management in WA (Eliot et al. 2011) and NSW (OEH 2018; see the NSW 'Coastal Management Act 2016' at https://www.parliament.nsw.gov.au/bills/DBAssets/bills/BillText/3291/Passed%20by%20both%20Houses.pdf).

To summarise, *beach erosion* refers to beach retreat during a high wave event; *beach recovery* refers to beach rebuilding to its original position following the erosion events; *beach recession* refers to the net retreat of the shoreline over time; *beach accretion* refers to the net building out of the shoreline over time. Beach oscillation (erosion and recovery) during a major erosion event is also defined as the storm demand and is used to define the *hazard zone* of potential erosion. The rate of beach recession is used to determine the *setback*, the distance behind the hazard zone to be kept as a buffer against future recession. Finally, many beaches also have a *buffer zone*, which usually incorporates the foredune so it can act as a natural buffer and storage of sand to combat wave erosion, protect against wind and aeolian sand transport, maintain the dune ecosystem and enhance beach amenity.

Beach rotation refers to the periodic erosion at one end of an embayed beach and simultaneous accretion at the other end and vice versa. The rotation or realignment of the beach planform in response to changing wave direction was observed near Sydney by Short (1967) and in Oahu (Short 1969) and reported in Port Phillip Bay by Bird (1993). The first detailed measurements of shoreline rotation and its causes were undertaken at Sydney's Narrabeen-Collaroy beach (Short and Trembanis 2004) where northerly rotation during periods of lower south swell induced erosion at the southern Collaroy end, while the northern Narrabeen end underwent substantial accretion, with the reverse occurring during more easterly waves. Beach rotation is caused by changes in wave direction, which in Perth and Port Phillip Bay have been related to seasonal shifts in wind and wave direction, while on the NSW coast, it has been related to periodic changes in wave direction induced by the Southern Oscillation (SOI) (Short and Masselink 1999), with a period of rotation of between 3 and 8 years. In general, more east to north waves (+ SOI/La Nina) induce a southerly rotation, while more southern waves (-SOI/El Nino) a northerly rotation. Short et al. (2014) has subsequently recorded regional-scale beach oscillation and rotation along the southern NSW coast, while the actual mechanism of sand transport and beach rotation in NSW has been assessed by Harley et al. (2011).

Longshore sand transport (also called littoral drift) refers to the net movement of sand along a sandy coast. The movement predominately takes place in the surf zone where breaking waves suspend sand which can then be transported by wave-induced

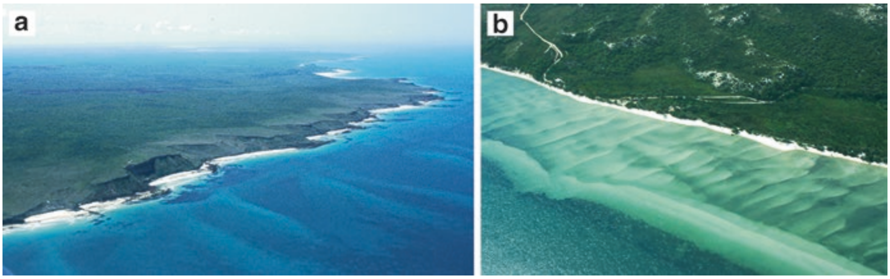


Fig. 1.27 Shore perpendicular sand waves indicating tidal current transport located off (**a**) Reid Pt (QLD 256-262) and (**b**) Elim Beach (QLD 627), both eastern Cape York Peninsula. (Photos: AD Short)

longshore currents. On higher energy double bar beaches, the maximum transport will occur over the outer bar during high wave conditions. The breaking wave suspends the sand, which is then moved longshore by the longshore component in the breaking waves, especially when waves are arriving obliquely to the beach. On the east Australian coast with predominately southeast waves, net transport is to the north. Likewise, on the west coast with southwest waves, it is also to the north. The direction of transport can reverse with changes in wave direction, in which case the sum of the two opposing transport rates will determine the net longshore transport and its direction. Rates of transport vary with wave conditions and estimated annual rate range from a high of about 500,000 $m^3\ yr^{-1}$ on the NSW-SE Queensland coast (Ware 2016) to between 3000 and 300,000 $m^3\ yr^{-1}$ on the Capricorn Queensland coast (BPA 1979) and between 8000 and 13,000 $m^3\ yr^{-1}$ on the beaches north of Cairns (BPA 1984). On parts of the Queensland coast, tidal currents also play a major role in longshore transport, transporting sand in the form of tidally driven large megaripples/sand waves as shown in Fig. 1.27. Sand will be transported longshore until it is deposited in a temporary or permanent sediment sink, which may be onshore into a dune system or estuary, offshore into a shelf sand body or longshore into the next compartment. Around Australia the southerly waves result in predominately northward transport along the east and west coast and onshore transport across the southern coast (Fig. 1.28) with major sediment sinks located in Torres Strait, the southeast Queensland sand islands, the Murravian Gulf and the Zuytdorp Cliffs.

The propensity of a beach to transport sand will depend to what degree on its alignment relative to the dominant wave direction. *Drift-aligned beaches* occur where the dominant wave crests arrive oblique to the shore inducing net longshore transport in the direction of wave travel. In contrast *swash-aligned beaches* occur where the dominant wave crests arrive parallel to the shore and do not generate net longshore sand transport. The rate of longshore transport will therefore be a function of the degree of drift alignment, the wave height and the sand size, increasing the more oblique waves, higher waves and finer sand.

Headland bypassing refers to the subaqueous transport of sand around at headland or obstacle to longshore transport. On coasts experiencing net longshore sand transport, the presence of headlands can pose a barrier to this transport. On the northern NSW coast where there are longer beaches bordered by headlands, the

Fig. 1.28 Generalised sketch of major sediment transport paths on the Australian coast. (Source: Short and Woodroffe 2009)

sand 'bypasses' the headlands subaqueously. This occurs as the sand moves around the southern updrift side of the headland as subaqueous transport driven by waves and in places tidal currents, possibly in the form of megaripples (see, e.g. BPA 1984). The sand moves around the outer part of the headland and manifests itself on the northern downdrift side as intertidal and supratidal elongate migrating sand waves and/or sand spits, which eventually merge with the beach and continue on as longshore transport (Short and Masselink 1999). When the sand wave-spit is developed on the downdrift side, it usually generates a migratory topographic rip at the leading edge of the spit. This rip can in turn generate severe beach and dune erosion as it slowly moves downdrift, followed by the abundant sand of the sand spit and shoreline recovery. Headland bypassing occurs along the NSW-SE Queensland coast, as well as many parts of the central-northern east Queensland coast (Fig. 1.29a) where rates can reach 100000's $m^3\ m^{-1}$ on higher energy headlands. It is also common along the Brazilian coast (Short and Klein 2016; Vieira da Silva et al. 2016; Claudino-Sales et al. 2018) where rates have been estimated between 1000 and 800,000 $m^3\ year^{-1}$ and along the Portuguese coast (Robeiro 2017). It is a process which will no doubt be detected on many coasts with similar characteristics.

Headland overpassing. Fine to medium beach sand can be transported across headlands by moderate to strong wind as aeolian transport. The sand can be moved onshore into coastal dune systems and removed from the compartment and the budget. It can also move up and over headlands as part of the longshore transport system, known as headland overpassing. *Headland overpassing* refers to aeolian transport of sand across a headland from an updrift beach via migratory sand dunes

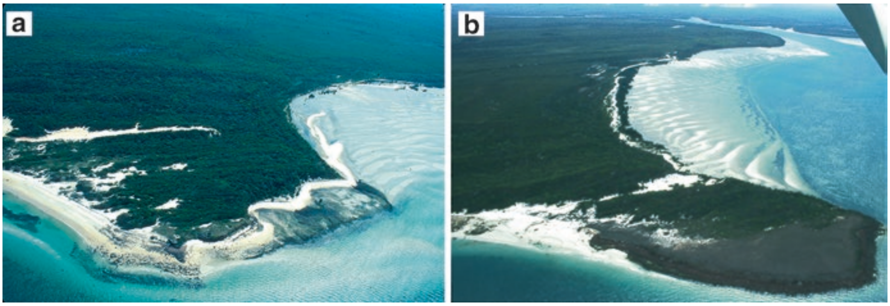


Fig. 1.29 (**a**) Orford Ness has dune sand overpassing the headland, as well as bypassing around the head to form the elongate spit on its northern side (QLD 275-6), and (**b**) headland overpassing at Sharp Pt (QLD 232), both eastern Cape York Peninsula. (Photos: AD Short)

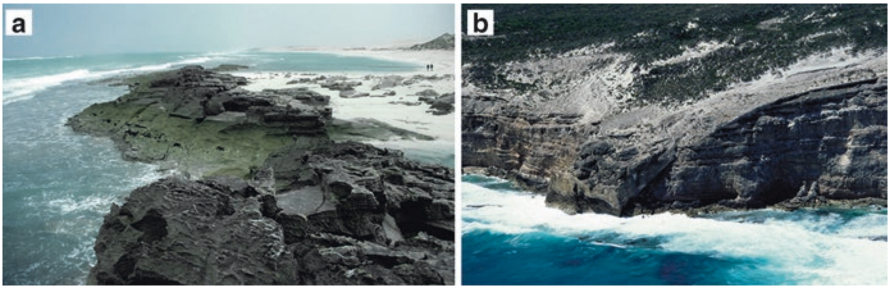


Fig. 1.30 (**a**) View along a beachrock reef at Coombra, SA (SA 1427), and (**b**) Pleistocene dunerock cliffs capped by white Holocene clifftop dunes, southern Eyre Peninsula, SA. (Photos: AD Short)

to the downdrift beach. Overpassing tends to occur where the headland is orientated oblique/perpendicular to the prevailing winds which then blow the sand across the headland. Overpassing has occurred in the past on some west-facing southern Australian headlands and today is more common on some south-facing northeast Queensland headlands (Fig. 1.29a). It also commonly occurs along the southern South African coast and parts of the Brazilian coast (Short and Klein 2016) where it contributes to the longshore transport system (Vieira da Silva et al. 2016). Stabilisation of the bypassing dunes will decrease and even cease sand transport to the downdrift beach, which can lead to beach recession. In South Africa dune stabilisation at Port Elizabeth and Cape St Francis reduced the overpass transport by 80% (100,000 m^3 $year^{-1}$), leading to severe downdrift shoreline recession (McLachlan et al. 1994).

Many Australian beaches have had parts of their beach and dune sand partially cemented by chemical processes, turning the previously unconsolidated sand into a 'rock'. This rock may be of three types beachrock, dunerock and coffeerock.

Beachrock (beach calcarenite) refers to the cementation of the intertidal beach sand by the precipitation of carbonate between the sand grains (Fig. 1.30a). It requires warm, carbonate-saturated waters and preferably carbonate-rich sands and occurs predominately across the tropical north of Australia, where it was first mapped in Australia and globally by Russell and McIntire (1965) and Davies (1973,1980). Beachrock can form in a few years to decades. It has a major impact on sandy beach systems as it replaces the mobile, porous unconsolidated sand with an often continuous layer of hard impervious rock, which may be 2–3 m thick and 20–50 m wide. If the beach retreats, the rock remains as an attached or detached reef (Fig. 1.30a) which severely impacts the surrounding beach behaviour.

Dunerock (also called dune calcarenite, aeolian calcarenite and (a)eolianite) forms in carbonate-rich sand dunes located in arid to semi-arid and tropical monsoonal environments as a result of pedogenesis. The sediment, vegetation and climate interact to form a calcrete soil which consists of a massive cemented upper horizon (~1 m thick), below which is a mottled semi-lithified lower horizon which may be metres to tens of metres thick (Fig. 1.30b), a process that takes hundreds to thousands of years to fully develop. The extent of Australian dunerock was first mapped by Davies (1973, 1980). It occurs right across the southern Australian coast, up much of the west coast and in parts of the north coast. On the humid east coast, the higher precipitation leaches the carbonate right out of the system, leaving unconsolidated predominately quartz dunes. Once formed dunerock turns part of the once unconsolidated dunes into rock of variable hardness. The rock will be exposed if the overlying sand is blown away and if the shoreline retreats, where it will form dunerock cliffs (Fig. 1.30b). Dunerock cliffs are common along the southern and Western Australian coast and form the 250 m long Zuytdorp Cliffs in Western Australia. Brooke (2001) reviewed the global distribution of aeolianites (dunerock) and found that it is largely derived from carbonate production on shallow shelves and banks, with the bulk of the carbonate comprising aeolianites being *heterozoan*, produced where there is low terrigenous sediment input in dominantly temperate cool-water and sub-tropical carbonate provinces. He also found that 'Quaternary cyclical movements of sea level have also controlled the form and rate of coastal carbonate deposition, with repeated pulses of sedimentation during highstands forming laterally coalesced, vertically stacked or composite dune successions'. Short (2013) reviewed the 9000 km long Australian temperate carbonate province and its roll in supplying carbonate sands to the beaches and dunes. This coast is the world's largest carbonate province, three times the length of the GBR, a fact that was not lost on Darwin (1851) who suggested the volume of the southern Australian aeolianites was comparable in size to Pacific coral reef complexes.

Coffeerock refers to the indurated sand layer in a Pleistocene soil, often composed of beach and/or dune sand. Along the humid east Australian coast, coffeerock forms in Pleistocene beach-dune deposits as a result of podsol soil formation (pedogenesis) over the past 100,000 years and more and is commonly exposed along the northern NSW and SE Queensland coast (Fig. 1.31). Podsolic soils contain an upper dark organic-rich layer where decaying organic matter accumulates. Weak organic acids from this layer seep down through the underlying sand slowly dissolving and leaching out carbonate and other materials, leaving behind the resilient white quartz dune and beach sand. The dissolved material moves down through the dune until it encounters the water table where some of the material is deposited between the sand grains forming a resilient dark organic indurated sand layer, known by various names including coffeerock (Thom et al. 1992 p.88). When exposed at the coast, the

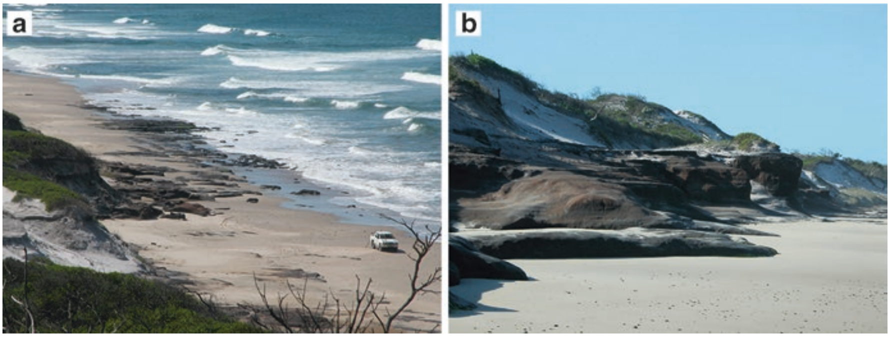


Fig. 1.31 Coffeerock exposed at the base of white Pleistocene dunes on (**a**) Broadwater Beach, NSW, and (**b**) Ten Mile Beach, NSW. (Photos: AD Short)

coffeerock forms dark erodible slabs of sand overlain by the white leached dune sands (Fig. 1.31). Ward et al. (1979) describe Pleistocene 'sandrock' at Rainbow Beach in Queensland, while Brooke et al. (2008) examined coffeerock in Moreton Bay and found that the cements are dominantly kaolinite and amorphous organic-rich complexes and that it both coats the grains and partially infills interstitial pores. They also found that pedogenesis occurs over long periods up to ~90,000 years, with incipient induration evident in deposits 16–2.6 ka.

1.6.3 Estuaries and Deltas

Estuaries and deltas are a major component of the Australian coast. There are more than 1000 rivers and estuaries around the coast (Fig. 1.9), together with over 1300 smaller creeks. An estuary is a sheltered body of water that receives freshwater fluvial input at its landward end and marine saltwater input at its seaward end. Around the Australian coast, the PMT flooded many coastal valleys and bays thereby providing a wide range of coastal embayments suitable for estuarine development. Ecologically, estuaries are protected shallow, nutrient-rich habitats for a wide range of organisms; chemically they range from freshwater through brackish to saltwater, while physically they provide shelter and anchorage for vessels and upstream a source of freshwater, and as a result, they became the site of all early settlements around the Australian coast and are the site of all state capitals (Brisbane, Sydney, Melbourne, Hobart, Adelaide and Perth) and numerous towns and settlements. As a consequence many estuaries, particularly on the east, southeast and southwest coasts, have been heavily impacted by coastal development.

Australian estuarine research commenced with occasional studies in diverse locations. It was not until Roy (1984) following studies of numerous NSW estuaries that a robust classification system was developed. This scheme has been expanded and applied Australia-wide by Geoscience Australian the results of

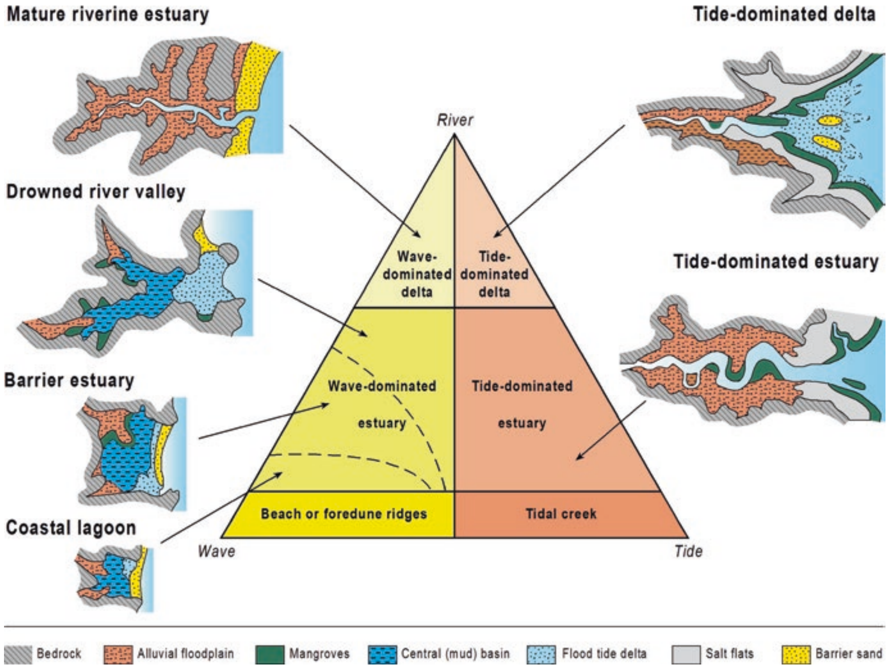


Fig. 1.32 An Australian estuary classification based on the relative contribution of rivers, waves and tides to estuary configuration and evolution. A full evolved 'mature' estuary becomes a delta. (Source: Short and Woodroffe 2009, modified from Harris et al. 2002)

which are available at OzCoasts website and for NSW at http://www.environment.nsw.gov.au/estuaries/. Roy's classification was based on wave-dominated NSW estuaries. In order to expand this Australia-wide, Heap et al. (2001) incorporated the TD northern Australian estuaries. Figure 1.32 illustrates the relative contribution of rivers/streams, waves and tides to estuary morphology and evolution. *Wave-dominated estuaries* occur predominately around the southern coast, with its high waves and micro-tides, and when infilled, as wave-dominated deltas in some exposed northern coast locations. *Tide-dominated estuaries* and deltas are exclusively restricted to the low waves and high tide regimes of northern Australia (Fig. 1.33). Table 1.3 lists the estuary/deltas by type and their occurrence in each state/territory. A brief description of the wave and tide-dominated estuaries is provided in the following section.

Harris et al. (2002), using the database developed by Heap et al. (2001), quantified the contribution of tides, waves, river discharge and river flow for 721 coastal clastic depositional environments around Australia. The environments were statistically classified and mapped into seven environments: wave-dominated (WD) deltas, tide-dominated (TD) deltas, WD estuaries, TD estuaries, strand plains, tidal flats and lagoons. They found a distinct regional pattern to their distribution, similar to Fig.1.33 and Table 1.4, with WD estuaries located across the south and TD estuaries

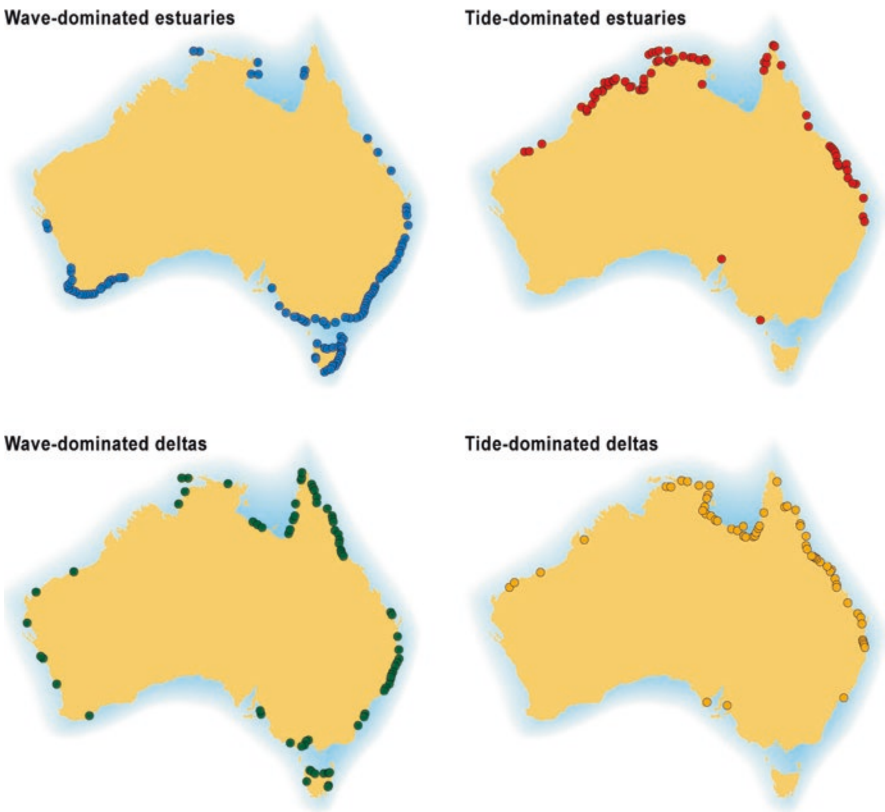


Fig. 1.33 Distribution of Australia's wave-dominated and tide-dominated estuaries and deltas. (Source: Short and Woodroffe 2009, based on Heap et al. 2001)

Table 1.4 Australian estuaries and coastal deltas indicating number in the major geomorphological types by state

Waterway type	QLD	NSW	Vic	TAS	SA	WA	NT	Total
WD delta	44	18	5	10	2	7	7	93
WD estuary	8	57	21	32	2	31	6	157
TD delta	50	1	0	1	1	4	16	73
TD estuary	38	0	1	3	1	24	28	95
Strand plain	19	9	10	5	0	5	12	60
Tidal creek/tidal flat	140	3	2	3	10	73	54	285
Total	299	88	39	54	16	144	123	763

Source: Heap et al. (2001)

Table 1.5 Distribution of estuarine areas by state (km^2). (From Bucher and Saenger 1991)

	Open water	Intertidal flats	Mangroves	Seagrass	Salt marsh	Total
QLD	4092	1574	3423	68	5322	14,412
NSW	1323	na	107	153	57	1487
VIC	2682	444	40	346	125	3291
TAS	1824	274	0	na	37	2136
SA	760	218	111	ns	84	1173
WA	18,824	2890	1561	11	2965	25,241
NT	5187	821	2952	23	5004	13,965
Total	33,694	6223	8195	601	13,594	61,707

in the north while WD deltas predominately along the east and north coast and TD deltas all in the north. Strand plans and tidal flats were also exclusively located around the northern half of the continent, while the few lagoons show no regional pattern. They also concluded that the high proportion of deltas, prograding strand plains and tidal flats located on the northeast Queensland and Gulf of Carpentaria coasts indicates that the hinterland of this region has a relatively high sediment yield in comparison with other regions of the continent.

Bucher and Saenger (1991) compiled an inventory of 783 estuaries right around the coast grouping them into 13 coastal biographic and climate zones and found that 415 were tropical, 179 sub-tropical and 198 temperate. They further mapped the area of open water, intertidal flats, mangroves, seagrass and salt march by state and for Australia (Table 1.5), which shows that WA, QLD and the NT have the most extensive estuarine systems.

Wave-dominated estuaries predominate around the humid sections of the southern Australian coast (Fig. 1.33; Table 1.4) where waves are higher and tides micro and in a few northern locations with meso-tides exposed to higher waves. They consist of three basic types – the drowned river valley, such as Sydney Harbour with wide usually bedrock entrances; the barrier estuary, where a sand barrier blocks the valley mouth with an open inlet providing connection to the sea; and the coastal lagoon, which is similar to a barrier estuary though usually smaller and the inlet is often closed. Barrier estuaries are also known as ICOLS (intermittently open-closed coastal lagoons). Each of these estuarine types is fed by a fluvial stream, creek or river, which delivers freshwater, nutrients and terrigenous sediments to the upper reaches of the estuary and deposited bayhead deltas. The coarser material is deposited to build the delta at the mouth of the stream, while the finer silts and mud settle in the deeper estuarine (or central) mud basin, or is carried out to sea via the inlet. At the seaward end, waves and flooding tides transport clean marine sand into the estuary mouth/inlet building a sandy flood tide delta.

Over time the continual inflow of marine and particularly fluvial sediment, combined with in situ organic production (mangroves, seagrass, shell organisms), led to

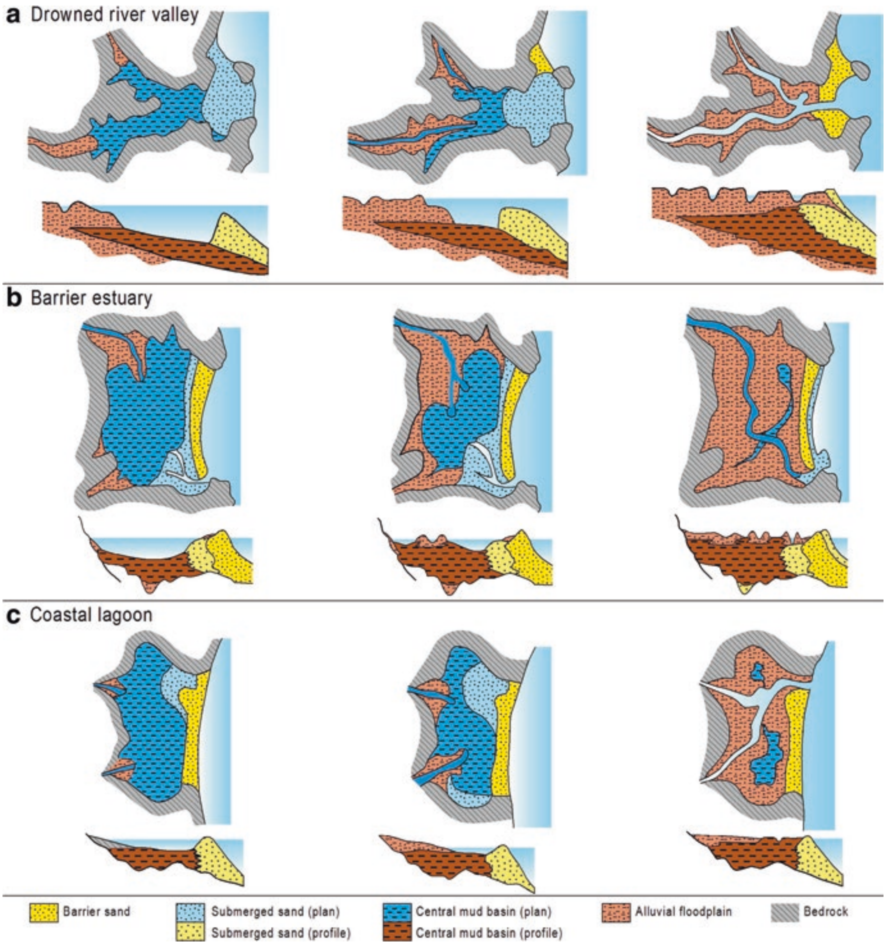


Fig. 1.34 The three wave-dominated estuary types and their stages of infilling from an immature (left) to mature (right) estuary. (Source: Short and Woodroffe 2009; based on Roy et al. 2001)

the gradual infilling of the estuary. The bayhead delta builds out over the shoaling mud basin to ultimately form a flat alluvial freshwater floodplain, while marine sand fill the mouth and outer estuary slowing over time as wave energy is reduced into the estuary. The nature and stages of infilling of the three WD estuaries are illustrated in Fig. 1.34.

Tide-dominated estuaries and deltas occur predominately across the north of Australia (Fig. 1.35, Table 1.4) where not only tides are higher and waves lower, but the numerous rivers deliver higher sediment loads to their estuaries, in many cases infilling of the estuaries leading to the formation of a delta. A *delta* is a river deposited accumulation of sediment at the river mouth where it enters the sea. They are

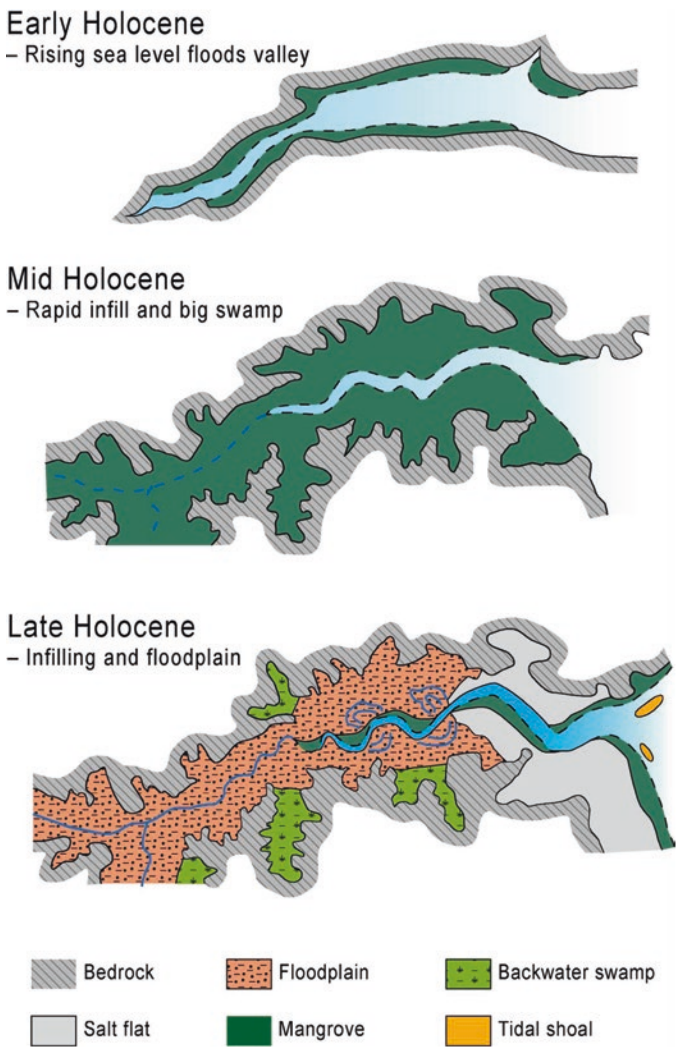


Fig. 1.35 The three stages of infilling of a tide-dominated estuary. During the early Holocene, the valley is flooded with mangroves lining the sides. As sedimentation infills the side and shoals, the estuary mangroves extend across the intertidal flats during the 'big swamp' stage. Finally, as continued sedimentation shoals the flats, the mangroves are replaced by salt flats and floodplains. (Source: Short and Woodroffe 2009)

essentially an infilled estuary, where the river delivers terrigenous bedload sediment directly to the coast and as a result may protrude seaward, to produce the classic Δ shape, though not in the case of TD deltas.

Northern Australian TD estuaries tend to be funnel-shaped to accommodate the large tidal flows that dominate the hydrodynamics and control the estuarine morphology and sedimentation. Morphologically they have an open seaward funnel section, narrowing to a meandering central tidal channel and finally the upstream fluvial channel. The open funnel section experiences high velocity flood and ebb tidal currents, which scour the channel bed and only allow coarse shell and gravel-rich linear sand tidal shoals to form on the channel floor. Sedimentation of the finer sand and mud is restricted to the quieter intertidal areas along the sides of the funnel and the meandering sections, particular where vegetated in dense mangrove forests. As these initially sub- to intertidal deposits build upwards and outwards, they provide a habitat for extensive mangrove forests, in northern Australia called the mid-Holocene 'big swamp' (Fig. 1.35). Continued sedimentation within the mangroves elevates the substrate to high and supratidal levels leading to replacement of the mangroves with supratidal salt flats and marshes. Ultimately these are elevated by river flooding to freshwater floodplains as the estuary transforms to a tide-dominated delta (Fig. 1.32). As Fig. 1.33 indicates, many of the northern tide-dominated estuaries have infilled to reach the delta stage.

Geoscience Australia has documented all Australian estuaries (www.ozestuaries.org) and classified them into the seven types based on wave-tide-river inputs. In NSW the Department of Primary Industries has mapped all recognised 67 NSW estuaries providing a habitat map for each estuary (see Creese et al. 2009 and http://www.dpi.nsw.gov.au/content/research/areas/aquatic-ecosystems/estuarine-habitats-maps), while Bucher and Saenger (1991) have mapped the estuarine areas by state (Table 1.4).

1.6.4 Dunes and Barriers

Most Australian beaches are backed by some form of sand dune, ranging from low narrow foredunes to massive transgressive dunes extending many kilometres inland. The beach and dunes and other adjacent sand deposits form what is termed a *barrier*, which represents the longer-term accumulation of sand in lee of a beach. Barriers always consist of the beach and nearshore sand and will include the backing dune systems and where adjacent to creeks and estuaries the tidal deltas. Around Australia there are 2538 barriers, many of which back more than one beach, with barriers occupying 12,841 km of the coast or 85% of the sandy/beach coast (Short 2010b, also see Chap. 34). This section briefly presents the type of dune and barrier systems found around the Australian coast.

Coastal dunes form behind beaches wherever onshore winds are of sufficient velocity (>20 cm s^{-1}) to transport fine to medium sand from the beach to its lee. The dunes can be of two types – regressive or transgressive. *Regressive dune* implies the sand is accumulating right behind the beach but not moving any further landward and in fact builds out or regresses out onto the beach. If the beach has a positive sediment budget, it will build seaward along with the prograding beach.

The *foredune* is the first dune behind the beach and extends down to spring high tide swash mark. It is vegetated with low salt and wind-tolerant grasses, succulents and creepers, called primary stabilisers, which grade landward with increasing pro-

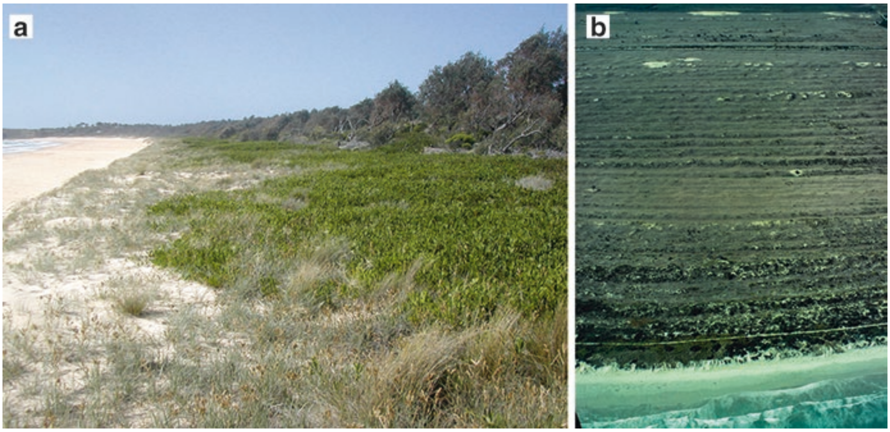


Fig. 1.36 (**a**) Well-vegetated incipient foredune vegetated with *spinifex* and low *acacia* and backed by taller *banksia* on the foredune, on the NSW South Coast (NSW 566) and (**b**) a series of ~50 foredune ridges at Rivoli Bay, SA (SA 70). (Photos: AD Short)

tection into shrubs on its crest and lee side. Continued aeolian (wind-blown) sand transport builds up the foredune and may reach 10 m + in height and be tens of metres in width (see Hesp 1984 and 2002, for foredune morphodynamics). Along its seaward edge, there is usually a low vegetated *incipient foredune* (Fig. 1.36a) which is commonly eroded by high waves and then recovers over a period of years. Foredunes can be classified by their degree of vegetation cover/instability (Short and Hesp 1982; Hesp 2002).

On beach systems with a positive sediment budget and an accreting shore, new foredunes are built as the shoreline moves seaward resulting in a series of foredunes called a *foredune ridge plain* (also termed a *strand plain*). Foredune ridge plains are common around the Australian coast and may reach several kilometres in width and contain as many as 80 foredune ridges (see, e.g. Murray-Wallace et al. 2002) (Fig. 1.36b).

Transgressive dunes are dunes that move landward of the beach and foredune. They occur on all beaches that have no foredune to trap the sand and on foredune-backed beaches when the foredune is destabilised and its sand released to blow further inland. The volume of sand transported by wind increases at the cube of the wind velocity. Therefore, in order to have transgressive dunes, and in particular large transgressive dues, the coast must be exposed to strong on/alongshore winds.

Transgressive dunes have a series of evolutionary forms dependent on wind direction and velocity and degree of vegetation cover. Where sand is transported from a destabilised foredune, both wind and vegetation play a role in the sand transport and dune morphology. The first dune form is a *blowout*, which is a small depression in the foredune from which sand is blown inland as a depositional lobe (Hesp 2002). As the sand is removed, it leaves behind a bare deflation hollow in the

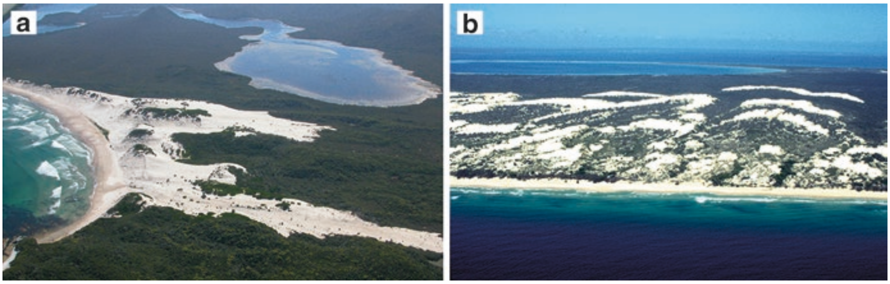


Fig. 1.37 (**a**) Large blowout to parabolics at Towterer Beach, TAS (TAS 684), and (**b**) nested or imbricated parabolic dunes on Groote Eylandt, NT. (Photos: AD Short)

otherwise vegetated foredune. While blowouts may start small, they can grow in size over time to tens of metres in dimensions (Fig 1.37a).

If the blowout detaches from the foredune and continues to move inland, it becomes a parabolic dune. The *parabolic* consists of a central elongate deflation basin, parallel to the wind direction, side walls that are partly vegetated and a leading depositional lobe, parabolic in shape, which slowly advances landward (~5–10 m year^{-1}) burying whatever is behind it (Fig. 1.37a). In regions of strong unidirectional onshore winds, the parabolic may travel 100's m to kilometres inland where it is termed a *long-walled parabolic*. Also, over time, there may be episodes of dune transgression and parabolic dune formation leading to them piling one on top of the other, which are called *nested or imbricated parabolics* (Fig. 1.37b).

During the PMT and stillstand, there were many areas exposed to high waves receiving large volumes of sand that was transported inland as transgressive dunes. Where they encountered sea cliffs, the wind-built sand ramps to enable the dunes to move up onto the cliffs and in places move inland as *clifftop dunes*. Clifftop dunes occur commonly on exposed south-facing NSW headlands and right across the southern Australian coast and up the west coast as far as Shark Bay. Most of the sand ramps were eroded thousands of years ago with only a few still active today (Fig. 1.38).

In areas where there is no vegetation to hold or retard the sand movement, the dune morphology is a function of just the wind direction, sand size and sand thickness. Where the sand is thick and the wind unidirectional, it is arranged in *transverse dunes*, which lie perpendicular to the wind direction. They have relatively straight crests separated by swales spaced 100–200 m apart. They range in height from 5 to 10 m with fine sand up to 20 m with medium sand (Fig. 1.39a) and migrate downwind at between 5 and 10 m year^{-1}. They consist of a lower gradient (~15°) windward or stoss slope and a steeper (32–36°) downwind slope called the 'slip face'.

As the transverse dunes migrate and the sand thickness decreases it allows the underlying harder boundary surface to becomes exposed. As this occurs the dunes respond by developing an increasing sinuous ridge line and form called a *barchoil-*

Fig. 1.38 Active sand ramp and clifftop dune near Red Bluff, WA (WA 1451). (Photo: AD Short)

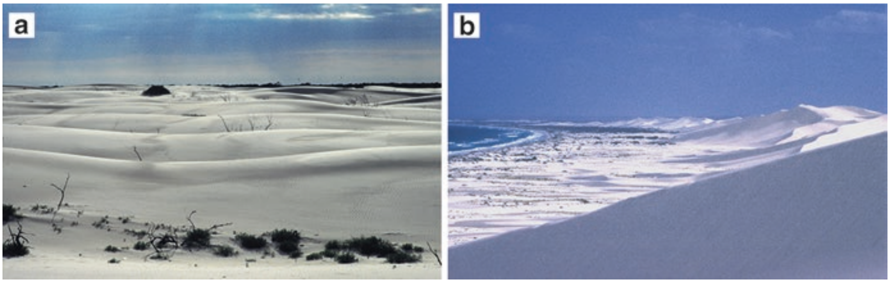


Fig. 1.39 (**a**) View across the crests of a series of transverse dune, Hearder Hill, southeast WA (WA 3), and (**b**) star dunes at Bilbunya, southeast WA (WA 23). (Photos: AD Short)

dal ridge. Finally, if sand thickness continues to decrease and more bare surface is exposed, the ridges detach and form individual *barchans dunes* which are U-shaped in the wind direction. In desert regions, these dunes go one stage further and form long linear longitudinal dunes, characteristic of the Australian sand deserts. They do not however occur in Australian coastal dune fields.

In areas where strong winds may blow from more than one direction, the bare sand may be rounded up into a *star dune*. A star dune is a peak of bare sand surrounded by several migration arms or sand ridges. A large star dune will be several hundred metres across and have several (~6–10) ridges and a peak reaching over 100 m high. In Australia they are only found in the southeast of Western Australia (Fig. 1.39b).

A final classification of dunes is whether they are primary or secondary. Davies (1973, 1980) defined *primary dunes* as being derived directly from the beach and may be 'free' or transgressive and unvegetated (transverse, barchans, etc.) or 'impeded' and vegetated, i.e. foredune. *Secondary dunes* are derived from erosion and reworking of primary dunes and include all transgressive dunes that evolve from foredunes. Both primary and secondary dunes occur commonly around the entire Australian coast.

Coastal barriers, like the dunes, can be either regressive, stable or transgressive. *Regressive barriers* build seaward and are usually relatively low and even and capped with increasing wave energy by cheniers, beach ridges or foredunes. *Cheniers* are low usually shelly beach ridges that sit atop and are separated by high tide mud flats (Rhodes 1982). They occur predominately in northern Australia adjacent to extensive mud flats (Fig. 1.40a), usually close to river mouths, the source of the mud. The chenier is usually composed of coarse carbonate detritus-shells winnowed from the mud flats. In the north they are usually capped by minor aeolian deposits and vegetated with casuarina. *Beach ridges* consist of low, often shelly ridges composed of swash-deposited beach material (Nott et al. 2013), sitting atop and separated by intertidal to supratidal sand flats. They occur in lower energy area where there is insufficient energy to build foredunes, though they may have minor aeolian capping. They are common across the north and in the South Australian gulfs. Note that cobble and boulder beach ridges are a type of beach ridge and can occur in high energy locations, where because of their coarse matrix they have no aeolian capping. *Beach ridge plains* consist of a regressive series of beach ridges.

Stable barriers usually consist of one or more stable foredunes that have been in place for a considerable period (hundreds to thousands of years). They tend to be well vegetated, often with shrubs and trees, and tend to occur in sheltered locations with a fixed and stable sediment budget.

Transgressive barriers are barriers which are moving landward either through shoreline recession and/or dune transgression. Any barrier form that has a negative sediment budget will have an eroding shoreline and thereby be receding or

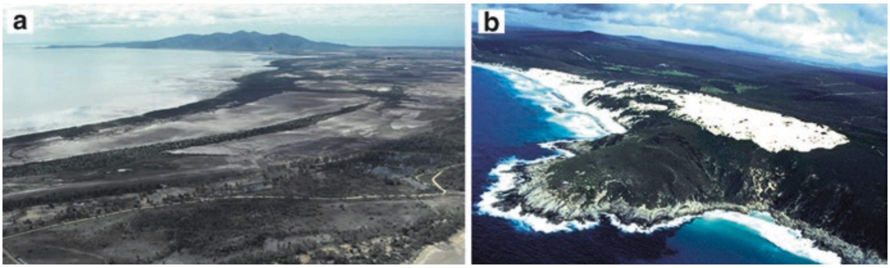


Fig. 1.40 Two contrasting barrier systems. (**a**) A regressive chenier plain in Cleveland Bay, QLD, and (**b**) a climbing transgressive dune/barrier at Cordinup, southern WA (WA 357). (Photos: AD Short)

transgressing landward. Transgressive barriers also include all those backed by transgressive dunes that are moving landward (Fig. 1.40b), irrespective of the stability of the shoreline. A transgressive barrier may be composed of a former primary barrier (foredune ridges) overridden by blowouts, parabolics or transverse dunes or entirely primary dunes. The dunes may be stable (vegetated) or partly or fully unstable (free).

Pleistocene dunes and barriers. Around much of the Australian coast are beaches, dunes and barriers that were deposited at or above present sea level during the last interglacial high sea level approximately 120 ka and in places some of the earlier higher sea levels on Pleistocene palaeoshorelines (Murray-Wallace and Belperio 1991). During and following the Holocene rise in sea level and stillstand, many of these older Pleistocene deposits have been either eroded or overlapped and/or onlapped by the Holocene deposits depending on their location and elevation relative to the Holocene sea level. Where they occur in combination, particularly if separated by an interbarrier depression, the landward Pleistocene barrier is called the *inner barrier* and the seaward Holocene barrier the *outer barrier*. The older Pleistocene systems are usually heavily weathered with well-developed soils, the soil type depending on the climate and dune mineralogy. In quartz-rich dunes of the humid east, this weathering leads to the formation of podsolic soils and coffeerock (Figs. 1.31). In more tropical regions, the quartz grains may become coated in red iron oxide (Fig. 1.41a). In the south and west where the dunes are rich in carbonate and the climate drier, calcrete soil formation leads to partial lithification and formation of dunerock (Fig. 1.30). All these dunes may also have multiple palaeosols which when exposed at the coast form the so-called coloured sands of Fraser Island (Fig. 1.41b) and the stacked palaeosequences commonly visible in dune calcarenite cliffs in the south and west (Fig 1.30b).

Short (2010b) documented all 2476 Australian coastal mainland barriers including their location, beach systems, size, stability, volume and rates of sediment supply. The results are listed in Table 1.6, where they are grouped into 3 provinces (eastern, south and west and northwest) and 17 'sub-provinces'. The largest barrier systems are located in higher energy southeast Queensland, eastern Victoria and across the south-west coast, with the smallest in the lower energy and generally

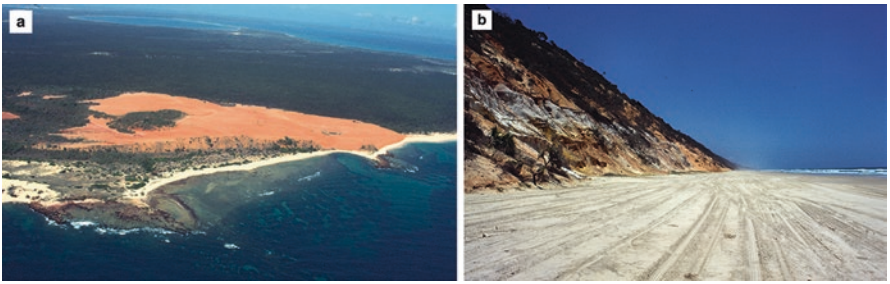


Fig. 1.41 (**a**) Bright red Pleistocene dunes on Groote Eylandt, NT (GE 97–99), and (**b**) the scarped Pleistocene dunes on Fraser Island exposed the various white through red soil horizons (palaesols), which are known as the 'coloured sands' (FI 8). (Photos: AD Short)

Table 1.6 Characteristics of Australian sedimentary provinces and sub-provinces

	Province	Coast length (km)	Barrier length (km)	Number barriers (#)	Total barrier area (km^2)	Unstable area (km^2)	Unstable (%)	Barrier volume (km^3)	Mean barrier vol ($m^3\ m^{-1}$)	Holocene rate supply ($m^3\ m^{-1}\ year^{-1}$)
	Eastern									
1	W Gulf Carp	1750	579	144	413	41	10.0	2.7	4658	0.8
2	E Gulf Carp	1469	913	67	2624	18	0.7	14.7	16,096	2.7
3	E Cape York	1032	582	91	1702	70	4.1	19.8	10,272	1.7
4	E Queensland	3325	1198	310	1435	43	3.0	10.0	8335	1.4
5	SE Queensland	854	410	25	2910	196	6.7	29.1	70,968	11.8
6	NSW	1590	924	278	815	78	9.5	7.3	7848	1.3
7	E Victoria	440	408	49	991	197	19.9	10.7	50,737	4.4
8	N&E Tasmania	1518	486	186	246	48	19.5	2.2	4424	0.7
		11,978	**5500**	**1150**	**11,136**	**691**	**9.2**	**96.5**	**21,667**	**3.1**
	South and west									
9	W Tasmania	717	178	77	238	41	17.3	4.4	24,719	4.1
10	W Victoria	744	337	85	1270	128	10.1	17.5	51,991	8.7
11	S Australia	3273	1580	197	1926	670	34.8	29.3	18,529	3.1
12	Kangaroo Is	458	113	15	500	19	3.8	7.5	66,404	11.1
13	S West Aust	1930	1335	157	4681	723	15.5	93.6	70,077	11.7

14	SW West Aust	2465	1261	135	2123	396	18.6	26.8	21,222	3.5
		9587	**4626**	**589**	**10,738**	**1936**	**16.7**	**174.7**	**42,157**	**7.0**
	Northwest									
15	Pilbara	1421	770	123	936	55	5.9	7.2	9417	1.6
16	Kimberly	4333	456	368	223	66	17.8	1.0	2205	0.4
17	W North Territory	3352	823	246	422	17	4.0	1.6	861	0.1
		9106	**2049**	**737**	**1581**	**138**	**9.2**	**9.8**	**4161**	**0.7**
	Total	**30,671**	**12,175**	**2476**	**23,455**	**2765**	**11.7**	**281**	**22,662**	**3.6**

Source: Short (2010b)

[1]Includes Fraser, Moreton and Stradbroke islands

more sheltered northwest and parts of the northeastern coasts. The same database is utilised in this book to assess the barriers within the ACSC framework (discussed in Sect. 1.7), with regional and compartment barrier dimensions presented in the following chapters and an updated Australia-wide assessment of the size, volume, extent and stability of the barriers based on ACSC presented in Chap. 34.

1.6.5 Rocky Coast Morphodynamics

Rocky shores form approximately half the Australian coast and as such are a major component of the coastal zone and shoreline. The geology of the entire coast including the origin, age and rock type has been mapped at a scale of at least 1:250000 by state geological surveys. An excellent overview of the evolution and geology of Australia is provided by Blewett (2012). Short and Woodroffe (2009) discuss the range of rock types that occur around the coast and which include granites and basalts and a wide range of sedimentary and metasedimentary rocks. They also discuss the nature of rocky coast erosion and in some (particularly sedimentary rocks and basalts) the formation of cliffs and rock platforms.

Rocky coasts do erode, and with changing climate and rising sea level, the rates of erosion are anticipated to increase. In friable rocks this is already becoming a problem as described by Fotheringham (2009) at Beachport in South Australia. However, the scientific study of Australia's rocky coast, which was reviewed by Stephenson and Thronton (2005), remains as they concluded 'limited' and focused on rates of erosion and the formation of rock (shore) platforms. They further state the 'Australian coast offers significant opportunities and excellent environments to expand our understanding of rock coasts' using a 'morphodynamic approach to processes operating on rock coasts'. However, we still await this research and understanding.

Short (2010a) examined the role of geological inheritance (i.e. rocky boundaries) on beach morphodynamics around the Australian coast. He found that wave refraction and attenuation over and around rock substrate and boundaries produced shorter, more crenulate rock-bound beaches with lower wave energy and lower energy beach states, and a major reason why lower energy R beach dominates by number (Table 1.3). As a result, Australia-wide, rock substrate has a profound effect on the coast and its beach systems and ultimately many of its barrier systems, through what is referred to as 'geological control'.

1.6.6 Sea Level and Climate Change

Sea level is tied to global temperature and as such is impacted by changing climates at scales of decades to millennium. Figure 1.43a illustrates sea level over the past 250,000 years. It illustrates how sea level falls to its lowest levels (~120 m depth),

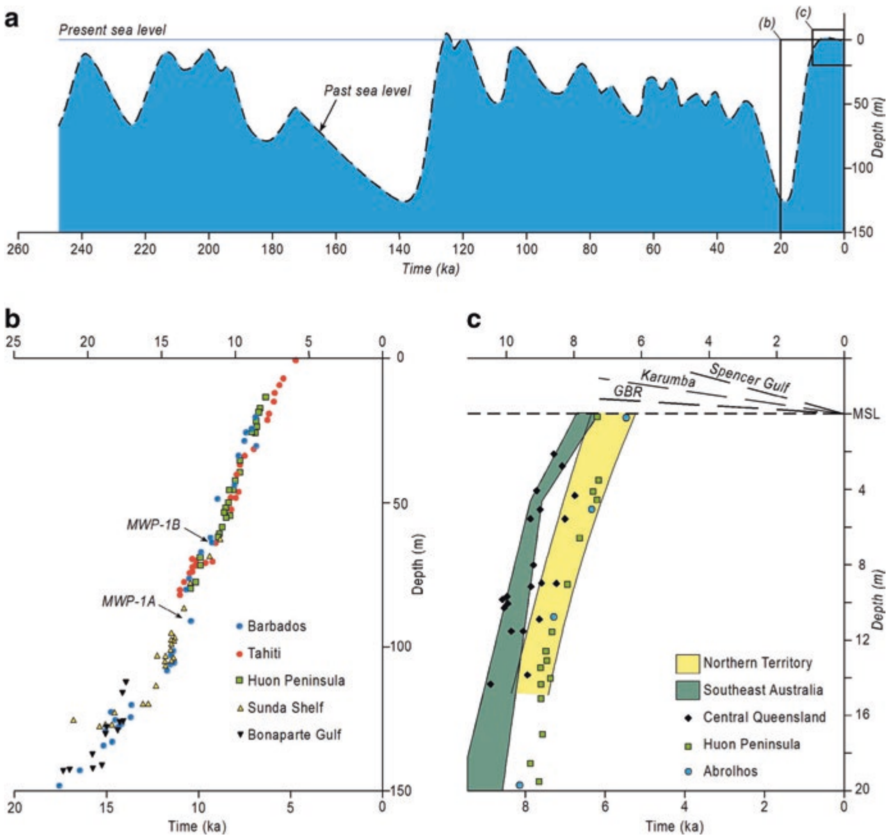


Fig. 1.42 (**a**) Oscillation is global sea level over the past 250,000 years; (**b**) the recent postglacial sea-level rise from various global locations; and (**c**) plot of Holocene rise in sea level, its maxima and regional variation at some Australian locations. (Source: Short and Woodroffe 2009)

roughly every 100,000 years, and likewise reaches its highest levels with the same periodicity. In between it oscillates at periods of 20,000 to 40,000 years. These regular oscillations in sea level are tied to changes in the Earth's temperature, with low stands of the sea accompanying cool 'glacial' periods when ice sheets form over Europe and North America and the intervening warmer 'interglacial' periods when these ice sheets melt and sea level rises to its present level or even higher. Sea level was ~120 m below present 18 ka and rose at approximately 1.2 m per century for 11,000 years, stabilising at or near the present sea level between 8 and 7.5 ka (Fig. 1.42b, c). This rise in sea level flooded the continental shelves and coastal valleys and formed the present coastal line.

There have been numerous studies around the Australian coast attempting to plot and fine-tune the Holocene sea-level rise, in particular when it reached its maximum level, often above present sea level, and when and how it fell to the present level (Fig. 1.42c). For more detailed discussion of both Pleistocene and Holocene sea levels around Australia, see Hopley (1983), Nakada and Lambeck (1989), Murray-Wallace and Belperio (1991), Belperio et al. (2002), Baker et al. (2005), Sloss et al. (2007), Watson (2011) and Murray-Wallace and Woodroffe (2014).

Lewis et al. (2013) reviewed the PMT around Australia and concluded it attained modern levels between 8 and 7.5 ka and then either fell smoothly from a 1–2 m highstand or remained at these levels for a few thousand years before falling to the present level, with it behaving differently around the coast owing to regional neotectonics and hydro-isostacy. The exact level of the highstand and the timing and nature of its fall however are still being resolved around the coast.

Sea level is now increasing again as the world warms as a result of greenhouse-induced climate change. Over the past century, it has risen at an average rate of 1.7 mm year^{-1} and depending on location is presently rising between 2 and 6 mm year^{-1} but is anticipated to accelerate in the future decades (see Watson 2011, 2017; Murray-Wallace and Woodroffe 2014 for recent reviews). The potential impacts of this rise are discussed in Chap. 34.

Rising atmospheric and sea temperatures will also affect other aspects of climate and oceanography. The Earth's pressure and wind systems are governed by surface temperate and latitude; as temperatures rise, there is expected an expansion and poleward shift in pressure systems, as well as an intensification of low-pressure systems, owing to the warmer ocean waters. These shifts and changes will impact global wind systems and cyclonic systems and thereby the generation of ocean waves and the location, frequency, intensity and track of tropical, east coast and mid-latitude cyclones. All of these will impact wave climates – their direction, height, period and duration – which will in turn impact every one of our beach systems, irrespective of sea-level rise. They will also impact coastal wind regimes.

Finally, rising sea level will also change the depth and configuration of the coast zone and coastal estuaries and embayment. On the open coast, this will impact wave attenuation and refraction leading to changes in wave height and direction at the shore. It will also impact coastal tidal regimes, which may lead to an increase or decrease in the tide range. Any change in tide range will impact shoreline behaviour and could result in major changes within TD estuarine and deltaic systems.

Rising sea surface temperatures is also impacting marine organisms, generating a poleward migration of tropical and temperate marine organisms. This in turn will impact the ecology of the entire Australian coastal zone, particularly if mangroves and tropical sea greases begin to spread further south. In addition, rising sea level and any changes in tide range will impact all tide-dependent organisms, particularly seagrasses, mangroves and salt marshes which will all need to shift (vertically and landward) to maintain their habitats. All these impacts are reviewed in Chap. 34.

1.7 Coastal Sediment Compartments

The Australian coast is usually categorised by its seven States/Territories, as in Table 1.3. While these are useful for comparing the attributes of the States, they ignore the nature of the coast and its natural behaviour based on climate, orientation, geology and coastal topography. For this reason this book has adopted a new classification of the coast based on a hierarchy of natural attributes. The division of the coast used in these volumes is based on the Australian Coastal Sediment Compartments (ACSC) project. This project was based on a UK approach to coastal management (Cooper and Pontee 2006) and initiated by Geosciences Australia (GA) in 2012 as described by McPherson et al. (2015). GA gathered a team of coastal experts to define and map in Google Earth all of Australia's coastal provinces, divisions, regions and primary and secondary sediment compartments. Once these were mapped and defined, the project was transferred to the National Climate Change Adaptation Research Facility (NCCARF). During this stage the team developed descriptions for each of the 354 secondary sediment cells including an assessment of the compartment's sensitivity to climate change. An overview of the project is provided by Thom et al. (2018).

Stul et al. (2012) define *sediment compartments* as spatially discrete areas of the coast within which marine and terrestrial landforms are likely to be connected through sediment exchange. The nature and behaviour of sediment within and potentially between the compartments are at the core of this approach, as the sediment budget determines the stability of the shoreline now and into the future. Compartments therefore include sediment supply (sources), sediment loss (sinks) and the sediment transport processes linking them (pathways). The transport pathways include both alongshore and cross-shore processes. Sediment compartments are also natural management units with a physical basis and commonly cross-jurisdictional boundaries. They provide a summary of coastal data in a simple format and can be used to:

- Identify the spatial context for coastal evaluations
- Provide a visual framework for communicating about the coast with people of any background
- Support coastal management decision-making
- Support a range of technical uses largely relating to coastal stability assessment, such as interpreting historic trends and understanding contemporary processes and basis for projection of potential future coastal change
- Reduce problems caused by selection of arbitrary or jurisdictional boundaries

Compartment boundaries have been defined by Eliot (2016) using three descriptors relating to the physical nature of the boundary, its mobility and its capacity to allow transport of sediment to adjoining compartments. The physical boundary itself may be a clearly identifiable *point* or a more ambiguous *zone*. Fixed boundaries include rocky headlands and capes, while zone boundaries include river mouths and sandy cuspate forelands. Based on the physical nature of the boundary, they can be defined as *fixed* or immovable (e.g. headland) or *ambulatory* or potential shifting, such as the river or foreland. Finally, with regard to the interconnectivity of compartments and in particular their ability to transport sediment from one to the next, they may be *closed*, with no transfer of sediment; *leaky*, with partial or periodic transfer, such as via headland bypassing or overpassing; or *open*, with a clear throughput of longshore sediment transport.

Table 1.7 The division of the Australian coast into provinces, divisions and regions based on the Australian Coastal Sediment Compartments project

Australia	Province	No.	Division	No.	Region	Prim	Secondary
Chapter 2	**Tropical**						
3–4		1	Northwest	1	Pilbara	8	23
5–6		2	Kimberley-Territory	3	Kimberley	5	14
7				3	Western NT	2	10
8				4	North Arnhem	4	10
9–10		3	Gulf of Carpentaria	5	East Arnhem	2	7
11				6	Southern Gulf	2	4
12				7	W Cape York Pen	2	3
13–14		4	Northeast	8	E Cape York Pen	8	34
15				9	Central QLD	4	21
16	**Temperate**					0	
17–18		5	Southeast	10	Central eastern	6	22
19				11	Southern NSW	6	34
20				12	Gippsland	3	5
21				13	Eastern Tasmania	6	17
22–23		6	Great Southern	14	Western Tasmania	3	13
24				15	Northern Tasmania	4	8
25				16	Central and west Vic	3	17
26				17	Southeast SA	4	8
27				18	SA gulfs	2	13
28				19	Western Eyre Pen.	4	11
29				20	Nullabor	3	9
30				21	Southeast WA	7	26
32–32		7	Southwest	22	Southwest WA	7	21
33				23	Central west WA	7	24
	2	7		23		102	354

The aim of ACSC was therefore to provide coastal managers with basic information of all of Australia's coastal sediment compartments in a readily accessible format. The NCCARF website contains background material on the project together with an interactive map all compartments and their descriptions. This was released in August 2016 and is available at:

https://www.nccarf.edu.au/CoastAdapt-beta-release
http://coastadapt.com.au/coastadapt-interactive-map

Hierarchical classification. The project used the following criteria to divide the coast into a hierarchical classification (Table 1.7):

- Provinces (2): based on climate and latitude and divided roughly along the Tropic of Capricorn (between North West Cape 21°45'S and Sandy Cape 24°40'S) into the northern *tropical* coastal province and southern *temperate* coastal province (Fig. 1.43a). This book devotes a chapter to each of the provinces.

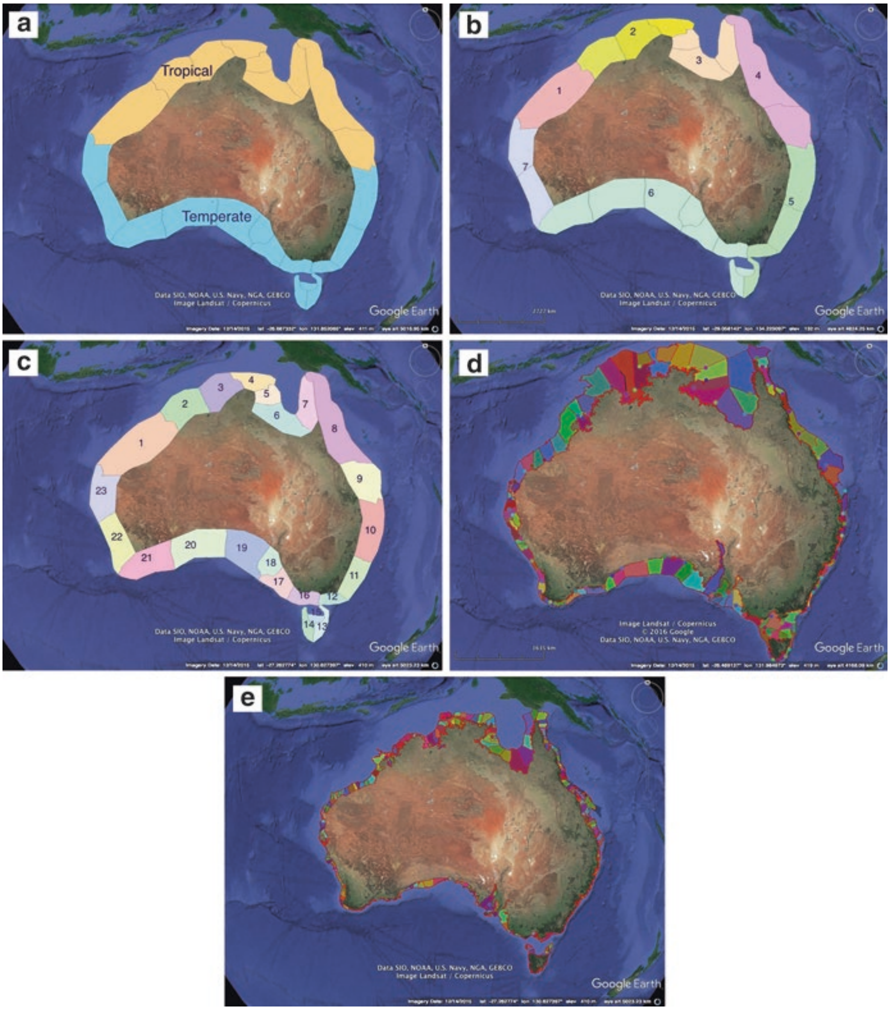


Fig. 1.43 Australia's (**a**) tropical and temperate provinces; (**b**) the 7 divisions; (**c**) the 23 regions; (**d**) the 102 primary compartments; and (**e**) the 354 secondary compartments. See Table 1.6 for names of provinces, divisions and regions

- Divisions (7): based on *province* and then primarily coastal orientation (NW, NE, SE, S and SW), apart from the Gulf of Carpentaria (Fig. 1.43b). This book devotes seven chapters to the divisions.
- Regions (23): based on *division* and then geology, with some contribution from coastal orientation/configuration, as in Tasmania and South Australian gulfs (Fig. 1.43c). This book devotes a chapter to each of the 23 regions.
- Primary compartments (PC) (102): based on *regions*, which are then subdivided at major physical coastal boundaries into primary compartments (Fig. 1.43d). In this book the 23 regional chapters are further subdivided to discuss each PC.

- Secondary compartments (SC) (354): based on *primary compartments*, with subdivisions into secondary compartments based on secondary coastal boundaries (Fig. 1.43e). Each of the SCs is discussed in this book.
- Tertiary compartments (TC) (>1000): based on *secondary compartments*, which are subdivided at obstructions (usually major headlands) into inter-compartment tertiary sediment cells, some as small as an individual beach. Only in WA has the entire coast been divided into tertiary compartments and assessed at this level (see Eliot et al. 2011; Stul et al. 2014a, b, c and 2015). Only a few TCs, where they form part of a well-studied secondary compartment, are discussed in this book.

Eliot et al. (2011) outlines the compartment approach and application for the WA coast, while Fig. 1.44 provides an example of the nesting of primary, secondary and tertiary compartments for part of the Western Australian coast. A manual on how to apply CoastAdapt to coastal sediments, beaches and soft shore was developed by Eliot (2016).

The structure of this book is based on the provinces (Chaps. 2 and 16), the divisions (Chaps. 3, 5, 9, 13, 17, 22 and 31) and the regions (Chaps. 3–33) which include the PCs and SCs (Table 1.6). These provide the framework within which the main concerns of this book can be addressed in a consistent and logical order, providing information on the geology, climate, coastal processes and sediments, the beaches and barriers, a primarily qualitative assessment of sediment sources and transport, and a first order quantitative assessment of barrier area and volumes. The material

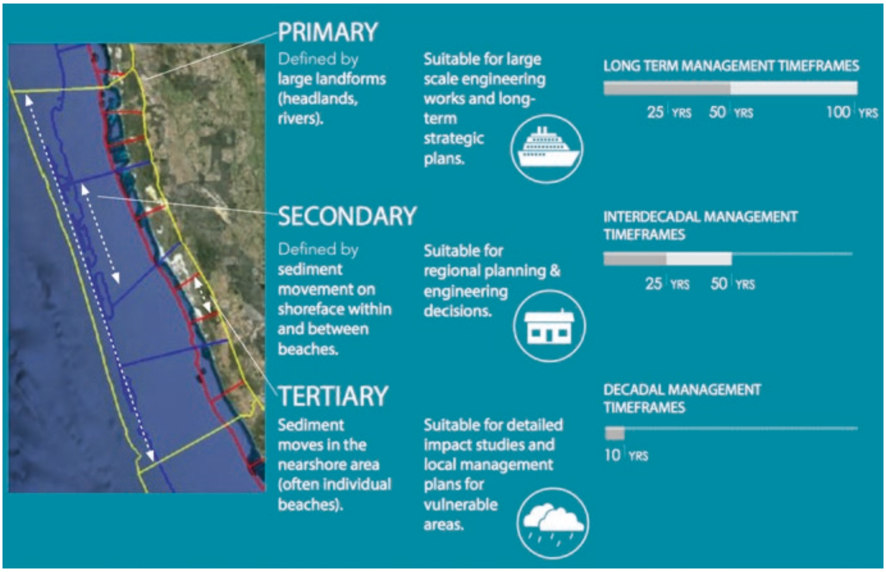


Fig. 1.44 An example of a WA primary compartment (yellow boundary), containing four secondary (blue) and eight tertiary (red) compartments. (Source: Thom 2015)

for the book is based on the author's knowledge of the coast, the ABSAMP, a database compiled by the author on all Australian beaches and barriers, and the published literature. It has attempted to reference and incorporate all relevant materials for each region/compartment. For more information on the ACSC project, see the above websites, Eliot (2016) and Thom et al. (2018).

References

Baker RG, Haworth RJ, Flood PG (2005) An oscillating Holocene sea-level? Revisiting Rottnest Island, Western Australia and the Fairbridge eustatic hypothesis. J Coast Res 42:3–14

Belperio AP, Gostin VA, Cann JH, Murray-Wallace CV (1988) Sediment-organism zonation and the evolution of Holocene tidal sequences in southern Australia. In: de Boer PL et al (eds) Tide-influenced sedimentary environments and facies. D Reidel Publ Co, Dordrecht, pp 475–497

Belperio AP, Harvey N, Bourman RP (2002) Spatial and temporal variability in the Holocene palaeosea-level record around the South Australian coastline. Sediment Geol 150:153–169

Birch WD (ed) (2003) Geology of Victoria. Geological survey of Australia special publication No 23. Geological Society of Australia, Melbourne, 842 p

Bird ECF (1978) The nature and source of beach materials on the Australian coast. In: Davies JL, Williams MA (eds) Landform evolution in Australasia Press. Australian National University Press, Canberra, pp 144–157

Bird ECF (1993) The coast of Victoria. Melbourne University Press, Melbourne, 324 p

Blewett R (ed) (2012) Shaping a nation- a geology of Australia. Geoscience Australia, Canberra. http://www.ga.gov.au/data-pubs/data-and-publications-search/publications/shaping-a-nation

Bourman RP, Murray-Wallace CV, Harvey N (2016) Coastal landscapes of South Australia. University of Adelaide Press, Adelaide, 405 p

BPA (1979) Capricorn Coast Beaches: Brisbane. Beach Protection Authority, Brisbane, 238 p

BPA (1984) Mulgrave Shire (Cairns) Northern Beaches. Beach Protection Authority, Brisbane, 366 p

Brander R, Scott T (2016) Science of the rip current hazard. In: Tipton M, Wooler A (eds) The science of beach lifeguarding. CRC Press, Boca Raton, pp 67–85

Brearley A (2005) Swanland – estuaries and coastal lagoons of south-western Australia. University of Western Australia Press, Perth, 550 p

Brooke B (2001) The distribution of carbonate eolianite. Earth Sci Rev 55:135–164

Brooke B, Preda M, Lee R, Cox M, Olley J, Pietsch T, Price D (2008) Development, composition and age of indurated sand layers in the Late Quaternary coastal deposits of northern Moreton Bay, Queensland. Aust J Earth Sci 55:141–157

Brooke BP, Nichol SL, Huang Z, Beaman RJ (2017) Palaeoshorelines on the Australian continental shelf: morphology, sea-level relationship and applications to environmental management and archaeology. Cont Shelf Res 134:26–38

Bucher D, Saenger P (1991) An inventory of Australian estuaries and enclosed marine waters: an overview of results. Aust Geogr Stud 29:370–381

Burrett CF, Martin EL (1989) Geology and mineral resources of Tasmania. Geological survey of Australia special publication No 15. Geological Society of Australia, Brisbane, 574 p

Chapman DM, Geary M, Roy PS, Thom BG (1982) Coastal evolution and coastal erosion in New South Wales. Coastal Council of New South Wales, Sydney, 341 p

Claudino-Sales V, Wanf P, Carvalho M (2018) Interactions between various headlands, beaches, and dunes along the coast of Ceará state, northeast Brazil. J Coast Res 34:413–428

Cooper NJ, Pontee NI (2006) Appraisal and evolution of the littoral 'sediment cell' concept in applied coastal management: experiences from England and Wales. Ocean Coast Manag 49:498–510

Courtney C, Dominey-Howes D, Goff J, Chagué-Goff C, Switzer AD, McFadgen B (2012) A synthesis and review of geological evidence of palaeotsunamis along the coast of southeast Australia: the evidence, issues and potential way forward. Quat Sci Rev 54:99–125
Creese RG, Glasby TM, West G, Gallen C (2009) Mapping the habitats of NSW estuaries, Fisheries final report series No 113. Industry and Investment NSW, Nelson Bay, 95 p
Darwin CR (1851) Geological observations on Coral Reefs, Volcanic Islands and on South America, being the Geology of the Voyage of the Beagle, under the Command of Captain Fitzroy during the years 1832 to 1836. London, Smith, Elder Co
Davies JL (1973) Geographical variation in coastal development. Hafner, New York, 204 p
Davies JL (1974) The coastal sediment compartment. Aust Geogr Stud 12:139–151
Davies JL (1977) The coast. In: Jeans DN (ed) Australia, A geography. Sydney University Press, Sydney, pp 134–151
Davies JL (1980) Geographical variation in coastal development, 2nd edn. Longmans, London, 212 p
Day RW and others (1975) Queensland geology. Geological survey of Queensland publication 383. Geological Survey of Queensland, Brisbane, 194 p
Drexel JF, Preiss WV (1995) The geology of South Australia. v 2: The phanerozoic, South Australian Geological Survey Bull 54. Mines and Energy, South Australia, Geological Survey of South Australia, Adelaide, 242 p
Easton AK (1970) The tides of the continent of Australia, Research paper No. 37. Horace Lamb Centre of Oceanographical Research, Flinders University, Adelaide
Eliot M (2016) Coastal sediments, beaches and other soft shores, CoastAdapt information manual 8. National Climate Change Adaptation Research Facility, Gold Coast, 88 p
Eliot I, Nutt C, Gozzard B, Higgins M, Buckley E, Bowyer J (2011) Coastal compartments of Western Australia: a physical framework for marine & coastal planning. Report to the Departments of Environment & Conservation, Planning and Transport. Damara WA Pty Ltd, Geological Survey of Western Australia and Department of Environment & Conservation, Western Australia
Fellowes TE, Vila-Concejo A, Gallop SL (2019) Morphometric classification of swell-dominated embayed beaches. Mar Geol 411:78–87
Fotheringham DG (2009) Cliff top erosion adjacent to Cape Dombey, Robe, South Australia, Coastal Management Branch, technical report 2009/08. Department Environment Heritage, Adelaide, 17 p
Galloway RW (1982) Australian islands. Cartography 12:233–237
Galloway RW, Bahr ME (1979) What is the length of the Australian coast? Aust Geogr 14:244–247
Galloway RW, Story R, Cooper R, Yapp GA (1980) Coastal lands of Australia: CSIRO Division Land Use Research, Tech Memo 80/24, 61 p
Geological Survey of Western Australia (1990) Geology and mineral resources of Western Australia, Western Australian Geol Survey Memoir 3. State Printind Division, Perth, 827 p
Gill ED (1982) Eight coasts of Australia: CSIRO Division Applied Geomechanics, technical report 199, 66 p
Gordon AD (1987) Beach fluctuations and shoreline change in NSW. In: 8th Australasian conference on coastal and ocean engineering, Launceston, pp 103–107
Gourlay M (1968) Beach and dune erosion tests, Delft Hydraulics Laboratory, report No M935/M936. Hydraulics Laboratory, Delft
Griffin C, Skene D, Hazelwood M, Nicholas WA, Anderson H, Xu J (2010) A nationally consistent geomorphic map and classification of the Australian coastal zone. Geoscience Australia Professional Opinion 2010/06, 47 p
Haigh ID, Wijeratne EMS, MacPherson LR, Mason MS, Pattiaratchi CB, Crompton RP, George S (2012) Technical report: estimating present day extreme total water level exceedance probabilities around the Australian coastline. UWA Ocean Inst, University of Western Australia, Perth, 89 p
Harley MD, Turner IL, Short AD, Ranasinghe R (2011) A reevaluation of coastal embayment rotation: the dominance of cross-shore versus alongshore sediment transport processes,

Collaroy-Narrabeen Beach, southeast Australia. J Geophys Res 116:F04033. https://doi.org/10.1029/2011JF001989

Harley MD, Turner IL, Kinsela MA, Middleton JH, Mumford PJ, Splinter KD, Phillips MS, Simmons JA, Hanslow, DJ, Short AD (2017) Extreme coastal erosion enhanced by anomalous extratropical storm wave direction. Scientific Reports. nature.com

Harris PT, Heap AD, Bryce SM, Porter-Smith R, Ryan DA, Heggie DT (2002) Classification of Australian clastic coastal depositional environments based upon a quantitative analysis of wave, tidal, and river power. J Sediment Res 72:858–870

Hazelwood M, Nicholas WA, Woolf M (2013) National Coastal geomorphology information framework implementation geoscience Australia record 2013/35, 27 p

Heap A, Bryce S, Ryan D, Radke L, Smith C, Smith R, Harris P, Heggie D (2001) Australian Estuaries & Coastal Waterways: a geoscience perspective for improved and integrated resource management, Record 2001/07. Australian Geological Survey Organisation, Canberra

Hemer MA, Zieger S, Durrant T, O'Grady J, Hoeke RK, McInnes KL, Rosebrock U (2017) A revised assessment of Australia's national wave energy resource. Renew Energy 114:85–107. https://doi.org/10.1016/j.rene.2016.08.039

Hesp PA (1984) Foredune formation in southeast Australia. In: Thom BG (ed) Coastal geomorphology in Australia. Academic, Sydney, pp 69–97

Hesp PA (2002) Foredunes and blowouts: initiation, geomorphology and dynamics. Geomorphology 48:245–268

Homes GM (1989) Global climate change and the role of the Permanent Committee on Tides and Mean Sea Level. In: 9th Australasian conference on coastal and ocean engineering, Adelaide, pp 280–286

Hopley D (ed) (1983) Australian sea levels in the last 15,000 years, Mono series No. 3. Department of Geography, James Cook University, Townsville

Hopley D, Harvey N (1978) Regional variation in storm surge characteristics around the Australian coast: a preliminary investigation. In: Heathcote RL, Thom BG (eds) Natural hazards in Australia: Canberra, Institute Australian Geographers. Australian Academy of Science, Canberra, pp 164–185

Hopley D, Smithers SG, Parnell KE (2007) The geomorphology of the Great Barrier Reef. Cambridge University Press, Cambridge, 532 p

James NP, Bone Y (2010) Neritic carbonate sediments in a temperate realm. Springer, Dordrecht

Johnson D (2004) The geology of Australia. Cambridge University Press, Melbourne, 276 p

Klein AHF, Miot da Silva G, Ferreira Ó, Dias JA (2005) Beach sediment distribution for a headland bay coast. J Coast Res SI 42:285–293

Laughlin G (1997) The users guide to the Australian Coast. New Holland, Sydney, 213 p

Levoy F, Anthony EJ, Monfort O, Larsonneur C (2000) The morphodynamics of megatidal beaches in Normandy, France. Mar Geol 171:39–59

Lewis SE, Sloss CR, Murray-Wallace CV, Woodroffe CD, Smithers SG (2013) Post-glacial sea-level; changes around the Australian margin: a review. Quat Sci Rev 74:115–138

Masselink G, Short AD (1993) The effect of tide range on beach morphodynamics and morphology: a conceptual model. J Coast Res 9:785–800

McLachlan A, Illenberger WK, Burkinshaw JR (1994) Management implications of tampering with littoral sand sources. J Coast Res SI 12:51–59

McPherson A, Hazelwood M, Moore D, Owen K, Nichol S, Howard F (2015) The Australian coastal sediment compartments project: methodology and product development geoscience Australia record 2015/25. https://doi.org/10.11636/Record.2015.025

Murray-Wallace CV, Belperio AP (1991) The last interglacial shoreline in Australia – a review. Quat Sci Rev 10:441–461

Murray-Wallace CV, Woodroffe CD (2014) Quaternary sea-level changes – a global perspective. Cambridge University Press, Cambridge, 484 p

Murray-Wallace CV, Banerjee D, Bourman RP, Olley JM, Brooke BP (2002) Optically stimulated luminescence dating of Holocene relict foredunes, Guichen Bay, South Australia. Quat Sci Rev 21:1077–1086

Nakada M, Lambeck K (1989) Late Pleistocene and Holocene sea-level change in the Australian region and mantle rheology. Geophys J 96:497–517

Nelson RC (1975) Tropical Cyclone storm surges in Australia 1880–1970, 2nd Australian Coastal Ocean Engineering Conference, Gold Coast, Inst Engineers, pp 193–199

Nott JF (2006) Tropical cyclones and the revolution of the sedimentary coast of northern Australia. J Coast Res 22:49–62

Nott J, Chague-Goff C, Goff J, Sloss C, Riggs N (2013) Anatomy of sand beach ridges: evidence from severe Tropical Cyclone Yasi and its predecessors, northeast Queensland, Australia. J Geophys Res 118:1710–1719. https://doi.org/10.1002/jgrf.20122,2013

OEH (2018) Coastal management manual. Office Environment Heritage, Sydney, Part A and B (available for download at: http://www.environment.nsw.gov.au/topics/water/coasts/coastal-management/coastal-management-manual)

Oliver TSN, Dougherty AJ, Gliganic LA, Woodroffe CD (2015) Towards more robust chronologies of coastal progradation: optically stimulated luminescence ages for the coastal plain at Moruya, south-eastern Australia. Holocene 25(3):536–546

Oliver TSN, Tamura T, Hudson JP, Woodroffe CD (2017) Integrating millennial and interdecadal shoreline changes: morpho-sedimentary investigation of two prograded barriers in southeastern Australia. Geomorphology 288:129–147

Porter-Smith R, McKinlay J (2012) Mesoscale coastal complexity and its relationship to structure and forcing from marine processes. Mar Geol 323–325:1–13

Porter-Smith R, Harris PT, Andersen OB, Coleman R, Greensladee D, Jenkins CJ (2004) Classification of the Australian continental shelf based on predicted sediment threshold exceedance from tidal currents and swell waves. Mar Geol 211:1–20

Rhodes EG (1982) Depositional model for a chenier plain, Gulf of Carpentaria, Australia. Sedimentology 29:201–222

Robeiro MSA (2017) Headland sediment bypass processes. PhD thesis, Department Geol, Ciẽncias ULisboa, 210 p

Roy PS (1984) New South Wales estuaries: their origin and evolution. In: Thom BG (ed) Coastal geomorphology in Australia. Academic, Sydney, pp 99–121

Roy PS, Williams R, Jones AR, Yassini I, Gibbs PJ, Coates B, West RJ, Scanes PR, Hudson JP, Nichol S (2001) Structure and function of south-east Australian estuaries. Estuar Coast Shelf Sci 53:351–384

Russell RJ, McIntire WG (1965) Southern hemisphere beach-rock. Geog Rev 55:17–45

Scheibner E, Basden H (eds) (1996) Geology of New South Wales. v2: geological evolution. Geol Survey NSW, Sydney, Memior 13, 666 p

Scott T, Masselink G, Russell P (2011) Morphodynamic characteristics and classification of beaches in England and Wales. Mar Geol 286:1–20

Shand TD, Goodwin ID, Mole MA, Carley JT, Browning S, Coghlan IR, Harley MD, Pierson WL, Kulmar MA (2010) NSW coastal storms and extreme waves. 19th NSW Coastal Conference, Batemans Bay, 14 p. http://www.coastalconference.com/2010/papers2010/Tom%20Shand%20full%20paper.pdf

Sharples C, Mount R, Pedersen T (2009) The Australian Coastal Smartline Geomorphic and Stability Map Version 1: Manual and Data Dictionary v1.1. Report for Geoscience Australia and Department of Climate Change, School Geography Environmental Studies, University Tasmania, 178p

Short AD (1967) A selective regional study of the coastal geomorphology of the Copacabana-Macmasters beach area. B.A. Hons thesis, Department of Geography, University of Sydney, 156 p

Short AD (1969) Simulation of sand volume changes at Maili beach, Oahu. M.A. thesis, Department of Geography, University of Hawaii, 79 p

Short AD (1996) Beaches of the Victorian Coast and Port Phillip Bay. Sydney University Press, Sydney, 298 p
Short AD (1999) Wave-dominated beaches. In: Short AD (ed) Beach and shoreface morphodynamics. Wiley, Chichester, pp 173–203
Short AD (2000) Beaches of the Queensland coast: Cooktown to Coolangatta. Sydney University Press, Sydney, 360 p
Short AD (2001) Beaches of the South Australian Coast and Kangaroo Island. Sydney University Press, Sydney, 346 p
Short AD (2002) The distribution and impacts of carbonate sands on southern Australia beach-dune systems. In: Magoon OT, Robbins LL, Ewing L (eds) Carbonate beaches 2000. American Society Civil Engineers, Reston, pp 236–250
Short AD (2005) Beaches of the Western Australian Coast: Eucla to Roebuck Bay. Sydney University Press, Sydney, 433 p
Short AD (2006a) Australian beach systems – nature and distribution. J Coast Res 22:11–27
Short AD (2006b) Beaches of the Tasmanian coast and Islands. Sydney University Press, Sydney, 353 p
Short AD (2006c) Beaches of the Northern Australia coast: The Kimberley, Northern Territory and Cape York. Sydney University Press, Sydney, 463 p
Short AD (2007) Beaches of the New South Wales coast, 2nd edn. Sydney University Press, Sydney, 398 p
Short AD (2010a) Role of geological inheritance in Australian beach morphodynamics. Coast Eng 57:92–97. https://doi.org/10.1016/j.coastaleng.2009.09.005
Short AD (2010b) Sediment transport around Australia – sources, mechanisms, rates and barrier forms. J Coast Res 26:395–402
Short AD (2013) Australia's temperate carbonate coast: sources, depositional environments and implications. In: Martini P, Wanless HR (eds) Sedimentary coastal zones from high to low latitudes: similarities and differences. Geological Society London SP388, London. https://doi.org/10.1144/SP388.5
Short AD, Brander R (1999) Regional variation in rip density. J Coast Res 15:813–822
Short AD, Hesp PA (1982) Wave, beach and dune interactions in south eastern Australia. Mar Geol 48:259–284
Short AD, Jackson DJW (2013) Beach morphodynamics. In: Shroder JF (ed) Treatise in geomorphology, vol 10. Academic, San Diego, pp 107–129
Short AD, Klein AHF (2016) Brazilian beach systems. Springer, Coastal Research Library 17, Switzerland, 611 p. https://doi.org/10.1007/978-3-319-30394-9_1
Short AD, Masselink G (1999) Embayed and structurally controlled beaches. In: Short AD (ed) Beach and shoreface morphodynamics. Wiley, Chichester, pp 230–250
Short AD, Trembanis A (2004) Decadal scale patterns in beach oscillation and rotation Narrabeen Beach, Australia- time series, PCA and wavelet analysis. J Coast Res 20:523–532
Short AD, Trenaman NL (1992) Wave climate of the Sydney region: an energetic and highly variable ocean wave regime. Austr J Mar Freshwat Res 43:765–791
Short AD, Woodroffe CD (2009) The coast of Australia. Cambridge University Press, Melbourne, 288 p
Short AD, Bracs MA, Turner IL (2014) Beach oscillation and rotation: local and regional response on three beaches in southeast Australia. J Coast Res SI 70:712–717
Silvester R. Mitchell HL (1977) Storm surges around Australian coastlines. In: 3rd Australian conference on coastal and ocean engineering, pp 49–57
Sloss CR, Murray-Wallace CV, Jones BG (2007) Holocene sea-level change on the southeast coast of Australia: a review. Holocene 17:999–1014
Stephenson WJ, Thronton L (2005) Australian rock coasts: review and prospects. Aust Geogr 36:95–115
Stul T, Gozzard JR, Eliot IG, Eliot MJ (2012) Coastal sediment cells between Cape Naturaliste and the Moore River, Western Australia. Damara WA Pty Ltd and Geol Survey WA for Western Australian Department Transport, Fremantle

Stul T, Gozzard JR, Eliot IG, Eliot MJ (2014a) Coastal sediment cells for the Northampton Region between Glenfield Beach and the Murchison River, Western Australia. Report prepared by Seashore Engineering Pty Ltd and Geological Survey of Western Australia for the Western Australian Department of Transport, Fremantle

Stul T, Gozzard JR, Eliot IG, Eliot MJ (2014b) Coastal sediment cells for the Mid-West Region between the Moore River and Glenfield Beach, Western Australia. Report prepared by Seashore Engineering Pty Ltd and Geological Survey of Western Australia for the Western Australian Department of Transport, Fremantle

Stul T, Gozzard JR, Eliot IG, Eliot MJ (2014c) Coastal sediment cells for the Pilbara Region between Giralia and Beebingarra Creek, Western Australia. Report prepared by Seashore Engineering Pty Ltd and Geological Survey of Western Australia for the Western Australian Department of Transport, Fremantle

Stul T, Gozzard JR, Eliot IG, Eliot MJ (2015) Coastal sediment cells for the Vlamingh Region between Cape Naturaliste and Moore River, Western Australia. Report prepared by Seashore Engineering Pty Ltd and Geological Survey of Western Australia for the Western Australian Department of Transport, Fremantle

Sturman A, Tapper N (1996) The weather and climate of Australia and New Zealand. Oxford University Press, Melbourne, 476 p

Thom BG (1974) Coastal erosion in eastern Australia. Search 5(5):198–209

Thom BG (1984) Geomorphic research on the coast of Australia: a preview. In: Thom BG (ed) Coastal geomorphology in Australia. Academic, Sydney, pp 1–21

Thom BG (2015) Coastal compartments project: summary for policy makers. Department of Environment, Canberra, 5 p. [Available online at www.environment.gov.au/ climate-change/adaptation/publications/coastal- compartments-project-summary-policy-makers]

Thom BG, Hall W (1991) Behaviour of beach profiles during accretion and erosion dominated periods. Earth Surf Process Landf 16(2):113–127

Thom BG, Short AD (2006) Introduction: Australian coastal geomorphology 1984–2004. J Coast Res 22:1–10

Thom BG, Bowman GM, Gillespie R, Temple R, Barbetti M (1981) Radiocarbon dating of Holocene beach-ridge sequences in South-East Australia. Department of Geography, University of New South Wales at Royal Military Colledge, Duntroon

Thom BG, Shepherd M, Ly CK, Roy PS, Bowman GM, Hesp PA, (1992) Coastal geomorphology and Quaternary geology of the Port Stephens-Myall Lakes area. Department of Biogeog. Geom, Mono, 6, The Australian National University, Canberra, 407 p

Thom BG, Eliot I, Eliot M, Harvey N, Rissik D, Sharples C, Short AD, Woodroffe CD (2018) National sediment compartment framework for Australian coastal management. Ocean Coast Manag 154:103–120

Veevers J (2015) Beach sand of SE Australia traced by zircon ages through Ordovician turbidites and S-type granites of the Lachlan Orogen to Africa/Antarctica: a review. Austr J Earth Sci 62:385–408. https://doi.org/10.1080/08120099.2015.1053985

Vieira da Silva G, Toldo EE Jr, Klein AHF, Short AD, Woodroffe CD (2016) Headland sand bypassing – quantification of net sediment transport in embayed beaches, Santa Catarina Island North Shore, Southern Brazil. Mar Geol 379:13–27. https://doi.org/10.1016/j.margo.2016.05.008

Ward WT, Little IP, Thompson M (1979) Stratigraphy of two sandrocks at Rainbow Beach, Queensland and a note on humate composition. Paleogeogr Paleoclimatol Paleoecol 26:305–316

Ware D (2016) Tweed River entrance sand bypass project. Case Study for CoastAdapt, National Climate Change Adaptation Research Facility, Gold Coast, 8 p

Watson PJ (2011) Is there evidence yet of acceleration in mean sea level around mainland Australia? J Coast Res 27:368–377

Watson PJ (2017) Acceleration in European mean sea level? A new insight using improved tools. J Coast Res 33:23–38

Young IR (1999) Seasonal variability of the global ocean wind and wave climate. Int J Climatol 19:931–950

Websites

The following websites provide links to the Australian coastal sediment compartment maps and data

http://coastadapt.com.au/coastadapt-interactive-map

https://ozcoasts.org.au/maps-data/

https://nationalmap.gov.au

The national map website provides a range of satellite images of the Australian coast and its attributes, including low tide images showing the extent of the intertidal zone, a coastal digital elevation model and a range of maps from State agencies.

Chapter 2
Tropical Northern Province

Abstract Australia's tropical northern province spans 16,445 km of coast between Exmouth Gulf and Fraser Island. It is a vast lightly developed coast exposed to meso- through mega-tides, generally low to moderate seas in a climate that ranges from hot desert to monsoonal to humid equatorial together with seasonal tropical cyclones. Numerous rivers deliver summer floods and bedload to the coast, a coast which is dominated by carbonate sediments in the west and terrigenous in the east. Beach systems are predominately tide-modified to tide-dominated, and barrier systems range from low energy cheniers through to massive transgressive dune on exposed east-facing shores. This chapter describes the geology, climate, coastal and biological processes that contribute to the formation of the northern tropical coast.

Keywords Tropical · Northern Australia · Geology · Climate · Coastal processes · Biological processes

2.1 Introduction

Australia's northern tropical province extends for 16,445 km from Exmouth Gulf in the west to Hervey Bay in the east. It contains 54% of the Australian coast, roughly the entire coast above the Tropic of Capricorn and includes the coasts of northwest WA, the NT, Cape York Peninsula and eastern QLD down to Hervey Bay (see Figs. 1.1 and 1.44a). The province is unified by its tropical location, overall northerly orientation, sub-tropical to tropical climates, low to moderate waves and meso- through mega-tides. The warm tropical seas that surround the coast are host to some of the most extensive coral reef systems in the world, including the Great Barrier Reef (GBR), while in more sheltered locations lie most of Australia's mangrove communities. The summer wet season provides runoff for most of Australia's larger rivers in terms of both numbers and size. The rivers drain the ancient geology and contribute large volumes of sediment to the coast to build deltas and supply sand to downdrift beaches. The light to moderate southeast trade winds blow across the top end for much of the year, while summer brings the lighter northwest monsoon. Both wind systems generate usually low waves at the coast, while the monsoons also

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bring most of the rain. Tides range from 2 to 10 m and include some of the highest tides in the world. The interaction of the wind, waves and tides with the sediments and geology has formed the modern coast, and while rocky shore dominates ~60% of the coast, it still contains thousands of beaches and barriers and hundreds of kilometres of mangrove-lined creeks and estuaries.

2.2 Geology

The northern Australian coast contains three main geological units that decrease in age from west to east (Fig. 2.1 and Table 2.1). The oldest is the northern Australian Craton which extends from the Pilbara across to the western Gulf of Carpentaria (Fig. 1.2). It is an ancient (>1800 Ma) region of deformed and metamorphosed Palaeoproterozoic rocks that outcrop as the major tectonic units (orogens and inliers) surrounded by younger basin rocks. Next is the northeast orogens (Cape York and Coen), remnants of ancient mountain building, that include all of Cape York Peninsula west of Princess Charlotte Bay. Finally, on the east coast, south from Cape Melville is the northern section of the massive Tasman Fold Belt, a 400 Ma year-long accumulation of accretionary orogens and basins that extends south to Tasmania. Along the Queensland coast, it contains the northern Hodgkinson Basin and a number of blocks and arches that extend south to Hervey Bay. More detail of the northern Australian regional geology is provided in Chaps. 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14 and 15.

2.3 Climate

The climate of northern tropical province ranges from sub-tropical to tropical to equatorial (Fig. 1.8; Stern et al. 2000). In the west (Exmouth to King Sound) are the desert and grassland climates dominated by the sub-tropical high which are hot and persistently dry (BWh) grading north to summer rainfall with a winter drought (BSh); across the top (Kimberley to Cape York Peninsula) are tropical savanna monsoonal climates produced by the humid summer northwest monsoons, with wet summers and drier winters (Aw); then down the east Queensland coast are a series of humid climates ranging from equatorial (Am, Aw) (Cooktown to Whitsundays) to sub-tropical (Cwa-Cfa) (Repulse Bay to Hervey Bay), all affected by the humid southeast trades. East Queensland has year-round rainfall with a summer maximum in the north, grading southwards into a moderately dry winter around Broad Sound, with no dry season in southeast Queensland.

Australia's tropical climate is controlled by its latitude (9–25°S) and dominated by two major pressure systems – the sub-tropical high which resides over the continent year-round and the summer equatorial heat low which forms across northern Australia during the hot summer months (Fig. 1.4a). During winter the high shifts

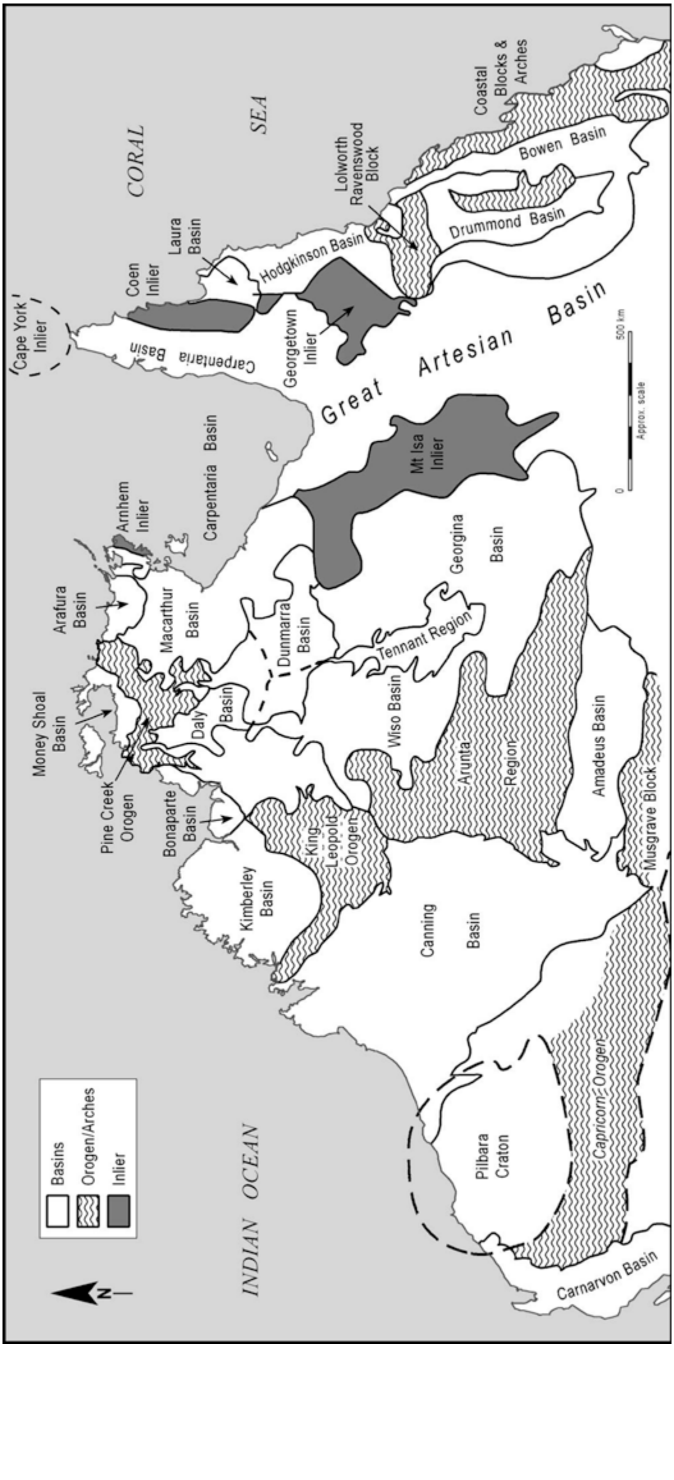

Fig. 2.1 Major geological provinces of northern Australia. (Source: Short 2006a)

Table 2.1 Major geological provinces of the northern tropical province, their geology and generalised coastal morphology. Orogens in **bold** (modified from Short 2000, 2005, 2006a)

Geological region	Age (Ma)	Coast location/ boundaries	Geology	Coastal morphology
N Australian craton				
Carnarvon Basin	450–0	Murchison R-C Preston	Sandstone, limestone	Beaches, calcarenite and sandstone cliffs
Pilbara craton	3800–2500	C Preston-Port Hedland	Granite-greenstone	Bedrock, deltas, coastal plain
Canning Basin	500–0	Port Hedland-king sound	Limestone	Low coastal pindan plain
King Leopold Orogen	1800	Eastern king sound	Folded sandstone and volcanics	Bedrock control, highly indented
Kimberley Basin	2000–400	Kimberley coast	Sandstone, shales, basalts	Bedrock control, deeply incised, joint-aligned and weathered
Bonaparte Basin	500–0	Cambridge gulf	Sedimentary	Tidal flats and bedrock
Pine Creek Orogen	2700–140	Darwin-Kakadu	Deeply weathered (laterised) sedimentary rocks	Kakadu escarpment, low bluffs in Darwin region
Money Shoal Basin	140–0	Kakadu coast, Van Diemen gulf, Coburg pen. Bathurst-Melville is	Deeply weathered (laterised) sedimentary rocks	Low bedrock bluffs, laterite reefs, tidal flats, beaches
Arafura Basin	2500–200	Hall Pt -Buckingham Bay Elcho-Wessel is.	Deeply weathered (laterised) sedimentary rocks	Low bedrock bluffs, laterite reefs, tidal flats, beaches
Arnhem inlier	1860–1800	Melville Bay-Gove to cape shield	Deeply weathered (laterised) meta-sedimentary rocks	Low bedrock bluffs, laterite reefs, tidal flats, beaches
McArthur Basin	1800–1400	Blue Mud Bay-Robinson R; Groote Eylandt	Deeply weathered (laterised) sedimentary rocks	Low bedrock bluffs, laterite reefs, tidal flats, beaches
Carpentaria Basin	180–100	South and East Gulf of Carpentaria	Quaternary continental and coastal sediments, some laterised bluffs	Tidal creeks and flats, cheniers, beach ridges, some bluffs
Northeast Orogens				
Cape York inlier	300	Torres Strait high islands	Granite and metamorphic	High islands, coral reefs
Coen inlier	1500	Temple Bay-cape Sidmouth	Clastic and chemical sediments, volcanics	Headlands and beaches
Laura Basin	180–100	Cape Sidmouth-Princess Charlotte and Bathurst bays	Continental and marine sediments	Weathered bluffs, tidal flats, beaches

(continued)

Table 2.1 (continued)

Geological region	Age (Ma)	Coast location/ boundaries	Geology	Coastal morphology
Tasman Fold Belt				
Hodgkinson Basin	410–350	Cape Melville-Hinchinbrook is	Volcaniclastic and carbonates	Headlands and beaches
Lolworth-Ravenswood block	500	North Halifax Bay	Volcanics and clastic sediments	Beaches
Burdekin Basin	370–320	Mid Halifax Bay	Clastic and carbonate sediments	Beaches
Bowen Basin	270–200	Townsville-Upstart Bay	Clastic sediments, limestone	Headlands, beaches, tidal flats
Connor arch	350	Cape upstart to Bowen	Volcanics	Headlands, beaches, tidal flats
Strathmuir syncline	270	Edgecumbe Bay	Volcaniclastic	Tidal flats
Campwyn block	360–250	Gloucester is – Broad sound	Volcaniclastic sediments, limestone	Headlands, beaches, tidal flats
Whitsunday block	130	Whitsunday Islands and coast	Volcanics	Rocky, beaches
Styx Basin	130	St Lawrence (broad sound)	Clastic sediments	Tidal flats
Stanage block	410–370	Long Island (broad sound)	Volcanics, limestone	Rocky
Coastal block	400–300	Stanage point-Rodds Bay	Arenite, chert, basalt, conglomerate, limestone	Headlands, beaches, tidal flats
Gympie block	270–200	Rodds Bay-wreck Pt and Caloundra	Clastic sediments, volcanics, limestone	Headlands and beaches

Ma = million years

northwards and dominates the climate across central and northern Australia, with its counter-clockwise circulation generating the southeast trades that flow across the northern half of continent, while westerlies flow below the high crossing the southern parts of the continent (Fig. 1.4a). On the northeast coast, the trades bring some winter rain along the coastal strip, while the entire interior, northern and northwest coast remains dry (Fig. 1.5b), with the now dry trades flowing offshore on north- and west-facing shores (Fig. 1.4a). Winter is therefore typified along the Queensland coast by low to moderate winter rains (May–November) (Cairns 275 mm in winter, 1735 mm in summer), with drier conditions along the northern (Darwin 103 mm in winter) and northwest coast (Derby 53 mm, Port Hedland 76 mm in winter) as shown in Table 2.2 and Fig. 1.5b. Winter temperatures along the coast range in the low to mid-20 °C (Fig. 1.5d).

During summer the winds are reversed, and the northwest monsoons flow across the northern coast and penetrate up to 1000 km inland bringing convectional sum-

Table 2.2 Northern Australia seasonal temperatures and precipitation from selected stations (data from Bureau of Meteorology)

Location	Latitude (°S)	Summer max (°C)	Winter max (°C)	Summer (mm)	Winter (mm)	Total (mm)
Northwest						
Exmouth	22.4	38	24	241	19	260
Port Hedland	20.5	37	27	271	76	319
Broome	18	34	29	587	24	611
North						
Wyndham	15.5	40	31	784	64	848
Darwin	12.6	33	31	1642	103	1727
Karumba	17.5	33	27.5	866	24	890
East						
Cairns	17	31.5	26	1735	275	2000
Townsville	19.2	31.5	25	1014	120	1134
Rockhampton	22.4	32	23	604	209	813

mer rainfall to the coast and northern interior between December and March (Table 2.2; Fig. 1.5a; Suppiah 1992). Further south, however, the high still dominates maintaining hot dry summer conditions. Mean daily temperatures range from the mid-20s in the east to high 20s across the top, peaking along the northwest coast in the low 30s (Fig. 1.5c). Tropical cyclones usually form in the Timor-Arafura Sea, the Gulf of Carpentaria and Coral Sea between November and April, peaking in February (Fig. 1.6b) and can bring strong winds, high waves, storm surges and heavy rain to the northern coast. Their landfall on the west coast is focused between 20 and 21°S (Port Hedland to Onslow, the so-called 'cyclone alley'), while on the east coast, landfalls are spread more broadly between 12 and 24°S (Fig. 1.6b).

The northern climate is therefore marked by its year-round high temperatures (20s–30s) and distinctly seasonal rainfall, which has a maximum at the coast during summer decreasing both inland and in general to the west. More details of the northwest, Kimberley-NT, Gulf of Carpentaria and east Queensland climates will be provided in their respective chapters (Chaps. 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14 and 15).

2.4 Coastal Processes

Northern Australia is bordered by the eastern Indian Ocean and southwest Pacific, which off Queensland is known as the Coral Sea, which are connected across the top by the Timor and Arafura seas (Fig. 1.1). The Timor Sea extends between the Kimberley-western NT and Timor and includes the large Joseph Bonaparte Gulf, while the Arafura Sea extends from the NT's Cape Don to Torres Strait, north to islands of the Indonesian archipelago and New Guinea, and includes the Gulf of Carpentaria. The oceanography of these seas is controlled by six factors.

1. Size and bathymetry, which includes their limited extent, the numerous islands and coral reefs in and bordering the seas, and generally shallow seafloor (<200 m).
2. Seasonal tropical climate, which delivers high sea surface temperatures (>26 °C), light to moderate northwest and moderate to strong southeast winds, seasonal summer rain and coastal runoff, and occasional tropical cyclones.
3. Wave climate, which consists of locally generated low to moderate seas.
4. Tide regime, which results in Australia's highest tides (2–10 m) due to shoaling across the shallow shelf, as well as amplification in King Sound, Cambridge Gulf and Broad Sound. The generally high tides also result in strong tidal currents both at the coast and across parts of the shelf.
5. Ocean circulation, which consists of a generally weak east to west flow of water through Torres Strait and down through the Indonesian islands exiting into the Indian Ocean.
6. Rich tropical biota, which is most manifest in the extensive coral reef systems, including the northern Great Barrier Reef, the intertidal mangroves which dominate all low energy shores and subtidal tropical seagrasses.

2.4.1 Waves

Waves are generally low across the northern coast, a product of the lack of ocean swell, the low to moderate velocity local wind regimes and limited fetch. Southern Ocean swell is precluded from the coast owing to the northerly orientation of most of the coast together with the landlocked nature of the seas and in the east the blocking of all trade wind waves by the GBR. The coast is therefore largely dependent on the prevailing southeast trades and summer northwest monsoonal winds, plus any accompanying sea breezes, for wave generation. The wave climate is further constrained and modified by the limited fetch, the varied orientation of the coast, which results in exposed windward and sheltered lee shores, the generally shallow nearshore gradients and the regional presence of islands and reefs all of which lead to substantial wave refraction and attenuation. The overall result is a very low to at most moderate energy coast.

Published wave data for northern Australia is very limited, and as yet no comprehensive or even regional wave climate exists, apart from waverider buoys off Weipa and Cairns, Bowen, Mackay, Gladstone and Burnett Heads, maintained by the Queensland Beach Protection Authority, the results of which are discussed in Chaps. 9 and 13, respectively.

Table 2.3 summarises the main wave sources and their characteristics for the northern coast. The southeast trades generate waves on all exposed coasts including along the eastern Cape York Peninsula coast, the western Gulf of Carpentaria including eastern Arnhem Land and a few east-facing sections of the Kimberley coast. Elsewhere the trades blow along or offshore. Strong trade winds in the Gulf can produce waves up to 2–3 m high with a period of 4–5 s; more commonly however

Table 2.3 Wave sources and characteristics across the northern Australian coast

	Location	Direction	Season	Characteristics
Sea breeze	Entire coast	Varies	Summer max	short, low seas
Trade winds	Entire coast	E-SE	Year round, winter max	short, seas to 3 m
Monsoonal winds	Kimberley-NT-Gulf	W-NW	Summer	short, seas to 2 m
Tropical cyclones	Entire coast	Varies	Summer	high seas to several metres

waves are less than 1 m, particularly at the shore. The summer northwest monsoon reverses the wave climate with the low to moderate velocity wind generating usually low, short waves with a breaker height less than 1 m and period of 3–4 s. The trades and monsoon waves are supplemented by sea breeze winds and waves, which depending on coastal orientation tend to arrive from the east through north. Tropical cyclone can deliver high waves (see Chap. 12); however, they are too temporally and spatially infrequent to have a significant impact on the annual wave climate, other than set the H_{max} limits.

Table 2.4 summarises the estimated breaker wave height and period compiled for each beach from the northern Australian ABSAMP database. These represent the wave height at the shore after undergoing wave refraction and attenuation and as a consequence will be lower than the deepwater waves. Breaker waves across the north are low averaging between 0.18 and 0.44 m, all with short periods (4–5 s). The lowest energy coast is the Kimberley owing to the very sheltered nature of many of its beaches with 50% of the beaches receiving waves averaging only 0.1 m, while only 10% receive waves averaging 0.4 m and greater, with the highest waves only reaching 1 m on six beaches. Waves on the northwest coast average 0.28 m but are skewed to lower waves (0.1–0.3 m) also owing to the considerable sheltering along the Canning and Pilbara coasts and in King Sound, with only the western Canning coast exposed to higher waves.

The NT has a modal wave height of 0.3 m (mean = 0.44 m), with waves ranging from a low of 0.1 m to a high of 1.5 m, the latter received by only three beaches, with wave period ranging from 3 to 7 s for most of the coast. Beaches receiving waves greater than 1 m are all located in east Arnhem Land which is exposed to the longer fetch of the Gulf over which the southeast trades generate waves up to 3 m with periods reaching 7 s.

Cape York Peninsula has a west and east coast wave climate. It receives waves ranging from a low of 0.1 m in the southern Gulf and protected east coast bays to a high of 1 m on the more exposed northern gulf and east coast beaches. On the east coast, beaches are protected from higher deep ocean waves and swell of the Coral Sea by the GBR, which also limits the fetch within the backing GBR lagoon. Wave period ranges from a low of 2 s in some of the sheltered fetch-limited bays to 4–5 s on the more open coast exposed to the trades. The central QLD coast has a bimodal (0.1 and 0.3 m) wave height with a mean wave height of 0.32 m, the low waves a product of both the sheltering by the GBR and the many sheltered bays and beaches.

Table 2.4 Percent occurrence of estimated breaker wave heights across northern Australia. Modal height in bold. Modified from Short (2006a)

Breaker wave height (m)	Northwest	Kimberley	Northern Territory	Cape York Pen.	Central QLD
0.1	**25.0**	**49.2**	12.5	10.5	**27.4**
0.2	**25.4**	28.3	16.0	7.5	15.9
0.3	**25.2**	12.3	**21.2**	17.8	**18.6**
0.4	9.9	3.8	15.0	**22.2**	16.2
0.5	7.1	2.6	10.0	17.9	12.1
0.6	4.3	1.0	6.0	9.8	6.5
0.7	2.1	0.4	4.0	4.7	2.7
0.8	1.0	1.4	3.5	3.6	0.5
0.9		0.5	3.5	2.2	0
1.0		0.4	5.0	3.9	0.2
1.1			1.2		
1.2			1.0		
1.3			0.6		
1.4			0.3		
1.5			0.2		
n	576	1360	1488	641	887
Mean height	0.28	0.18	0.44	0.44	0.32
σ	0.17	0.13	0.29	0.22	0.3
Mean period	4.9	4.6	4.4	5.0	5.2
σ	1.1	0.7	0.9	0.3	0.8

To summarise, northern Australia receives low to moderate southeast waves for much of the year, with lower waves accompanying the summer northwest monsoons. Deepwater waves average 1–1.5 m, with periods of 4–5 s; however, only a few exposed beaches receive the full force of these waves with the majority of beaches receiving some degree of sheltering from headlands, reefs, islands and shallow nearshore with 1308 beaches (28%) receiving waves 0.1 m or less and most receiving waves 0.5 m or less (Table 2.4).

2.4.2 Tides

Tides across northern Australia range from 2 m in Exmouth Gulf and the southern Gulf of Carpentaria to Australia's highest tides of 10–11 m in Cambridge Gulf and King Sound, together with mega-tides in Broad Sound (Table 2.5). Figures 1.15 and 2.2 illustrate the tidal regimes around the coast. On the northwest coast, the tidal wave arrives from the west reaching the coast almost simultaneously and then slows considerably as its moves around the Kimberley coast and into Cambridge Gulf and along the western NT coast. At the same time, it is amplified by the shallow shelf with tide range increasing up the northwest coast and into King Sound and

Table 2.5 Minimum and maximum regional tides

	Tide min. (m)	Tide max. (m)
Northwest	2.3	11.2
Kimberley	2.6	9.4
Northern Territory	1.4	5.8
Cape York	1.6	3.5
Central QLD	1.1	6.3

Cambridge Gulf. The NT tide is also associated with a tidal system with an amphidromic point located in the northern Arafura Sea, which propagates in a counterclockwise direction, moving from west to east across the NT coast.

The Gulf of Carpentaria receives its tide from another separate tidal system with an amphidromic point located just west of Torres Strait, as well as some tidal components arriving from the Coral Sea via Torres Strait. The tide in the Gulf ranges between 2 and 4 m, while the time of arrival is highly variable as indicated in Fig. 2.2a. The eastern Queensland coast receives its tides from a system located in the Pacific. The tidal wave has to penetrate the Great Barrier Reef and propagate up the coast with a slight south to north lag along the coast. Spring tide range is generally between 2 and 3 m in the south increasing >6 m in Broad Sound and to greater than 3 m close to the Strait.

In summary, tides across northern Australia are amplified and slowed by the wide shallow shelf and within large embayments such as King and Broad sounds, with all tides greater than 2 m, and much of the coast receiving spring tides reaching several metres (Fig. 2.2b). The tides and associated tidal currents play a major role in both the coastal and nearshore and shelf oceanography. At the coast the high tide range produces major daily oscillations of the shoreline, especially on the low-gradient intertidal flats which can be 1000 m wide, while at the coast and offshore, strong tidal currents are required to accommodate the tidal flows both longshore and cross-shore in river mouths, estuaries and inlets, through topographic constrictions and across the generally shallow seafloor. Figure 1.12 illustrates the dominance of tidal currents across much of the northwest and NT shelf.

2.4.3 Rivers

The northern tropical coast has approximately 100 larger rivers and over 1000 smaller streams and creeks (Table 2.6) most of which are delivering sediment to the coast and building deltas. The rivers are fed by the generally humid climate particularly during the summer wet season, together with occasional tropical cyclones which can result in heavy rain and river flooding, with the northwest rivers entirely dependent on cyclones. The rivers are a major source of sediment which while initially deposited across the lower deltaic plains at the coast is reworked as sand by wave, tide and current action to feed downdrift beaches and dunes.

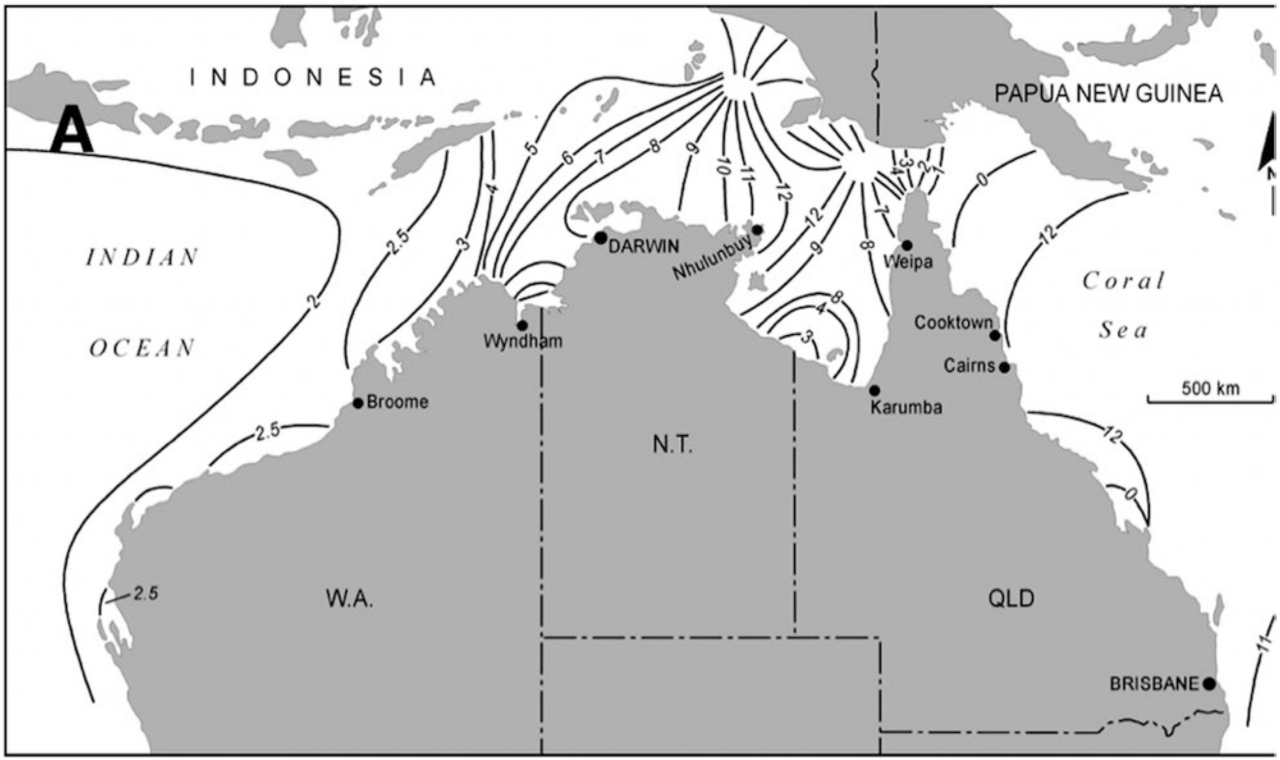

Fig. 2.2 (**a**) co-tide (left) and (**b**) co-range (right) lines for northern Australia. The co-tide illustrates the clockwise movement of the tidal waves around two amphidromic points south of New Guinea, together with others in the Pacific and Indian Ocean (not shown) resulting in a complex series of tidal systems across the northern coast. The lines link areas receiving the tide at the same time. The co-range lines show the areas with the same tide range from less than 1 m in the southern Gulf to >6 m in Broad Sound and >8 m in Cambridge Gulf and King Sound

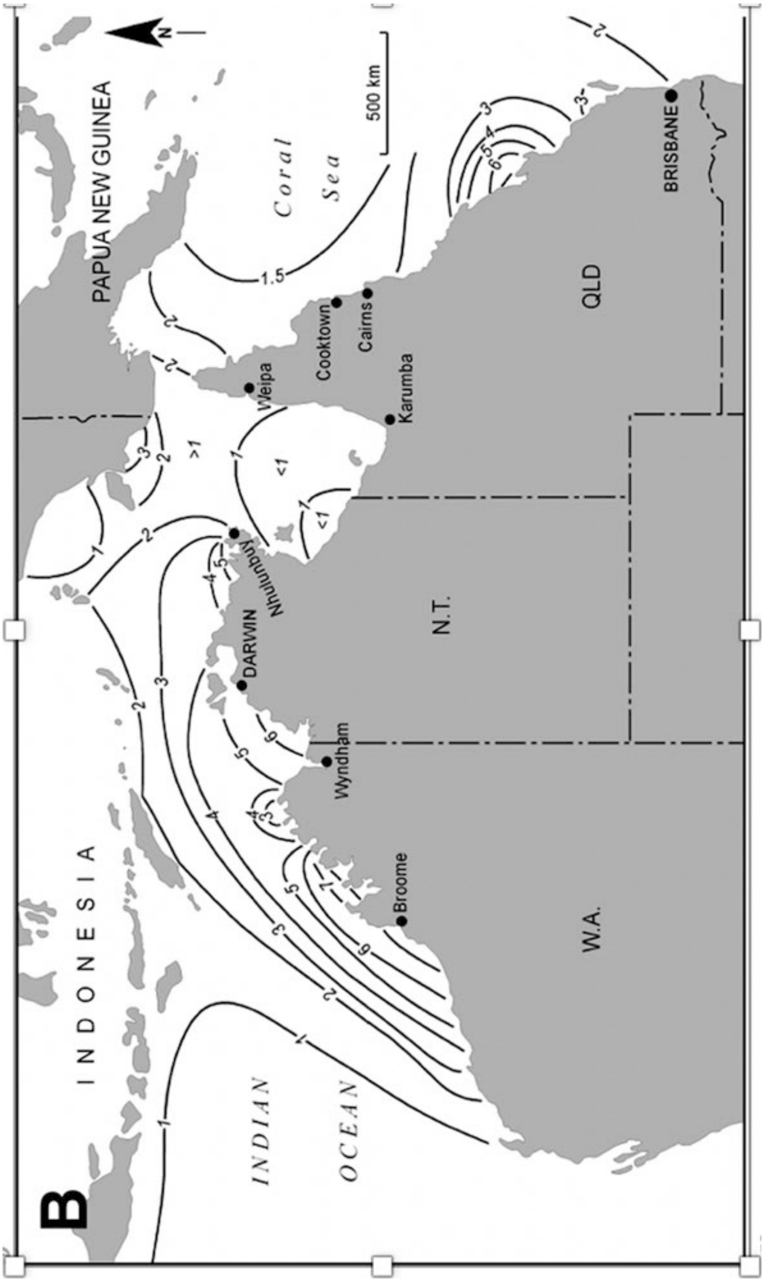

Fig. 2.2 (continued)

Table 2.6 Number of major rivers and streams in the northern province's regions

Region	Major rivers	All streams and rivers
Northwest	8	136
Kimberley	9	293
Western NT	6	60
Arnhem Land	6	159
Gulf: NT	10	103
Gulf: QLD	23	93
E Cape York Pen.	25	134
Central QLD	8	152
Northern province total	95	1130

Table 2.7 Beach sand characteristics of the northern divisions

	Northwest	Kimberley	NT	E Gulf	NE QLD	Central QLD
n	101	425	268	49	54	151
Size (mm)	0.51	0.6	0.38	0.33	0.84	0.34
σ (mm)	0.73	0.66	0.28	0.16	1.03	0.3
Sorting	0.68	0.81	0.75	0.72	0.78	0.58
σ	0.3	0.36	0.34	0.33	0.42	0.4
Carbonate (%)	47	56	47	21	19	13
σ (%)	31	33	28	12	31	18

2.4.4 Sediments

Sediments across the north are derived from three main sources: river supplied terrigenous mud, sand and gravel; shelf supplied generally quartz sand; and local carbonate production from the tropical seagrass meadows and fringing coral reefs. Table 2.7 lists the characteristics of the northern division's beach sand. There is considerable variation in size (0.33–0.84 mm) and percent carbonate (13–56%), with sorting ranging from moderately well to moderate. Compared to southern Australia, the beach sand is coarser and lesser sorted typical of lower energy TM and particularly TD beaches (Fig. 1.19a; Short 2006b). The size variation, together with the generally large standard deviation is also indicative of the variable sediment sources combined with limited longshore sand transport. The carbonate is at a maximum in the northwest, Kimberley and NT (~50%), decreasing to the east (<20%) as conditions become more humid supplying more quartz sand to the coast and shelf, and fringing reefs, a source of carbonate sand, decline in occurrence.

Table 2.8 Mean wave height, tide range and RTR associated with northern Australian (Kimberley, NT and Cape York Peninsula) beach types and states (modified from Short 2011)

Beach type/state[a]	BS	BS	H_b (m)	Tide range (m)	RTR
Wave-dominated	4	TBR	1.33	1.40	1
	5	LTT	0.87	1.40	2
	6	R	0.55	2.15	4
Tide-modified	7	R + LTT	0.64	2.99	5
	8	R + LTR	0.90	2.44	3
	9	UD	0.66	5.88	9
Tide-dominated	10	B + RSF	0.40	2.70	7
	11	B + SF	0.28	4.02	14
	12	B + TSF	0.16	5.03	31
	13	B + TMF	0.16	4.54	28
Beach + rock flats	14	R + RF	0.42	3.64	9
Beach+ coral flats	15	R + CF	0.26	4.32	17

[a]See Sect. 1.6.1 for description of beach types and states

2.4.5 Beach Types

The generally low waves and meso- through mega-tides combine with the medium to coarse beach sand to produce a wide range of RTR and beach types and states across the north ranging from WD TBR in the most exposed locations (Hb~1.3 m) to B + TMF in the more sheltered locations (Hb~0.16 m) (Table 2.8). The WD beaches occur where waves tend to be higher (0.5–1.3 m), tide lower (1.4–2.15 m) and RTR <4. The TM beaches occur where waves tend to be <1 m (0.6–0.9 m), tide range between 2.5 and 6 m and RTR ~3–9, while the TD beaches require low waves (<0.4 m) and higher tides (2.7–5 m) resulting in RTR between 7 and 28, in agreement with Short (2006b) and Short and Woodroffe (2009). The beach systems in each region, PC and SC are discussed in the following Chaps. 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14 and 15.

2.4.6 Sediment Transport

As noted above longshore sand transport is generally limited and localized resulting in highly variable longshore variation in sediment characteristics at the SC, PC, region and division levels, as will be discussed in the following chapters (3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14 and 15). The variability is a result of the range of sources (fluvial, shelf and local carbonate); the low level of wave energy and potential for sediment sorting and transport; and in places obstacle to sediment transport, as in the rugged Kimberley region. The region with the greatest potential for longshore transport is the northeast and central QLD coast where the southeast trades drive northerly transport. However, even here it is continually interrupted by major obstacles. Sediment transport is discussed at the PC and SC level in the following chapters.

2.5 Biological Processes

Northern Australia has the richest coastal biota on the continent, which includes the subtidal seagrass and coral reef systems, intertidal mangroves and supratidal samphire vegetation. In addition, the coast supports a little studied beach fauna and has a wide range of coastal dune vegetation. What is presented in this section is based on what is known about some of these systems, with much still to be investigated.

2.5.1 Coastal Dune Vegetation

Coastal dunes occur around the entire northern Australian coast. While most are foredunes, they also include small pockets of transgressive dunes along the northern NT and east Kimberley coast, extensive transgressive dunes on Groote Eylandt and eastern Arnhem Land and the massive QLD transgressive dune systems of Shelburne Bay-Cape Grenville and Cape Flattery. Most of the northern dunes are stable (~90%)

Fig. 2.3 A low vegetated foredune dominated by Triodia pungens (Soft Spinifex) near Cape Londonderry (K 1146). (Photo: AD Short)

and vegetated by a predictable succession of plants beginning with grasses, succulents and creepers on the incipient foredunes (Fig. 2.3), grading landward into a combination of sedgelands and shrublands on the foredune and hind dunes, and then into a climax succession of woodlands or forests. While the structure of the dune vegetation is similar around the coast, the species vary considerably from west to east as the climate and biogeographical regions change. The only regional coverage of coastal dune vegetation is by Craig (1983) for the Pilbara coast and Creswell et al. (2011) for the Kimberley coast, with little else on the coastal dune vegetation for much of northern Australia. The following lists some of the major plant communities and species found on parts of the coast.

Kimberley (see Creswell et al. 2011)

- Incipient foredune/foredune – coastal grasses (*Spinifex longifolius*, *Ipomoea brasiliensis*, *Salsola kali*, *Fimbristylis cymosa*, *Fimbristylis sericea*, *Cyperus bulbosus*)
- Foredune – low shrubs (*Acacia bivenosa*, *Lysiphyllum cunninghamii*, *Canavalia rosea*, *Triodia pungens*)
- Hind dune and hollows – dense shrub community of diverse plants, some *Pandanus spiralis*
- Grades into pindan or rocky vegetation.

Southeastern Cape York Peninsula

- Incipient foredune
  Coastal grasses, creepers and succulents (*Ipomoea pes-caprae* (goat's foot), *Cyperus pedunculatus* (pineapple sedge), *Thuarea involuta* (tropical beach grass), *Vigna marina* (beach bean), *Wedelia biflora* (beach sunflower)
- Foredune
  Grasses – *Cynodon dactylon* (couch grass), *Chloris gayana* (Rhodes grass)
  Shrubs – *Casuarina equisetifolia* (she oak), *Cocos nucifera* (coconut tree), *Terminalia catappa* (sea almond), *Hibiscus tiliaceus* (beach hibiscus), *Acacia crassicarpa* (brown salwood), *Calophyllum inophyllum* (beach calophyllum), *Scaevola sericea* (sea lettuce tree)
- Hind dune – *Corymbia tessellaris* (carbeen)

2.5.2 Samphire Vegetation

Samphire vegetation in association with algae grows along lower energy sections of the northern coast in the lower swales between beach ridges, in the saline back barrier depressions and dry lagoons, and on the often wide supratidal flats. The samphire vegetation is usually low (<1 m) and scrubby and forms a boundary in the supratidal zone between the shoreline and the landward terrestrial vegetation. In northern Australia the higher tide ranges produce wide inter- to supratidal zones suitable for samphire vegetation, while the hotter climate including the long winter dry period results in greater climate stress, restricting the development of salt marshes, which is also grown in the supratidal zone.

In Kimberley four communities of plants can occur in favourable locations across the supratidal zone:

1. A more seaward community of succulent samphires *Suaeda arbusculoides* at the seaward fringe, sometimes separated from *Halosarcia halocnemoides* by mud or sand flats covered with dense mats of blue-green algae
2. A mixed herbaceous and grass community in the mid- to upper marsh level containing *Limonium salicorniaceum*, water couch grass (*Sporobolus virginicus*) and rice grass (*Xerochloa imberbis*)
3. Herbs and low shrubs in higher well-drained locations containing *Halosarcia indica*, the halophyte *Frankenia ambita* and *Hemichroa diandra*
4. The most landward community which can tolerate the high salinity but not waterlogging, including *Neobassia astrocarpa*, *Trianthema turgidifolia* and some *Triodia* sp.

2.5.3 Mangroves

Mangroves are trees and some palms that grow in the saline intertidal zone usually between mean sea level and neap high tide. Mangrove woodlands and forests are well developed across northern Australia, which hosts most of Australia's 11,500 km^2 of mangroves (Table 2.9). Four factors favour the growth and extent of mangroves across the north. First is the warm tropical climate which permits all 39 mangrove species to be represented across the north; second are the generally lower energy shorelines which provide the sheltered habitats mangroves require; third are the generally lower gradient sedimentary shorelines and extensive intertidal sand and mud flats that provide a wide intertidal area for mangroves to inhabit; and fourth is the generally higher tide range (2–9 m) which combines with the lower gradient intertidal area to maximise the area suitable for mangrove growth.

The tropical climate not only permits a greater number of mangrove species but also results in taller mangroves (10–30 m) with a greater biomass. Therefore, mangrove communities in the north tend to be tall, diverse and relatively wide. As a consequence of these factors, the area of mangroves, number of species and bio-

Table 2.9 Mangrove area in northern Australia

	km^2	%
Kimberley	2256	20
Northern Territory	3360	29
Gulf of Carpentaria	2440	21
Northeast Queensland	805	18
Northern Australia	8861	88
Australia	11,500	100

mass increase substantially into the tropics. There are 8861 km^2 of mangroves located north of the Tropic of Capricorn (Table 2.9). Western Australia has 2430 km^2 of mangroves along the mainland, with another 90 km^2 on islands, which in total comprise 22% of Australia's mangroves, most located on the Kimberley coast (Table 2.9). The NT has the greatest area of mangroves (29%) followed by the Gulf (21%) and the tropical northeast QLD coast (18%), with the northern coast between Broome and Cooktown containing 88% of Australia's mangroves. On a global basis, Australia has the world's third largest area of mangroves after Brazil and Indonesia.

In terms of mangrove species, the greatest number (35) occurs in north QLD, with species numbers decreasing to the west and to the south (Table 2.10). The NT has up to 24 species, the Gulf 19 and the Kimberley 17. In contrast southern Australia has just one species of mangrove (*Avicennia marina*), which extends from southern NSW, across parts of southern Australia and southern Western Australia, up to Kalbarri. On the east coast, species number increases to 2 in southern NSW, 8 species by Brisbane and 35 in Cape York.

Semeniuk et al. (1978) provide a review of all WA mangrove systems their ecology and distribution and Creswell and Semeniuk (2011) in a review of the Kimberley coast mangrove systems provide a list of the 15 mangrove species that occur in WA and their western/southernmost limit. They range from 14.2°S for *Scyphiphora hydrophyllacea* to 33.3°S for *Avicennia marina*.

2.5.4 Seagrass Meadows

Seagrasses grow in suitable shallow locations around the Australian coast. Their growth is primarily determined by sunlight penetration, and they extend from the lower intertidal to the shallow subtidal zone, usually reaching a maximum depth of several metres. Seagrasses inhabit all types of seabed, from mud to rock; however, the most extensive meadows occur on sand and mud. They grow in coastal waters from tropical to temperate regions, with over 30 distinct temperate and tropical species found in Australian waters (Larkum et al. 2018). The number of species is greater in the tropics with only two species, *Halophila ovalis* and *Syringodium isoetifolium*, occurring in both regions.

Tropical seagrass species begin appearing in Shark Bay where the meadows cover 4000 km^2 and are the largest in the world. They are less prevalent due to lack of suitable habitat from Carnarvon north along the Pilbara and Canning coasts, while they again flourish in King Sound and around the Kimberley and NT coast. The most extensive and diverse seagrass communities are in the waters of Torres Strait and north-eastern QLD (Tables 2.11 and 2.12) where between 10 and 14 species are present.

Halodule uninervis is the most prominent of the tropical species, particularly where the large tides expose the substrate. *Halodule pinifolia* and *Halophila ovata* prefer the intertidal and shallow subtidal. *Thalassia* sp. is associated with coarser

Table 2.10 Distribution of mangrove species around Australia (from Short and Woodroffe 2009)

Species	SW WA	Cent WA	Pilbara	Kimberley	Bonaparte	Top End	West Gulf	East Gulf	NE QLD	Cent QLD	SE QLD	N NSW	Cent NSW	S NSW	Vic	S Aust
Acanthus ebracteatus				x	x	x	x	x	x							
Acanthus ilicifolius					x	x	x	x	x	x						
Acrostichum speciosum			x	x	x	x	x	x	x	x	x	x				
Aegialitis annulata			x	x	x	x	x	x	x	x	x					
Aegiceras corniculatum			x	x	x	x	x	x	x	x	x	x	x	x		
Avicennia integra						x										
Avicennia marina	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Bruguiera cylindrica								x	x							
Bruguiera exaristata			x	x	x	x	x	x	x	x						
Bruguiera gymnorrhiza						x	x	x	x	x	x	x				
Bruguiera parviflora				x	x	x	x	x	x	x						
Bruguiera sexangula						x		x	x							
Camptostemon schultzii			x	x	x	x	x	x	x							
Ceriops australis			x	x	x	x	x	x	x	x	x					
Ceriops decandra						x		x	x							
Ceriops tagal						x		x	x	x						
Cynometra iripa						x	x	x	x	x						
Diospyros littorea				x	x	x	x	x	x							
Dolichandrone spathacea								x	x							
Excoecaria agallocha				x	x	x	x	x	x	x	x	x	x			

(continued)

Table 2.10 (continued)

Species	SW WA	Cent WA	Pilbara	Kimberley	Bonaparte	Top End	West Gulf	East Gulf	NE QLD	Cent QLD	SE QLD	N NSW	Cent NSW	S NSW	Vic	S Aust
Heritiera littoralis								*x*	*x*	*x*						
Lumnitzera littorea						*x*	*x*	*x*	*x*							
Lumnitzera racemosa				*x*	*x*	*x*	*x*	*x*	*x*	*x*	*x*					
Nypa fruticans						*x*		*x*	*x*							
Osbornia octodonta			*x*	*x*	*x*	*x*	*x*	*x*	*x*	*x*	*x*					
Rhizophora apiculata						*x*		*x*	*x*	*x*						
Rhizophora lamarckii						*x*		*x*	*x*							
Rhizophora mucronata								*x*	*x*							
Rhizophora stylosa		*x*	*x*	*x*	*x*	*x*	*x*	*x*	*x*	*x*	*x*	*x*				
Scyphiphora hydrophylacea				*x*		*x*	*x*	*x*	*x*	*x*	*x*					
Sonneratia alba				*x*	*x*	*x*		*x*	*x*	*x*						
Sonneratia caseolaris								*x*	*x*							
Sonneratia lanceolata						*x*			*x*							
Xylocarpus granatum				*x*		*x*		*x*	*x*	*x*	*x*					
Xylocarpus moluccensis				*x*	*x*	*x*	*x*	*x*	*x*	*x*	*x*					
35	*1*	*2*	*9*	*18*	*17*	*30*	*20*	*33*	*34*	*21*	*13*	*6*	*3*	*2*	*1*	*1*

Table 2.11 Distribution of seagrass around Australia

	km^2	%
Queensland	22,000	40
New South Wales	155	<1
Victoria	100	<1
Tasmania	500	1
South Australia	9620	17
Western Australia	22,000	40
Northern Territory	900	2
Australia	55,275	100

Table 2.12 Distribution of major tropical and temperate seagrass species around Australia (from Short and Woodroffe 2009)

	Southwest WA	Shark Bay	Kimberley-NT	Gulf Carp.-Torres Strait	NE QLD	SE QLD	SE Australia	Southern coast
Tropical species								
Halodule uninervis		X	X	X	X	X		
Halodule pinifolia			X	X	X			
Cymodocea angustata		X		X				
Cymodocea rotundata			X		X			
Cymodocea serrulata		X	X	X	X	X		
Syringodium isoetifolium	X	X	X	X	X	X		
Enhalus acoroides			X	X	X			
Thalassodendron ciliatum			X	X	X			
Thalassia hemprichii			X	X	X			
Halophila ovalis	X	X	X	X	X	X	X	
Halophila ovata		X	X	X	X			
Halophila decipiens	X	X	X	X	X	X	X	
Halophila spinulosa		X	X	X	X	X		
Halophila tricostata			X	X	X			
Temperate species								
Amphibolis griffihii	X							X

(continued)

Table 2.12 (continued)

	Southwest WA	Shark Bay	Kimberley-NT	Gulf Carp.-Torres Strait	NE QLD	SE QLD	SE Australia	Southern coast
Amphilbolis antartica	X	X					X	X
Halophila australis	X						X	X
Hererozostera tasmanica	X						X	X
Hererozostera nigricaulis	X							
Hererozostera polychlamys	X							
Zostera mucronata	X							X
Zostera muelleri							X	X
Zostera capicorni						X	X	
Posidonia sinuosa	X	X						X
Posidonia coriacea	X	X						X
Posidonia australis	X	X					X	X
Posidonia denhartogii	X							X
Posidonia augustifolia	X	X						X
Posidonia robertsonae	X							
Posidonia ostenfeldi	X							X
Ruppia megacarpa	X						X	X
Thalassodendron pachyrhizum	X							
	19	13	13	13	13	7	9	13

sediments, and *Thalassodendron ciliatum* grows directly on coral and calcarenite reefs. Muddy intertidal areas are favoured by *Halophila ovalis.*

Seagrass meadows support a rich epibiota and contribute a high proportion of red algae, foraminifera and bivalve fragments to the beach sediments, as well as seagrass roots and detritus. They also help stabilise nearshore sands, and in the tropics are grazed by dugongs and green turtles, both of which are most extensive across northern Australia.

2.5.5 *Coral Reefs*

Coral reef systems occur right around the northern Australian coast. WA has the world's most poleward coral reef systems forming the Houtman Abrolhos islands and reefs that extend to 29°S. On the mainland fringing reefs become prominent north from Gnaraloo (24°S), forming the Ningaloo fringing-barrier reef complex between Amherst Point and North West Cape. Between Exmouth Gulf and Cape Leveque, the coast is dominated by generally low-gradient beaches, tidal flats and mangroves, and as a result reefs tend to occur off the coast as atolls and fringing islands, though there are areas of fringing reefs, as at Port Hedland. The most extensive WA system surrounds much of the Kimberley coast and particularly the adjoining islands which all lie between 15 and 17°S. There are also extensive fringing reefs along the predominantly rocky Kimberley coast, in addition to 163 usually small beaches fronted by fringing reefs. Table 2.13 lists the regional distribution of coral taxa and number of species around the northern Australian coast.

In the NT fringing reefs occur along much of the northern coast and islands including Bathurst-Melville, Cape Cockburn, the Goulburn and Wessel islands and around Cape Arnhem, with 35 mainland beaches fronted by fringing reef. They also extend into the western Gulf particularly on parts of Groote Eylandt and the Sir Edward Pellew Group.

In the southern Gulf, coral reefs occur on Vanderlin, Mornington and Bentinck islands, while they are largely absent from the sandy eastern Gulf coast. The reefs begin to dominate the coast and shelf in Torres Strait where they form a number of low islands and then merge into the northern GBR. On the eastern Cape York Peninsula coast, the northern GBR dominates the outer shelf and parts of the mid-shelf, together with fringing reef forming along parts of the mainland shore and fronting 20 beaches.

Coral reef systems have two main physical impacts on the mainland beaches. They cause wave breaking over the reefs, resulting in substantial wave attenuation and refraction and low to zero ocean waves at the shore. Barrier reefs usually attenuate all ocean swell, resulting in only fetch-limited wind-generated waves to their lee and low energy mainland shorelines. Fringing reefs also attenuate waves, through the sea and swell can reach the beach at mid- to high tide. The net result however is a substantially lower energy beach system. On the Queensland coast, ocean waves outside the reefs average 1–1.5 m and 9–10 s, while inside the reef, the seas average 0.5 m with 4–5 s periods, which represents an order of magnitude reduction in wave energy.

Secondly, reefs close to shore and all fringing reefs (Fig. 2.4) deliver coral and algal debris to the backing beaches, thereby acting as a major source of local beach material. This is apparent on the Kimberley and NT coasts where the beaches average 50% carbonate material, with some beaches reaching 100% (Table 2.14). In contrast the beaches on western Cape York Peninsula, free of reefs, average 21% carbonate. Down the northeast and central QLD coast, in lee of the GBR, the carbonate content is only 19 and 13%, respectively, as the GBR reefs usually lie some

Table 2.13 Dominant coral taxa; the number of species in the principal families and the most notable genera within them, from key sites around Australia (from Short and Woodroffe 2009)

Family	Genus	S WA	Rottnest	Abrolhos	Ningaloo	Kimberley	Rowley	Ashmore	Torres Strait	N GBR	CenGBR	S GBR	ElizMid	Lord Howe	SolIs
Acroporidae	*Acropora*		1	45	37	12	44	48	58	64	72	48	24	7	11
	Montipora	1	1	29	27	7	18	21	25	32	31	24	9	8	6
	Other			4	3	1	2	4	7	7	9	6	4	1	
Agariciidae	*Pavona*			5	6	1	8	9	8	8	8	8	5	4	3
	Other			7	8		8	10	11	11	11	8	3	2	1
Astrocoeniidae				1	1		2	1	2	2	2	2	2	1	
Caryophylliidae				2	4	4	5	5	7	7	7	6	1		
Dendrophylliidae	*Turbinaria*	3	3	8	9	6	3	5	3	6	9	7	3	4	1
	Other			2	2	1			1	2	2	1			1
Faviidae	*Favia*		1	9	8	2	10	12	10	13	13	8	5	3	1
	Goniastrea		2	8	7	4	3	6	5	7	7	7	4	3	2
	Platygyra			2	6	4	4	6	3	4	5	4	3	1	2
	Other	2	4	19	24	18	19	30	33	39	38	26	17	9	7
Fungiidae	*Fungia*				5	3	7	10	13	14	14	9	1		
	Other			4	9	7	9	14	11	16	18	9	1		1

Merulinidae				3	5	2	3	4	7	7	7	7	2	2	2
Mussidae			2	9	6		7	10	13	15	17	16	8	5	4
Oculinidae				1	2	2	2	2	3	3	3	3			
Pectiniidae				5	8	2	6	11	10	10	9	7	3	2	1
Pocilloporidae	*Pocillopora*		1	4	5	1	3	5	3	1	5	3	1	1	1
	Other			2	2	3	2	3	2	4	5	4	2	3	2
Poritidae	*Porites*			9	9	3	8	10	8	2	10	2			
	Goniopora			6	4	6	5	11	12	13	16	8	5	1	2
	Other			6	4	2	4	4	3	5	8	3	2	2	
Siderastreidae		2		9	9	6	6	8	9	11	10	6	7	3	3
Trachyphylliidae						1				1	1				

Fig. 2.4 Fringing coral reef flats fronting beaches near Cape Londonderry (K 1102–1104) in the northern Kimberley. (Photo: AD Short)

Table 2.14 Regional proportion of carbonate beach sands

Region	Mean carbonate %	σ %	Range (%)
Northwest	47	31	0.5–99
Kimberley	55	33	0.5–98
NT	47	28	0–100
West Cape York	21	12	0–63
Northeast QLD	19	31	0–99.7
Central QLD	13	18	0–99

tens of kilometres offshore and cannot physically supply sand to the coast, plus the fact that beach sediments are dominated by quartz-rich sands derived from the numerous coastal rivers and creeks. However, on some of the 20 east QLD beaches fronted by fringing reefs, the amount of carbonate material reaches as high as 99%.

2.5.6 Turtles

Six of the world's seven species of turtles are found across northern Australia (Table 2.15), and all use some of the beaches for nesting. During the breeding season, turtles crawl up on sandy beaches, dig a hole of the upper beach and lay their

Table 2.15 Northern Australia turtles and their nesting regions

Common name	Scientific name	Main nesting regions
Flatback	*Natator depressus*	Kimberley to east Queensland
Green	*Chelonia mydas*	NW Cape to Bundaberg
Hawksbill	*Eretmochelys imbricata*	Kimberley to east Queensland
Loggerhead	*Caretta caretta*	Shark Bay Ningaloo region and S GBR
Olive Ridley	*Lepidochelys olivacea*	Tiwi Islands and Arnhem Land
Leatherback	*Dermochelys coriacea*	Scattered nests in north and down east coast

eggs. When the eggs hatch, the hatchlings crawl down the beach to the water and swim out to sea to begin their life cycle. The beaches therefore provide a critical habitat for turtle nesting. See http://www.austurtle.org.au for more information.

2.5.7 Crocodiles

Crocodiles inhabit the estuaries, creeks and coastal waters of northern Australia from Exmouth Gulf in the west, right across the top and down the east coast as far as Rockhampton. There are two species, the smaller freshwater crocodile *Crocodylus johnstoni*, which grows to 3 m and lives in freshwater. It is considered timid and relatively harmless. The larger saltwater crocodile, *Crocodylus porosus*, can grow to over 5 m and weigh more than one tonne. It lives in salt, brackish and freshwater and is extremely dangerous. Saltwater crocodiles and their tracks are commonly found on northern Australian beaches, particularly in the Kimberley region. Both species have been protected since 1971 and have been slowly increasing in population and expanding their range ever since. It is estimated there are now 20,000 saltwater crocodiles in the Kimberley region, 75,000 in the NT and 20,000 in QLD, primarily along the western Cape York coast and rivers. The Australian population represents a substantial proportion of the world population of between 200,000 and 300,000. For more information on crocodiles and their management across northern Australia, see Letts (2004), Letnic (2004), Read et al. (2004), Mawson (2004) and Semeniuk et al. (2011).

2.6 The Tropical Divisions and Regions

The northern tropical province contains four divisions, the northwest, the Kimberley-Territory, the Gulf of Carpentaria and the northeast (Table 1.7 and Fig. 1.44b), and nine regions (Table 2.16 and Fig. 2.5). The province extends for 16,445 km and contains 4796 beaches, which occupy 6591 km or 39% the coast. The remainder of the coast is made up of rocky shore and in lower energy sections and bays contains

Table 2.16 The length and beaches of the tropical northern province and its divisions and regions

Division	Region	Length coast (km)	No. beaches	Length beaches (km)	% beaches
Northwest	Carnarvon[a]	360	71	140	39
	Pilbara	421	205	155	37
	Canning	1579	295	746	47
Kimberley-Territory	Kimberley	3376	1190	375	11
	Western NT	1936	198	430	22
	North Arnhem	1871	870	833	45
Gulf of Carp.	East Arnhem	828	384	476	57
	Southern Gulf	854	80	336	39
	W Cape York Peninsula	1015	148	745	73
Northeast	E Cape York Peninsula	2378	860	1264	53
	Central QLD	1827	497	827	45
	Province Total	16,445	4796	6328	39

[a]The ACSC Pilbara region combines Carnarvon, Pilbara and Canning subregions, which are listed above separately

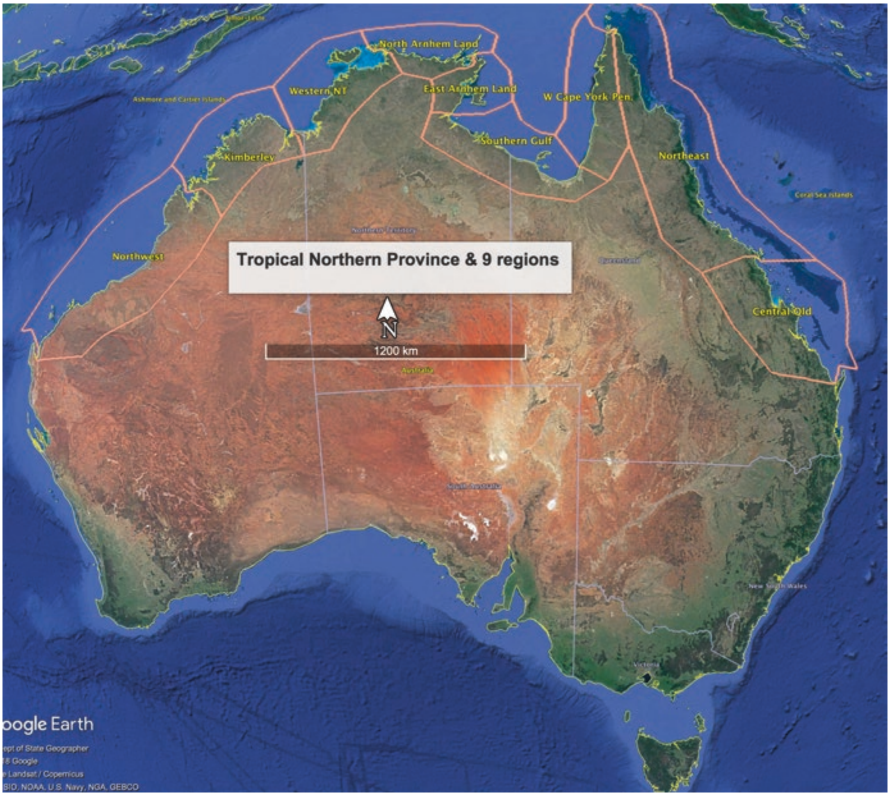

Fig. 2.5 The nine regions of the northern tropical province. (Source: Google Earth)

mangrove-lined tidal flats and open water at the many creek and river mouths. The geological evolution of northern Australia controls the coastal geology, orientation and topography, with the regions ranging from the bedrock-dominated Kimberley region, where beaches occupy only 11% of the coast and average just 0.3 km in length, to the mixed northeast division with beaches occupying 50% of the coast, to the sedimentary shorelines of the Canning Basin and the Gulf of Carpentaria divisions where beaches occupy 47% and 58% of the shore, respectively, averaging 2.5 km long in the Gulf.

The coast and beaches of each of these four divisions, their nine regions, 37 PCs and their 126 SCs are presented in the following 13 chapters (Chaps. 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14 and 15). Table 2.16 listed the length of coast and number and length of beaches in the four tropical divisions and their regions.

2.7 Summary

The northern Australia tropical province spans over half the Australian coast. It is a sub-tropical to tropical region with climate ranging from hot desert in the west, through tropical monsoonal across much of the top, to pockets of wet equatorial in the northeast. The coast is dominated by generally low waves and meso- through mega-tides, with much of the coast and shelf TD. Coastal sediments are derived from the many rivers and streams which deliver terrestrial bedload through mud and the marine environment which supplies carbonate detritus which makes up approximately half the beach material. The waves and tide deposit this material in estuaries, deltas, and in thousands of primarily TM and TD beaches usually fronted by extensive sand though mud flats. The coastal zone is also host to a wide range of tropical ecosystems including Australia's most extensive seagrasses, coral reefs and mangrove systems. The coast is sparsely populated and for the most part difficult to very difficult to access from the land. This coast contains four divisions and seven regions which will be discussed in Chaps. 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14 and 15.

References

Craig GE (1983) Pilbara coastal flora. Soil Conservation Service, WA Department of Agriculture, Perth, 96 p

Creswell and Semeniuk (2011) Mangroves of the Kimberley coast: ecological patterns in a tropical ria coast setting. J R Soc West Aust 94:213–237

Creswell ID, Bridgewater P, Semeniuk V (2011) The coastal habitats and vegetation of the Kimberley region. J R Soc West Aust 94:197–206

Larkum AWD, Waycott M, Conran JG (2018) Evolution and biography of seagrasses. In: Larkum AWD, Kendrick GA, Ralph PJ (eds) Seagrasses of Australia: structure, ecology and conservation. Springer, Cham, pp 3–30

Letnic M (2004) Crocodile management in the Northern Territory of Australia. In: Crocodiles, Proceedings of the 17th working meeting of the Crocodile Specialists Group, IUCN, The World Conservation Union, Gland, Switzerland, and Cambridge UK, pp 4–12
Letts G (2004) History of crocodile conservation in Australia. In: Crocodiles, Proceedings of the 17th working meeting of the Crocodile Specialists Group, IUCN, The World Conservation Union, Gland, Switzerland, and Cambridge UK, pp 1–3
Mawson P (2004) Corcodile management in Western Australia. In: Proceedings of the 17th working meeting of the Crocodile Specialists Group, IUCN, The World Conservation Union, Gland, Switzerland, and Cambridge UK, pp 28–37
Read M, Wright B, Enoch C (2004) Crocodiles in Queensland – an overview. Proceedings of the 17th working meeting of the Crocodile Specialists Group, IUCN, The World Conservation Union, Gland, Switzerland, and Cambridge UK, pp 13–27
Semeniuk V, Kenneally KF, Wilson PG (1978) Mangroves of Western Australia. Western Australian Naturalist Club, Handbook 12, Perth, 92 p
Semeniuk V, Manolis C, Webb GJW, Mawson PR (2011) The saltwater crocodile, *Crocodylus porosus* Schneider, 1801, in the Kimberley coastal region. J R Soc West Aust 94:407–416
Short AD (2000) Beaches of the Queensland coast: Cooktoen top Coolangatta. Sydney University Press, Sydney, 360 p
Short AD (2005) Beaches of the Western Australian coast: Eucla to Roebuck Bay. Sydney University Press, Sydney, 433 p
Short AD (2006a) Beaches of the Northern Australia coast: the Kimberley, Northern Territory and Cape York. Sydney University Press, Sydney, 463 p
Short AD (2006b) Australian beach systems – nature and distribution. J Coast Res 22:11–27
Short AD (2011) Kimberley beach and barrier systems: an overview. J R Soc West Aust 94:19–30
Short AD, Woodroffe CD (2009) The coast of Australia. Cambridge University Press, Melbourne, 288 p
Stern H, de Hoedt G, Ernst J (2000) Objective classification of Australian climates. Aust Meteorol Mag 49:87–96
Suppiah R (1992) The Australian summer monsoon: a review. Prog Phys Geogr 16:283–318

Chapter 3
Northwest Division

Abstract The tropical northwest Australian coast grades from hot desert in the south to monsoonal in the north and the geology from the ancient Pilbara Craton to the Carnarvon and Canning sedimentary basins. Tide range increases northwards from meso to mega and waves are predominately low to moderate seas which are further reduced by the shallow shelf and nearshore and an island and reef studded inner shelf. Coastal sediments are a mix of shelf carbonate and terrigenous material, the latter delivered by usually dry rivers which flood following tropical cyclonic rains and which have aggraded the coastal plain and deposited deltas at the coast. The climate and carbonate-rich sediment have combined to lithify the low linear Pleistocene barriers and barrier islands which dominate parts of the coast. The predominately southerly waves and flooding tides drive a northerly sediment transport which is interrupted by numerous hard obstacles and tidal creeks and rivers. The beaches are predominately tide-dominated with extensive tidal flats and the barriers a mix of regressive beach-foredunes and limited dune transgression.

Keywords Northwest Australia · Geology · Climate · Coastal processes · Sediment transport · Beaches · Barriers

3.1 Introduction

The northwest division occupies the northwest corner of Australia and extends for 2338 km from Exmouth Gulf to King Sound. It contains one region – the Pilbara (which can be subdivided geologically into the Carnarvon, Pilbara and Canning subregions), eight PCs (Table 3.1 and Fig. 3.1) and 23 SCs. The southern Carnarvon Basin subregion extends for 358 km from Giralia Bay at the southern extremity of Exmouth Gulf to the first bedrock outcrop on the coast at James Point. It begins in the very low wave energy, micro-tidal but TD southern gulf with its very wide mangrove-lined tidal flats and supratidal basins. At the northern end of the gulf, the Ashburton marks the first in a series of rivers draining the Pilbara Craton's Hamersley Range that episodically deliver sediment to the coastal plain and coastal zone where they have built a series of deltas (Ashburton, Cane, Robe, Fortescue, Maitland,

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Table 3.1 Northwest division, subregions and PCs

PC No.[a]	Name	Boundaries	WA & K Beach ID[b]	No. beaches	km[c]	Total km
Carnarvon						
WA 11.01	Exmouth	Girilia Bay-Locker Pt	1634-1658	25	4392-4532	140
WA 11.02	Fortesque	Locker Pt-James Pt	1659-1703	45	4532-4750	218
			Subtotal	70		358
Pilbara						
WA 11.03	Dampier	James Pt-Cape Lambert	1704-1831	128	4750-5015	265
WA 11.04	Hedland	C. Lambert-Beebingara Ck	1832-1908	77	5015-5258	243
			Subtotal	205		508
Canning						
WA 12.01	Keraudren	Beebingara Ck-Shoonta Well	1909-1957	*49*	5258-5466	208
WA 12.02	80 Mile	Shoonta Well -Cape Jaubert	1958-1974	17	5466-5668	202
WA 12.03	Dampier Pens.	C. Jaubert-Swan Is	1975-2051+ K 1-93	170	5668-6221	553
WA 12.04	King Sound	Swan Is-Pt Usborne	K 94-152	59	6221-6730	509
			Subtotal	295		1472
			Division total	570		2338

[a]NCCARF primary compartment number
[b]Distance from SA-WA border
[c]ABSAMP beach ID for Western Australia and the Kimberley

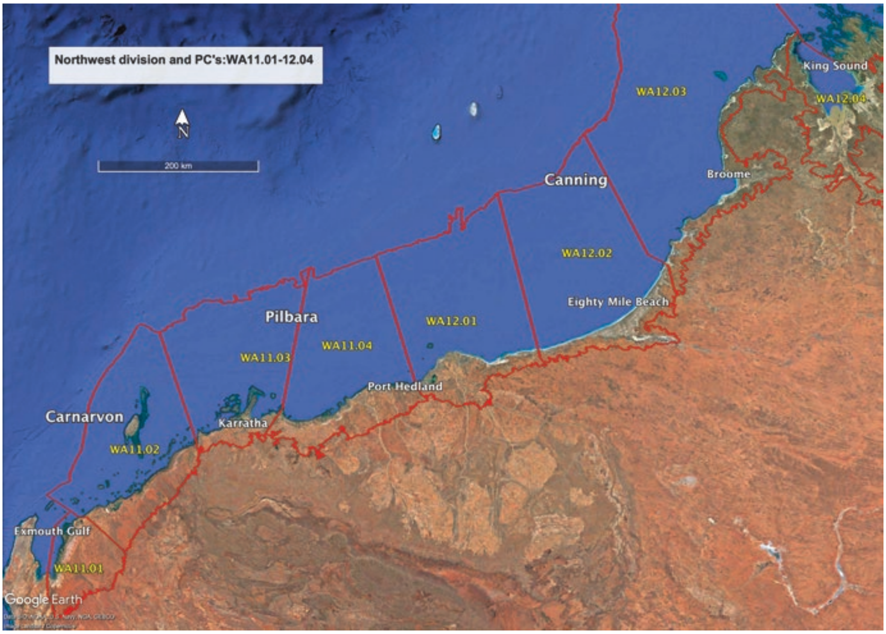

Fig. 3.1 The northwest division and its eight PCs (11.01–12.04) are located between Exmouth Gulf and King Sound. It includes the Carnarvon (WA11.01-02), Pilbara (WA11.03-04) and Canning (WA12.01-04) subregions. (Source: Google Earth)

Sherlock, Harding, Yule, Turner and De Grey). The central Pilbara subregion extends for 508 km from James Point to Cape Thouin. While the hinterland is dominated by the rugged ancient Pilbara Craton and its uplands, the coast tends to be a low-lying coastal plain, including several deltaic systems, apart from the sections of bedrock outcrop between Cape Preston and Cape Thouin. The northern Canning Basin subregion is entirely low lying and includes the 222 km long Eighty Mile Beach and the large low-lying Dampier Peninsula and the shores of King Sound, with a total shoreline of 1472 km. On the open coast sediment is transported by the low waves and tidal currents in a general northeast direction both alongshore and on the inner shelf. The coast however in detail contains a range of landforms including 295 beaches and their barriers, numerous tidal creeks and their supratidal basins, extensive areas of mangrove-lined tidal flats, the rivers and their deltas, bedrock along the Pilbara coast, pindan bluffs around the Dampier Peninsula and inherited Pleistocene features including lithified-beachrock (limestone) barrier islands. The general geomorphology of the PCs and SCs will be presented in the following sections. For more detailed descriptions of the regions geology-geomorphology, see Semeniuk (1993) and Brocx and Semeniuk (2017) who provide a detailed classification of coastal types and their geoheritage significance, while Eliot et al. (2011, 2013) and Stul et al. (2014) provide a detailed assessment of the Pilbara coastal land systems their geomorphology and susceptibility and vulnerability to coastal hazards, as well as providing planning advice. This chapter will not attempt to replicate these comprehensive studies; rather it will draw on their relevant findings.

The northwest division is unified by its tropical arid climate (Fig. 1.8), northwest orientation, low waves, meso- to mega-tide ranges and generally northeast longshore sand transport with coastal sediments a mix of terrigenous sands and carbonate detritus. The entire coast is also exposed to seasonal tropical cyclones and accompanying strong winds, storm surges, heavy rain and flooding (Fig. 1.6). It is also exposed to occasional tsunami generated in the Indonesian archipelago.

There is limited coastal development in this division with the only substantial coastal towns being Onslow (700), Dampier (1500), Karratha (27000), Wickham-Port Samson (2000), Cape Lambert (1500), Anketell (planned), Roebourne (900), Port Hedland-South Hedland (20000), Broome (15000) and Derby (5000). Most of these towns were initially developed as ports in the late nineteenth century, with Onslow, Karratha and Port Hedland now major ports for the export of LPG, iron ore and salt, while Broome has boomed as a tourist destination, and Derby remains an administrative centre. Offshore there are mining operations on Barrow Island (oil), and Cockatoo and Kolan islands (iron ore), together with deep ocean LPG rigs. There are also several small aboriginal communities and tourist ventures, together with several pearl and fish farms located around the Dampier Peninsula, while most of the coast and hinterland is taken up in large pastoral leases for cattle production and the Beagle Bay Aboriginal Land occupying the northern half of the Dampier Peninsula.

3.2 Geology and Geomorphology

The northwest division consists of three distinct geological regions. In the south is the northern extension of the Perth Basin, called the Carnarvon Basin; in the centre is the rugged Pilbara Craton, while the low-lying Canning Basin occupies the northern half of the division.

The *Carnarvon Basin* is an elongated basin extending for about 1000 km between the Murchison and the Dampier Archipelago of the Pilbara Craton (Figs. 1.3 and 2.1), essentially from Kalbarri to James Point. It contains up to 7000 m of mainly Palaeozoic sediments deposited between 400 and 0 Ma. The sediments are a mix of fluvial, coastal and shallow marine deposits and include the red sandstones that dominate the Kalbarri coast. Elsewhere, Tertiary limestone dominates the coastal deposits. Only the northern 350 km of the Carnarvon Basin is located in the northwest division. The northern basin is 75 km wide at its southern boundary in Exmouth Gulf narrowing northwards to its apex at Cape James. It is bordered to the east by the rugged Hamersley Range where the Yannarie, Ashburton, Cane, Robe and Fortescue rivers rise and flow across the basin depositing a broad coastal plain consisting of Tertiary through Holocene fluvial sediments, reworked superficially into north-south trending longitudinal dunes. The coastal zone is a low gradient coast plain containing extremely low gradient salt and tidal flats up to 15 km wide in Exmouth Gulf, while further north the Ashburton, Robe and Fortescue rivers have deposited regressive tide-dominated deltas at the coast. The southern 110 km of shoreline is dominated by mangrove-fringed tidal creeks and flats, with beaches occupying only 17 km (15%) of the shoreline, while beaches occupying 39% of the total basin shoreline.

The ancient *Pilbara Craton* covers an area of 60,000 km^2 and contains some of the oldest remnants of the Earth's original crust. It represents the accumulation of deep-seated volcanic greenstone terrains, including granite-gneiss complexes, which began accumulating in association with the Earth's then thin crust as early as 3500 Ma and was possibly cratonised by 3000 Ma (Hickman 1983). Following its formation the craton underwent a long period of mobility resulting in the building of mountain chains adjacent to the craton. In WA the Capricorn Orogen formed between the Pilbara and Yilgarn cratons between about 2000 and 1600 Ma, the Albany-Fraser Orogen bordered the south and eastern side of the Yilgarn Craton between 2000 and 1800 Ma, and the King Leopold Orogen surrounded the Kimberley Basin between 1900 and 400 Ma (Fig. 2.1; Table 2.1). Today the Pilbara Craton is a relative low (<700 m) heavily dissected plateau with deep V-shaped valleys and gorges, which grades towards the coast, into a broad low gradient coastal plain that occupies 40% of the region and consists of a relatively thin veneer of sand and gravel deposits (<40 m thick) over bedrock (Hickman 1983). The upland region is the source of much of Australia's iron ore with mining commencing in 1966 at Mount Goldsworthy. The coast is a mix of bedrock with granite and greenstone outcrops between Cape Preston and the prominent Burrup Peninsula and in the south between Cape James and Point Samson. East of Point Samson, the coast is dominated by the extensive fluvial deposits of the Maitland, Harding, George, Sherlock, Peewah and Yule rivers, with the Maitland and Harding forming regressive tide-dominated deltas. Beaches occupy just 23% of the shoreline, the remainder predominately mangroves together with areas of bedrock and beachrock. Semeniuk (1993) identified three major Quaternary suites along the Pilbara coast: the Pleistocene red siliciclastic sediments (alluvium, deltaic sediments and aeolian sand) that form the inland zone; Pleistocene limestones (beachrock) that form linear coastal barriers, both submerged and emerged; and Holocene sediments contained in deltas, beaches-dunes, tidal flats and tidal embayments. Along the coast he divided these into five sedimentary landform types: active deltas; beach barriers; inactive eroding deltas and their barriers; limestone barriers, bays and associated limestone barriers; and bedrock. For a comprehensive overview of the Pilbara coast and its coastal processes and sediment compartments, see Eliot and Eliot (2013).

The *Canning Basin* is the largest basin in Western Australia, occupying 1500 km of coast between Port Hedland and King Sound and extending up to 1000 km inland (Figs. 1.3 and 2.2) and up to 250 km out onto the wide northwest continental shelf. It covers an area of 415,000 km^2 and contains up to 10,000 m of shallow marine sediments ranging in age from the Ordovician to the Holocene (500–0 Ma) (Table 2.1). Today its onshore extension is largely blanketed by the longitudinal dunes of the Great Sandy Desert, while the low-lying Eighty Mile Beach and Roebuck Bay dominate much of the shoreline south of Broome, with the low Dampier Peninsula occupying the area between Broome and King Sound. Sixty-six percent of the shoreline is sandy beaches, the remainder predominately mangrove-lined tidal flats, particularly in Roebuck Bay and King Sound. In the south the Turner and large De Grey rivers have deposited wide coastal plains and two of the larger tide-dominated deltas. This is followed by a 1000 km section (Eighty Mile Beach, Roebuck Bay and the entire Dampier Peninsula) with no rivers, while the large Fitzroy flows into the sheltered southern end of King Sound forming a 25 km wide, 45 km long funnel-shaped TD delta.

Eliot et al. (2011) identified four major landform types along the coast. These are the inner shelf morphology and islands; subtidal shoreface including reefs; intertidal shoreface including rivers, streams, tidal creeks, deltas, beaches, rocky headlands, cliffs and rock flats; and backshore morphology including riverine plains, outwash plains and barriers.

3.3 Climate

The northwest climate ranges from hot desert (BWh) in the southern Carnarvon-Pilbara sector where the Australian desert reaches the coast to hot semi-arid grassland in the northern Canning region (BSh) (Fig. 1.7). Rainfall ranges from 260 mm in Exmouth, one of the driest locations on the Australian coast, to 691 mm at Derby (Fig. 1.5a, b). At the same time, the temperature decreases towards the equator from a mean maximum of 38 °C and 37 °C at Exmouth and Port Hedland to 34 °C and

31 °C at Broome and Derby (Fig. 1.5c, d). The northerly increase in rainfall and decrease in temperature are due to the onset of the summer monsoons which arriving from the north being summer clouds, humidity and rain to Broome and Derby, which also lower the summer temperatures, while further south less rain, clear skies, intense radiation and higher temperatures prevail at Port Hedland and Exmouth. Throughout the region more than 80–95% of the rain falls between either December or January and June and July, with winters dry (July–November) (Table 2.2). The rain is derived primarily from the summer monsoon, with periodic and more localized heavy rain events associated with tropical cyclones. Winds are predominately onshore during the summer, with the offshore easterly trades dominating during the winter (Fig. 1.7). The seasonal winds are however modulated by the ENSO, with stronger easterly winds during La Niña phase and stronger westerly during El Niño conditions.

The summer tropical cyclones deliver the most severe weather and marine conditions to the Pilbara coast, in particular as it is the focus of cyclone landfalls (Fig. 1.6). The cyclones which peak during December to March are accompanied by strong winds, high waves, strong shelf currents, storm surges and high rainfall which can lead to river and coastal flooding and inundation of the generally low-lying coastal plain. During winter rain is occasionally generated by northwest cloud bands connected to midlatitude cyclones to the south.

3.4 Coastal Processes

The northwest coast is characterised by low waves, with tides increasing to the northeast from micro to mega. Winds are generally easterly particularly in winter, with afternoon onshore sea breezes. Eliot et al. (2011) found at a broad regional scale there is a paucity of historical information describing ocean and coastal processes for the northwest, with exceptions related to localised projects.

3.4.1 Waves

Deepwater waves off the northwest coast originate from four sources – Southern Ocean southwest swell, easterly Indian Ocean swell, local wind waves and tropical cyclones (Eliot et al. 2011). Owing to the coast orientation to the northwest and the Coriolis effect, the southwest swell tends to head north and bypass the coast, while the easterly swell heads offshore, leaving only the local wind waves and periodic cyclones to generate waves, with the local wind waves dominating. Li et al. (2008) using hindcasting found that deepwater wave height off the Dampier coast averaged about 1.42 m with a period of 7 s, the short period indicative of wind waves. Across the inner shelf and at the shore, the waves averaged less than 1 m with periods between 3 and 5 s. As Fig. 1.12a indicates wave energy is low along the entire northwest coast, with monthly/seasonably variability increasing northwards (Fig. 1.12b) owing to the seasonal wind and wave reversal associated with the winter offshore southeast trades and summer onshore northwest monsoons.

The northwest coast has a mean breaker height of 0.28 m ($T = 4.9$ s) (Table 2.4), which is skewed to lower waves between 0.1 and 0.3 m. The lowest waves occur along the reef and island-sheltered northern Carnarvon and Pilbara, and King Sound shores, with the higher waves (0.4–0.8 m) arriving along the more exposed sections of the western Canning coast between Eighty Mile Beach and Cape Leveque. The Carnarvon subregion has a mean $H_b = 0.19$ m ($T = 3.8$ s), the Pilbara 0.22 m ($T = 5$ s) and the Canning 0.33 m ($T = 5$ s).

These values confirm the low-wave height at the shore, while their short period is indicative of a local source, which combine to produce very low levels of wave energy at the shoreline (Fig. 1.12a). The low waves are a product of both the limited source of waves together with the wide shallow continental shelf and in places very low gradient nearshore and wide intertidal zones, together with sections of offshore islands and reefs, including beachrock reefs. All these factors combine with the already low deepwater wave climate to substantially reduce wave height at the shore. The high tide ranges and wide intertidal zones also lead to tide modulation of the waves, with higher waves arriving during the deeper high tides and lower and at times no waves reaching the shore at low tide, as they are filtered by all the above. The actual wave height, while generally low, varies considerably alongshore in response to all the above mitigating factors.

3.4.2 Tides

Tides along the northwest coast arrive from the west and reach the northwest coast almost simultaneously (Fig. 2.2). They range from micro at Exmouth (mean spring range = 1.8 m) to mega at Broome (8.3 m) and Derby (10.1 m). Table 3.2 shows the gradual increase in tide range northwards along the coast, peaking in King Sound. The increase in range is due to two factors. First is the increasing width of the continental shelf north from Exmouth, which leads to greater shoaling and amplification of the tidal wave; and second is tidal resonance within the rectangular-shaped King Sound, which further amplifies the tide to the highest in Australia, and third highest in the world.

The high tide ranges and shallow nearshore shelf generate strong tidal currents across the shelf, which increase in strength to the east as tide range increases. However, the most extreme currents and continental shelf waves are generated by extreme winds associated with the passage tropical cyclones (Pearce et al. 2003). These currents are strongly influenced by local bathymetry and the presence of islands, with currents increasing through island passages and forming wakes in the lee of islands (Pearce et al. 2003). Porter-Smith et al. (2004) found that waves dominate the northwest shelf between Exmouth and Dampier, with tidal currents domi-

Table 3.2 Tidal characteristics for selected stations along the northwest Western Australian coast

Location	Mean spring high tide (m)	Mean spring low tide (m)	Mean spring tide range (m)	Relative time of arrival 0 h = Perth- = before + = after
Northwest division: Exmouth Gulf				
Exmouth	2.3	0.5	1.8	+0.1
Learmonth	2.6	0.5	2.1	0.0
Pilbara coast				
Onslow	2.5	0.6	1.9	+0.5
Fortescue Road	3.7	0.3	3.4	+0.1
Dampier	4.4	0.7	3.7	+0.5
Hauy Island	4.8	0.7	4.1	0.0
Depuch Island	5.7	0.7	5.0	+0.2
Port Walcott	5.5	0.8	4.7	+0.5
Port Hedland	6.8	0.9	5.9	+0.6
Kimberley coast				
Broome	9.4	1.1	8.3	+0.5
Derby	11.2	1.1	10.1	+1.0

nating the entire shelf north from Dampier (Fig. 1.13), the currents also exceeding the threshold for grain size entrainment on the shelf.

Off Cable Beach in Broome Wright et al. (1982) measured wave and tidal currents at 8 m depth. They found that shore parallel tidal currents reached up to 0.16 m s^{-1} with a mean northerly component of 0.127 m s^{-1}. In the subtidal zone, the tidal currents were equivalent in velocity to the wave-generated currents and concluded that the tidal currents were sufficient to suspend sediment and generate northerly bedload transport, transport that would be enhanced with additional wave suspension of the sediments. They added that the patterns of sediment accumulation north of Cable Beach, where inlet infill and north-trending recurved spits occur, are indicative of net northerly longshore sand transport.

3.4.3 Storm Surges

The northwest coast is exposed to seasonal tropical cyclones, which tend to track down the coast and make landfall between Port Hedland and Onslow (Fig. 1.6). The cyclones bring low atmospheric pressure, strong winds and high waves and as they move across the wide shallow shelf generate storm surges up to several metres high along the coast. The impact of the surges depends in part on the state of the tide when they arrive, with the surges damped by a low tide, while if they accompany a high tide coastal inundation is maximized. Extreme water levels occur when the storm surge coincides with high tide and is further amplified by wave set-up, by wave run-up and locally by river flooding. Hopley and Harvey (1978) rate the northwest coast as having moderate to high risk to storm surge.

Based on dated wrack lines near Onslow Eliot and Dobson (2010), Eliot et al. (2011) and Dobson et al. (2014) found evidence of extreme storm surges at elevations between 2 and 10 m above MSL which occurred within the last 1500 years. Nott (2011) examined shell ridges in Shark Bay and found they contained evidence of major tropical cyclone storm surges and their deposits over the past 6 ka. Likewise, May et al. (2017, 2018) examined washover deposits and cheniers at the base of Exmouth Gulf and concluded they were deposited by tropical cyclone storm surges coupled with cyclone-induced flooding and that sea level was 1-2 m higher in the mid-Holocene.

3.4.4 Coastal Currents

Coastal and shelf currents along the northwest shelf are dominated by tidal currents, particularly as tide range increases to the east (Eliot et al. 2011). Pearce et al. (2003) found that extreme currents are generated by strong winds and shelf waves associated with tropical cyclones and once in motion are affected by local bathymetry and islands.

3.4.5 Tsunami

The northwest coast lies just over 1000 km south of the Indonesia archipelago, a source of volcanic eruptions, earthquake and tsunami, the latter capable of reaching the northern Australian coast with damaging waves. This area has the highest probability of receiving damaging tsunami in Australia, peaking in the Exmouth region (Fig. 1.16).

Burbridge and Cummings (2007) and Burbridge et al. (2008) modelled potential tsunami impact along the Western Australian coast (at 50 m depth) and found that the most hazardous area was offshore of Exmouth. The tsunami hazard is moderate between Broome and Dampier, moderate to high between Dampier and Shark Bay, much lower to the south of Shark Bay and very low along the south coast of WA.

Eliot et al. (2011) reviewed modern tsunami impact along the northwest coast and noted the impact of five tsunamis between 1883 and 2007 whose run-up reached elevations between 0.8 and 2.5 m. They found the major impact of tsunami was to flatten dunes and to be funnelled through natural dune breaches, access tracks and creeks inundating the backing low-lying areas. Eliot and Donson (2010) and Dodson et al. (2014) investigated historic wrack lines at elevations between 6 and 10 m in the vicinity of Onslow and concluded that at least three high-magnitude cyclones or more likely tsunami events have impacted the coast in the past 2000 years leaving debris at those elevations. They also reported wrack lines of similar elevation at Cleaverville, Anketell, Cossack and Balla Balla. However, in response to publications that tsunami are responsible for many large coastal deposits, Dobson et al. stated that 'The potential tsunamigenic origin of many coastal deposits around

Australia, including those in northwest Australia has been a source of debate, much of which has hinged on the proxy nature of evidence used to identify their origin. This is somewhat surprising, since there is a suite of well-established proxies that have been developed from observations of recent, historical and prehistorical tsunami impacts in several countries, to more unequivocally identify depositional features left by tsunami inundation'.

3.4.6 River Flooding and Sediment Supply

Eight larger rivers are located along the northwest coast, the largest being the Ashburton, and Fortescue in the Carnarvon subregion, the De Grey in the Pilbara and Fitzroy in the Canning (Table 3.3). These large rivers together with the smaller rivers and creeks in the region are predominately ephemeral, relying on the occasional TCs and in the north monsoonal rains, to deliver heavy rain, stream flow and possibly flooding and sediment transport. Even when flowing not all streams reach the coast with many of the smaller rivers and creeks discharging into tidal basins and outwash plains. While the streams are ephemeral in nature, they still play a major role at the coast, being the source of most terrestrial sediment, with the larger rivers building substantial deltas. Also during heavy rain, they can cause widespread flooding of the low-lying coastal plain. The combination of storm surge, river flooding and tsunami makes this coast highly susceptible to flooding and inundation.

Table 3.3 Major northwest division rivers

River	Catchment (km^2)
Carnarvon	
Ashburton	78,420
Cane	4472
Robe	7487
Fortescue	49,759
Pilbara	
Maitland	2123
Sherlock	5168
Harding	1797
Yule	10,845
Turner	4555
De Grey	54,752
Canning	
Fitzroy	103,900

3.4.7 Deltas

The northwest rivers and streams deliver pulses of terrigenous sediment to the coast, usually in association with heavy cyclonic rainfall and flooding events in the Hamersley hinterland. The fines are transported in suspension and deposited on the coastal plain, on the tidal flats and particularly on the inner shelf. The bedload is deposited in the usually dry river channels, then as they fan out during floods across the wide coastal plains as alluvial deposits, with only the major rivers regularly depositing bedload at the coast. At the river mouths and distributaries, these sediments form shoals and bars, which are generally reworked by the prevailing waves, winds and flooding tide and transported to north and east, in places forming migratory barrier islands and elongated spits.

Eliot and Eliot (2013) present a conceptual model of the role of sediment supply along the Pilbara coast (Figs. 1.16 and 3.2). The major rivers build protruding deltas like the Ashburton and De Grey, while with decreasing sediment supply, the smaller rivers flow into TD estuaries, and the smallest rivers and creeks fan out across tidal flats flowing into tidal lagoons, linked to the ocean by tidal creeks.

3.4.8 Sediments

Coastal sediments along the northwest coast are derived from two main sources, the ~150 rivers and creeks along the Carnarvon-Pilbara coast together with the large Fitzroy River in King Sound (Table 2.6), which deliver suspended mud and silt and terrigenous sand bedload, and from in situ shallow water carbonate production, with

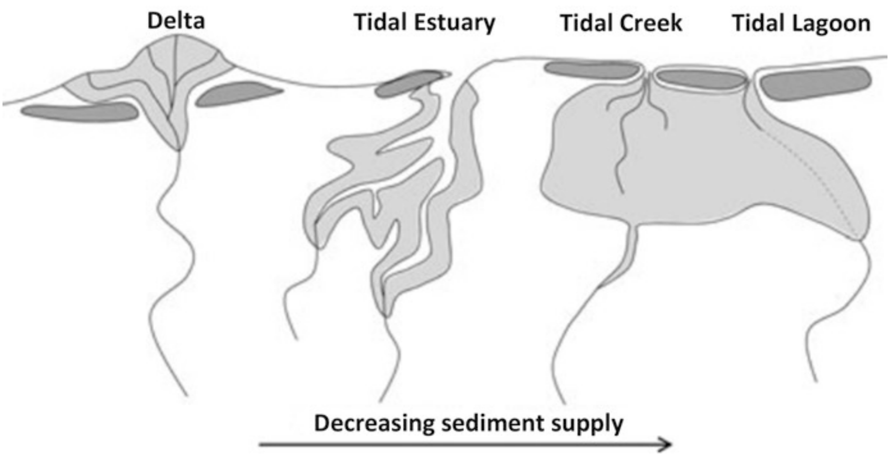

Fig. 3.2 Conceptual relationship between sediment supply and estuary form along the Pilbara coast. (Source: Eliot and Eliot 2013)

carbonate detritus averaging around 50% (Table 2.7). The carbonate production takes place across the beach, intertidal and subtidal, as well as in the shallow reef systems and consists of benthic foraminifera, molluscs, bryozoans, echinoids, calcareous algae, corals, bivalves and reef organisms. The detritus is eroded and broken-up by waves and delivered to the coast as a mix of fine to coarse sand particles. In general, the sediments are primarily carbonate-rich, medium through coarse, well to moderately sorted sand, with considerable variation longshore, indicative of local supply, low wave energy and limited longshore transport. The marine geology of the northwest shelf was investigated by Jones (1973), who reported sediment movement across the entire shelf. James et al. (2004) concurred noting the presence of long low swell during winter months as well as shorter higher waves during cyclones, together with the occurrence of a series of prominent large subaqueous dunes 70-in 90–70 m depth. James et al. (2004) also investigated the Quaternary carbonate sedimentation on the northwest shelf and characterized it as “an ocean-facing carbonate ramp that lies in a warm-water setting adjacent to an arid hinterland of moderate to low relief.” They found the sea floor is strongly affected by cyclonic storms, long-period swells and large internal tides, resulting in preferentially accumulating coarse-grained sediments, with the sediments palimpsest, and a variable mixture of relict, stranded and Holocene grains. The inner ramp (<50 m depth) contained a mixture of heterozoan and photozoan elements, where the depositional facies reflect episodic environmental perturbation by riverine-derived sediments and nutrients, resulting in a mixed habitat of oligotrophic (coral reefs and large benthic foraminifera) and mesotrophic (macroalgae and bryozoans) indicators. The inner sediments were poorly sorted gravel and sand and a mixture of terrigenous and carbonate mud.

3.4.9 Sediment Transport

Waves arrive predominately from the west and drive an east to northeast longshore sediment transport, as is evident from the many east-trending spits and migratory recurved spits and easterly deflected creek and river mouths. Rates of transport would expect to be low, on the order of 1000s to perhaps a few 10,000 s m^3 $year^{-1}$ on more exposed beaches. Stul et al. (2014) developed conceptual models of sediment transport along the Carnarvon and Pilbara coast based on episodic river supply and a general northeast longshore transport. They noted that sediment is transported both on the inner shelf and alongshore, with interruptions and shore normal supratidal exchange occurring through the many tidal inlets to and from the basins and outwash plains. They found continuous northeast transport northeast from Hope Island, with an obstacle at Cape Preston and a major obstacle posed by the Dampier Archipelago. They found transport rates were high at and near the river mouths, decreasing downdrift. Along the Onslow coast, Dobson et al. (2014) estimate net rates between 5000 and 105,000 m^3 $year^{-1}$, while at the Port Hedland, spoil bank rates of 12,000–20,000 m^3 $year^{-1}$ have been estimated by Eliot (2010, 2014).

3.4.10 Water Temperature

Water temperature in the northwest is controlled by the coast's tropical location, coupled with the south-flowing Leeuwin Current which originates in the warm northeast Indian Ocean and flows south as an eastern boundary current down the WA coast, bringing warm topical water to the coast. During summer coastal sea temperatures reach up to 30 °C, dropping to the low 20s in winter (Fig. 1.17).

3.5 Northwest Beach Systems

Beaches occupy 1043 km (45%) of the northwest coast the remainder dominated by mangrove-lined tidal flats particularly in Exmouth Gulf and King Sound, as well as the numerous tidal creeks, together with sections of rocky coast particularly in the Dampier Peninsula region and areas of Pleistocene limestone barriers and reefs. The beaches are spread throughout the three regions, with beach number, length and type increasing from south (Carnarvon-Pilbara) to north (Canning) where 51% of the shore is sandy beaches (Table 3.4). This transition is due to considerably sheltering along the lower gradient Carnarvon coast with the Pilbara coast also sheltered by both low gradients and rocky-reef sections leading to fewer, shorter, lower energy beaches, while the more exposed higher gradient western Canning region has longer and higher energy beaches, as will be discussed in the following sections on the three subregions. See Short (2005, 2006) for a detailed description of all the division's beaches.

The division's 570 beaches have a mean length of 1.83 km and tend to face southwest (270°). They have a moderate gradient (5.5°) and are relatively wide at ~60 m, with a low level of embaymentisation (0.87) reflecting the lack of headlands in the Carnarvon and Canning subregions (Table 3.5). The majority (67%) have sand flats averaging 755 m in width with just 20 having mud flats averaging 815 m in width. Rock flats front 34 beaches mainly in the Pilbara region and average 215 m in width, while from Broome north coral reefs fringe 90 beaches and average 495 m

Table 3.4 Beach number and length for the northwest division and subregions

	Carnarvon subregion	Pilbara subregion	Canning subregion	Northwest division
Beach number	71	204	295	570
Beach length (km)	140	155	746	1043
Total length (km)	357	508	1475	2340
Beach %	39	27	51	44.7
Mean (km)	1.97	0.76	2.53	1.83
σ (km)	1.96	1.24	5.34	4.03
Max length (km)	8.7	12	73	73
Min length (km)	0.05	0.05	0.05	0.05

Table 3.5 Some characteristics of northwest division beaches

	n	mean	σ	min	max
Orientation (deg)	570	270	122	1	360
Gradient (deg)	570	5.5	1.5	1.5	10.5
Embaymentisation	570	0.87	0.19	0.1	1
Beach width (m)	570	48	63	10	500
Sand ridges (m)	14	7	3	3	14
Sand flats (m)	381	755	810	10	6000
Mud flats (m)	20	815	583	300	2500
Coral flats (m)	90	495	415	100	2000
Rock flats (m)	34	214	240	50	1000

in width. There are 14 B + RSF beaches with an average of 7 ridges. In terms of beach type, the majority are TD (45%) followed by TM (37%), a product of the low waves and high tide ranges, with rock and reef flats (11%) and WD (8%). The dominant beach states by length are the TD B + SF and B + TSF (42%) particularly in the Carnarvon, Pilbara and the sheltered Canning sections. The higher energy UD (33%) and R + LTR (4%) however make up 37% by length (Table 3.6) and reflect higher energy condition particularly along the exposed west-facing Canning coast, including the long Eighty Mile Beach.

The main factors contributing to beach types along the coast are the low waves and increasingly higher tides, together with sediment size, which can include substantial amounts of coarse carbonate detritus. Because of the low waves, the only WD beach type is the low energy R, while the increasingly higher tides result in a dominance of TM and particularly TD beaches. Local geology and the tropical climate contribute the presence of those beaches bounded by headlands and fronted either by intertidal rock flats, including beachrock and fringing coral reef flats.

3.6 Northwest Barrier Systems

There are 174 barrier systems along the northwest division coast (Table 3.7), which occupy 43% of the coast, the remainder either mangrove-lined tidal flats or rocky shore. The barriers are predominately low regressive beach-foredune ridge plains and include numerous spits and recurved spits adjacent to the creeks and rivers, while the larger rivers have regressive deltas containing multiple beach-foredune ridge plains and spits. The barriers are lowest and smaller along the sheltered Pilbara coast (14,125 ha), increasing size in the Carnarvon region (17,905 ha) in association with the deltas, and are substantially larger in the more exposed western Canning region (79,665 ha), where there are areas of higher energy TM beach backed by transgressive dunes, 10% of which are unstable. The division barriers have a total area of 11,471 ha, volume of 10,901 M m^3 and a relatively low per metre volume of 10,532 $m^3\ m^{-1}$.

Table 3.6 Northwest division beach type, number and length

BS	BS	No.	% no.	Total length (km)	mean (km)	σ (km)	% length
6	R	28	4.9	84	1.7	1.8	8.1
7	R + LTT	61	10.7	41.3	0.9	1.8	4.0
8	R + LTR	0	0.0	0.0	0.0	0.0	0.0
9	UD	62	10.9	341.4	5.6	10.0	32.7
10	B + SR	14	2.5	9.0	0.6	0.7	0.9
11	B + SF	140	24.6	216.8	1.6	2.4	20.8
12	B + TSF	153	27.1	221.2	1.5	2.0	21.2
13	B + TMF	8	1.4	15.6	2.0	2.0	1.5
14	R + RF	90	14.9	109.3	1.4	2.3	10.5
15	R + CR	17	3.0	4	0.5	0.7	0.4
		570	100.0	1042.6	1.8		100.0

Table 3.7 Northwest division and subregion barrier dimensions

	Carnarvon (N)	Pilbara	Canning	Northwest
No.	31	48	101	180
Total length (km)	164	181	690	1035
Mean length (km)	5.3	3.8	6.8	5.8
Width range (m)	570–1400	150–400	520–1270	–
Mean height (m)	6.2	7	9.4	–
Area (ha)	17,905	14,125	79,665	111,695
Unstable area (ha)	2140	900	8628	11,461
Volume (M m^3)	1227	1162	7612	10,901
Unit volume (m^3 m^{-1})	6875	5888	11,651	10,532

Chapter 4 examines the nature of the coast, beaches and barriers in Carnarvon, Pilbara and Canning subregions, their 4 PCs and 23 SCs.

3.7 Summary

The northwest division covers an area of hot arid to semi-arid coast encompassing the central ancient Pilbara Craton, bordered by the low Carnarvon and Canning basins. The coast reflects both the hot desert to monsoonal climate and the generally low waves and increasingly higher tides that reach over 10 m in King Sound. Into this environment periodic cyclonic events fill the catchments, and the numerous usually dry rivers flow to the coast delivering their sediments to the coastal plain and the tide-dominated deltas. The bedload is reworked predominately to the north and east by waves and flooding tidal currents as spits and barrier islands. The sediments are enriched by local biogenetic material leading to the formation of beach and dunerock which in turn armours the beaches and barriers, including all the Pleistocene barriers. The resulting shoreline ranges from wide tidal flats fringing by mangroves, to low spits and beach-foredune ridge barriers to areas of moderate dune transgression, together with bedrock in the Pilbara section and limestone (beach-dunerock) scattered throughout. The beaches are a mix of a few WD and TM in exposed areas and TD elsewhere.

References

Brocx N, Semeniuk V (2017) Impacts of ports along the Pilbara Coast, Western Australia – a coastline of global geoheritage significance that services a mineral-rich hinterland. Annals Geophysics, 60 Fast track 7, 12 p

Burbidge D, Cummins P (2007) Assessing the threat to Western Australia from tsunami generated by earthquakes along the Sunda Arc. Nat Hazards 43:319–331

Burbidge D, Cummins P, Mleczko R, Thio HK (2008) A probabilistic tsunami hazard assessment for Western Australia. Pure Appl Geophys 165:2059–2088

Dobson J, Eliot I, Eliot M, Chagié-Goff GJ (2014) Wrack line signatures of high-magnitude water-level events on the northwest Australian coast. Mar Geol 355:310–317

Eliot MJ (2010) Sediment transport studies for the Port Hedland outer harbour quantum project. Global Environmental Modelling Systems, GEMS report to BHP Billiton Iron Ore

Eliot M (2014) Port Hedland spoil bank marina: coastal engineering assessment. Seashore Engineering Pty Ltd, Report SEO13-01-Draft B, Perth, 24 p

Eliot I, Dodson J (2010) Geoheritage features of the Onslow embayment: coastal landforms, coral reefs and wrack lines. Unpublished report 82–04-Addendum 1: geochronology and other laboratory analyses. Damara WA Pty Ltd

Eliot M, Eliot I (2013) Interpreting estuarine change in northern Australia: physical response to changing conditions. Hydrobiologia 708(1):21

Eliot I, Gozzard B, Eliot M, Stul T, McCormack G (2011) Geology, geomorphology and vulnerability of the Pilbara coast. In the shires of Ashburton, East Pilbara and Roebourne, and the town of Port Hedland, Western Australia. Damara WA Pty Ltd and Geological Survey of Western Australia, Innaloo, Western Australia

Eliot I, Gozzard B, Eliot M, Stul T, McCormack G (2013) Geology, geomorphology and vulnerability of the Pilbara Coast. In the Shires of Ashburton, East Pilbara and Roebourne, and the Town of Port Hedland, Western Australia. Damara WA Pty Ltd and Geological Survey of Western Australia, Innaloo, Western Australia, 387 p

Hickman AH (1983) Geology of the Pilbara Black and its environs. Geol Survey Western Australia, Perth, Bull 127:266

Hopley D, Harvey N (1978) Regional variation in storm surge characteristics around the Australian coast: a preliminary investigation. In: Heathcote RL, Thom BG (eds) Natural Hazards in Australia. Institute Australian Geographers, Canberra, pp 164–185

James NP, Bone Y, Kyser TK, Dix G, Collins L (2004) The importance of changing oceanography in controlling late quaternary carbonate sedimentation on a high-energy, tropical, oceanic ramp: North-Western Australia. Sedimentology 51:1170–1205. https://doi.org/10.1111/j.1365-3091.2004.00666.x

Jones HA (1973) Marine geology of the northwestern Australian continental shelf. Bur Min Res Geol Geophys Bull 136, 102 p

Li F, Griffiths CM, Asiles-Taing T, Dyt CP (2008) Modelled seabed response to possible climate change scenarios over the next 50 years in the Australian Northwest. Report No. 08–001,

Predictive Geoscience, CSIRO Petroleum, The fourth report of Australian seabed model, Wealth from Oceans Flagship
May SM, Brill D, Leopold M, Callow JN, Engel M, Scheffers A, Opitz S, Norpoth M, Brückner H (2017) Chronostratigraphy and geomorphology of washover fans in the Exmouth gulf (NW Australia) – a record of tropical cyclone activity during the late Holocene. Quat Sci Rev 169:65–85. https://doi.org/10.1016/j.margeo.2017.03.005
May SM, Gelhausen H, Brill D, Callow JN, Engel M, Opitz S, Scheffers A, Joannes-Boyau R, Leopold M, Brückner H (2018) Chenier-type ridges in Giralia Bay (Exmouth gulf, Western Australia) - processes, chronostratigraphy, and significance for recording past tropical cyclones. Mar Geol 396:186–204. https://doi.org/10.1016/j.margeo.2017.03.005
Nott J (2011) A 6000 yr tropical cyclone record from Western Australia. Quat Sci Rev 30:713–772
Pearce A, Buchan S, Chiffings T, d'Adamo N, Fandry C, Fearns P, Mills D, Phillips R, Simpson C (2003) A review of the oceanography of the Dampier Archipelago, Western Australia. In: Wells F, Walker D, Jones D (eds) The marine flora and fauna of Dampier, Western Australia. Western Australian Museum, Perth, pp 13–50
Porter-Smith R, Harris PT, Andersen OB, Coleman R, Greensladee D, Jenkins CJ (2004) Classification of the Australian continental shelf based on predicted sediment threshold exceedance from tidal currents and swell waves. Mar Geol 211:1–20
Semeniuk V (1993) The Pilbara coast: a riverine coastal plain in a tropical arid setting, northwestern Australia. Sediment Geol 83:235–256
Short AD (2005) Beaches of the Western Australian coast: Eucla to Roebuck Bay. Sydney University Press, Sydney, 433 p
Short AD (2006) Beaches of the northern Australia coast: the Kimberley, Northern Territory and Cape York. Sydney University Press, Sydney, 463 p
Stul T, Gozzard JR, Eliot IG, Eliot MJ (2014) Coastal sediment cells for the Pilbara region between Giralia and Beebingarra Creek, Western Australia. Report prepared by Seashore Engineering Pty Ltd and Geological Survey of Western Australia for the Western Australian Department of Transport, Fremantle, 73 p
Wright LD, Nielsen P, Short AD, Green MO (1982) Morphodynamics of a macrotidal beach. Mar Geol 80:97–128

Chapter 4
Pilbara Region: Carnarvon, Pilbara and Canning Coasts

Abstract The Pilbara region extends from Exmouth Gulf to King Sound and includes the Pilbara deltaic coast, Eighty Mile Beach and the large low Dampier Peninsula and the adjoining King Sound. It is an arid region where the hot desert reaches the coast grading northward into monsoonal conditions, all exposed to tropical cyclones. Coastal sediments are a mix of shelf carbonate and terrigenous. Tides increase northwards from meso to mega, and waves are predominately low to moderate seas, all of which drive low rates of northerly sand transport, interrupted by numerous tidal creeks, limestone and bedrock shores and inflections in the coast. The beach systems are predominately tide-dominated shifting to tide-modified in more exposed northerly locations. Barriers are small to moderate in size and range from regressive beach-foredune ridges to some areas of moderate dune transgression. The region contains three geologically defined subregions: the southern Carnarvon Basin coast, the more rugged Pilbara with its seasonal rivers and bedrock and the long low Canning Basin coast. This chapter describes the processes, beaches, barriers and sediment transport in each of these subregions, all set within a framework of hierarchical sediment compartments.

Keywords Pilbara · Carnarvon Basin · Canning Basin · Deltas · Meso-tides · Mega-tides · Tropical cyclones · Beaches · Barriers · Sediment transport · Sediment compartments

4.1 Introduction

The northwest division occupies the generally hot arid to semi-arid northwest corner of Australia with its 2338 km of coast extending from Exmouth Gulf to King Sound encompassing the low northern Carnarvon Basin coast, the more rugged Pilbara coast and the long low Canning Basin coast. The division consists of one region, the Pilbara, which in this chapter is treated in three subregions based on the geological divisions of the Carnarvon Basin, the Pilbara craton and the Canning Basin, as presented in Chap. 3. The Carnarvon subregion contains 2 PCs and 3

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SCs, the Pilbara 2 PCs and 6 SCs and the Canning 4 PCs and 12 SCs, a total of 8 PCs (Table 3.1) and 21 SCs, each of which is discussed below. The climate, geology and coastal and biological processes of this division are presented in Chap. 2 and an overview of its beach and barrier systems in Chap. 3.

Much of the Pilbara coast (Carnarvon, Pilbara and Canning) has been investigated in considerable detail by Semeniuk (1981a, b, 1996, 2008) and more recently by the group from Damara (Eliot et al. 2011, 2013) and Stul et al. (2014). Stul et al. (2014) mapped the hierarchy of sediment compartments (PC, SC and TC) for the Pilbara coast (Gialia to Beebingarra Creek) that are used in this chapter. Eliot et al. (2011) mapped much of Carnarvon-Pilbara-Canning coast (Locker Point to Cape Jaubert) and identified 13 coastal landform types, partly based on Semeniuk's (1996) classification, which they then ranked as to their nature and level of instability. Eliot et al. (2013) then used the landform classification to assess the susceptibility, instability and vulnerability of sediment compartments down to the tertiary level. The beaches of the region are described by Short (2005, 2006). These publications provide an excellent introduction to and overview of the Pilbara coast its geology, processes and landforms and the management implications for these systems. Their findings are discussed wherever relevant.

4.2 Carnarvon Coast

4.2.1 Introduction

The Carnarvon Basin coast extends from Giralia Bay at the base of Exmouth Gulf north along the tide- and mangrove-dominated eastern gulf shoreline to eastern gulf entrance at Locker Island a distance of 140 km. It then continues for another 217 km northwest to the metasedimentary rocks of James Point. It contains two PCs WA11.01 and 11.02 and four secondary compartments (Table 4.1) and includes the larger Ashburton, Robe and Fortescue rivers and their substantial deltas, together with several smaller rivers and creeks that drain onto the supratidal flats. The 70

Table 4.1 Carnarvon subregion SCs

SC[a]	Name	Boundaries	Beach ID[b] WA	No. beaches	km[c]	Total km
WA11.01.01	Giralia Bay	Giralia-locker Pt	1634–1658	25	4393–4532	139
WA11.02.01	Ashburton R	Locker Pt-Coolgra Pt	1659–1676	18	4532–4598	66
WA11.02.01	Robe River	Coolgra Pt-Peter Ck	1677–1689	13	4598–4693	95
WA11.02.03	Fortescue R	Peter Ck-James Pt	1690–1703	14	4693–4750	56
				70		357

[a]NCCARF compartment number
[b]ABSAMP WA beach number
[c]Distance from SA/WA border

beaches in this region occupy 142 km (40%) of coast, with a mean length of 2 km, while their backing barriers extend along 164 km (46%) of the shore, indicating that some formative beaches have been eroded, leaving inactive barriers. The remainder of the shore, particularly in Exmouth Gulf, is dominated by 15–20 km wide mangrove-lined intertidal and supratidal salt flats, together with numerous tidal creeks, including a continuous 60 km long mangrove/creek section in the southern gulf and another 100 km long section between Yardie Landing and Mount Salt. Many of the beaches, particularly the longer ones, are associated with the three major river deltas, with the longest 8.7 km in length.

The only development on the coast is at Onslow and the Port of Ashburton, located 12 km west of Onslow and opened in 2018. The offshore gas pipeline comes ashore at this port, and liquid natural gas is processed and exported from the port. Onslow is the only location where the public can access the coast by vehicle, with no public access to the port. Most of the coast is backed by pastoral properties with 4WD tracks to some coastal locations. However tidal creeks, mangroves and tidal flats up to several kilometre wide make vehicle access to the coast difficult, if not impossible, in many locations.

4.2.2 PC:WA11.01 Giralia Bay to Locker Point

PC:WA11.01 extends for 139 km, from the base of Exmouth Gulf at Giralia Bay, north-northwest along the eastern gulf shore to Locker Point and contains one SC:WA11.01.01 (Fig. 4.1). The entire shore is both very low energy and low gradient consisting of 1–2 km wide low tide flats, a 3–4 km wide mangrove fringe and 10–15 km wide supratidal salt flats, interrupted to the north by a few limestone and active barrier islands. The southernmost 60 km between Giralia and Hope Island consists of 10–15 km wide, very low gradient supratidal salt flats and intertidal sand flats, drained by about 20 funnel-shaped mangrove-lined tidal creeks along the shoreline, together with partly drowned north-south trending Pleistocene longitudinal (desert) dunes (Fig. 4.1). There are no beaches along this TD section.

A series of cheniers and washover chutes located at the tip of Giralia Bay was examined in detail by May et al. (2017, 2018). They found the cheniers were deposited between ~2850 and 170 years ago and attributed them to tropical cyclone storm surge inundation. Likewise, the washover were attributed to both the cyclones and associated cyclone-induced flooding.

The next 32 km long section between Hope and Tent Islands contains a series of 16 beaches all fronted and backed by kilometre-wide tidal flats associated with a series of limestone barrier islands (Hope, Simpson Burnside (Fig. 4.2a), unnamed and the larger Tent Island) each separated by broad mangrove-lined tidal inlets The beaches tend to be short (average length 0.9 km) and interrupted by beachrock outcrops, smaller tidal creeks and changes in orientation. The beaches occupy 15 km (46%) of this section. Sediment transport is predominately tidally-driven and shore normal along this section, with sand moving down either side of Tent Island forming crenulate barrier spits (Fig. 4.2b).

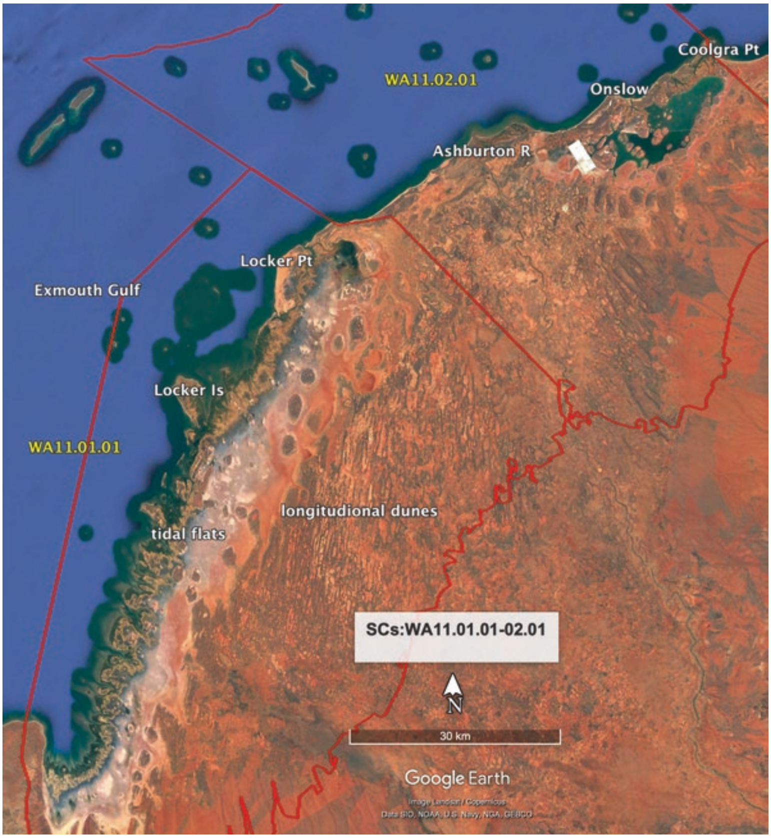

Fig. 4.1 WA:SC11.01.01and 11.02.01 extends from Giralia Bay at the base of Exmouth Gulf to Coolgra Point and includes the Ashburton River delta. (Source: Google Earth)

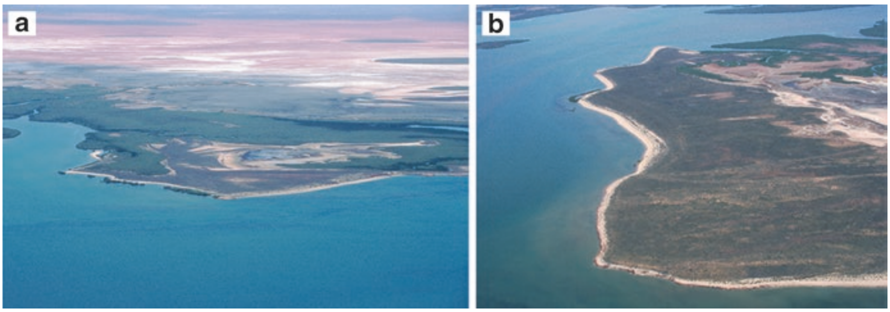

Fig. 4.2 (**a**) Burnside island and the backing belt of mangroves and then wide supratidal flats (WA-1638-41) and (**b**) the crenulate northern shoreline of Tent Island (WA-1648). (Photos: AD Short)

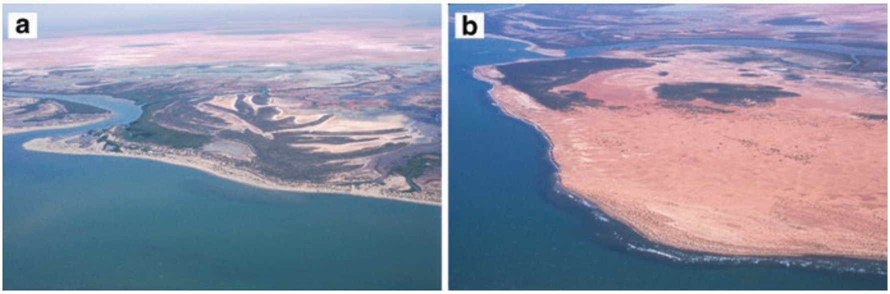

Fig. 4.3 (**a**) Urala Creek showing the multiple recurved spits and wide surpatidal flats (WA-1652) and (**b**) Tubridgi Point on Locker Island and its transgressive dune sheet (WA-1654-5). (Photos: AD Short)

To the north of Tent Island is a very low-energy 25 km wide open embayment, sheltered by the offshore islands and reefs together with the very low nearshore gradient. The shoreline consists entirely of 5 km wide mangrove-lined tidal flats, grading landward to 10 km wide supratidal flats, with no beaches. Urala Creek marks the switch from tidal flats to low-energy beach and multiple recurved spits (Fig. 4.3a), as wave energy increases northwards towards Locker Island. The island is capped by active northward-migrating transgressive dunes (Fig. 4.3b) blanketing earlier beach ridges, an unusual feature on this low-energy coast. The island shore trends northwest for 10 km to Locker Point then turns and trends northeast with the northern side of the island consists of a partly covered 3 km wide series of regressive beach-foredune ridge spits, with a large tidal creek bisecting the barrier. The creek drains the northern 10 km wide tidal flats in lee of the island.

On Locker Island, Nott (2006) surveyed Tubridgi Point (Fig. 4.3b) after tropical cyclone Vance (March 1999) and found evidence of a storm surge reaching up to 7 m elevation. The surge eroded two outer rows of 6 m high vegetated dunes and transported their remains as a sand sheet up to 300 m inland.

4.2.2.1 Rivers and Creeks

The only river along this section is the Yannarie, which dissipates into the coastal plain 40 km inland feeding into broad clay pans up to 7 km wide, with only a small (200 m wide) dry meandering creek to mark its mouth where it reaches the salt flats. There are however about a dozen funnel-shaped tidal creeks each 1–1.5 km wide at their mouths penetrating up to 10 km inland through the mangroves to the salt flats, providing a connection between the gulf and the flats.

4.2.2.2 Sediments and Coastal Processes

This is a very low-energy section of coast owing to the low deepwater waves of the northwest, which are further reduced by the sheltering within Exmouth Gulf in the south, by the scores of islands that lie just off the coast, and by the very low gradient inner shelf and nearshore, resulting in very low to zero waves at the shore. Breaker wave height is estimated to average 0.2 m, with a period of 3.8 s. Spring tide range is 1.8 m in the south at Exmouth and 1.9 m at Onslow, which combines with the low waves to maintain a RTR between 6 and 20.

Sediment supply along this section is limited to episodic flooding of the Yannarie in the south, to sediment reworked from the gulf floor, the flooded longitudinal dunes of the coastal plain, and to in situ carbonate production, all resulting in low levels of sediment input and no subaerial deposits along the eastern gulf shore. This is coupled with predominately shore-normal, tide-driven, currents and sediment transport through the many inlets that connect the extensive supratidal flats with the gulf and which are slowly accumulating fine material. The first indication of northerly longshore transport occurs at Tent Island, where there are a series of north-trending recurved spits. However most of the tidal creeks and adjacent spits between Tent and Locker Islands recurve to both the north and south (Fig. 4.3a), suggesting a more balanced TD sediment transport, primarily associated with the TD inlets.

4.2.2.3 Beaches

The very low waves along the eastern gulf shore maintain a predominately TD coast dominated by mangroves and funnel-shaped tidal creeks, with 25 beaches occupying just 27% of the shore and with 22 of the beaches (82%) fronted by sand and tidal sand flats averaging 240 m in width. The remaining beaches are either WD reflective (13%) or fronted by rock flats (5%) (Table 4.2).

4.2.2.4 Barriers

There are no barriers along the gulf shore south of Hope Island, with eight located between Hope and Locker Islands, all associated with the limestone barrier islands. The Holocene barriers along this PC are predominately stable, low-energy beach ridge-recurved spits and regressive beach-foredune ridges, the largest containing 30 ridges. The barriers range in mean width between 330 m and 1.52 km and have an average height of 5.5 m. They occupy 38 km of the shore (27%) that has a total area of 3820 ha and volume of 205 M m^3, which represents relatively low 5394 m^3 m^{-1} (Table 4.3). Most of the barrier are stable, apart from the extensive 2140 ha transgressive dune field on Locker Island, which represents 37% of the compartment's barriers.

Table 4.2 PC/SC:WA11.01.01 beach type and state by number and length

BS[a]	BS	No.	%	Length (km)	%	Mean (km)	σ (km)
6	R	1	4	4.9	13.1	4.9	–
11	B + SF	9	36	18.45	49.3	2.05	2.25
12	B + TSF	13	52	12.2	32.6	0.94	0.68
14	B + RF	2	8	1.88	5.0	0.94	–
		25	100	37.43	100	–	–

[a]BS, beach states; see Table 1.2

Table 4.3 Carnarvon PCs barrier dimensions

WA11.01&11,02	11.01	11.02	Carnarvon
No.	8	23	31
Total length (km)	38	126	164
Mean min width	330	655	570
Mean max width	1525	1360	1400
Mean height (m)	5.5	6.4	6.2
Area (ha)	3820	14,085	17,905
Unstable (ha)	1400	740	2100
Total volume (M m^3)	205	922	1127
Unit volume (m^3 m^{-1})	5394	7318	6872

4.2.2.5 PC Overview

This is a low to very low-energy section of coast, containing broad tidal flats and mangrove-lined tidal creeks, with predominately TD beaches and barriers only appearing along the northern slightly more exposed section. There is limited contemporary terrestrial sediment input, with the only river dissipating into clay plans inland from the coast. The southern half is totally dominated by shore perpendicular tidal flow through the inlets and across the kilometres-wide supratidal flats. The northern barrier island section does shown evidence of northerly sand transport, together with reversals at inlet mouths, including the boundary at Locker Point, which consists of south-trending recurved spits, indicating southerly longshore transport from the adjoining PC:WA11.03. This appears to be a closed sediment compartment consisting of a series of smaller TCs based around the tidal creeks and islands, with little if any linkage between them. The 205 M m^3 of sand that has accumulated on the northern islands is probably derived from the northern sources in the case of Locker Island, together with onshore transport from the gulf floor and in situ carbonate production. Because of its very low gradient, the coast is already very exposed to storm surge inundation which will increase as sea level rises.

4.2.3 PC:WA11.02 Locker Point to James Point

This PC trends northeast for 218 km between Locker and James points and contains three SCs (WA11.02.01–03) (Table 4.1 and Figs. 4.1, 4.4). This is a slightly more energetic section of coast receiving episodic sediment input from the Ashburton, Cane, Robe and Fortescue rivers, with the larger Robe and Fortescue building protruding deltas (Fig. 4.4). It is a low gradient depositional coast containing no bedrock apart from remnants of Pleistocene shores in the form of limestone (beachrock) barrier islands and cemented sediments. It terminated at 30 m high Point James, the beginning of the Pilbara region.

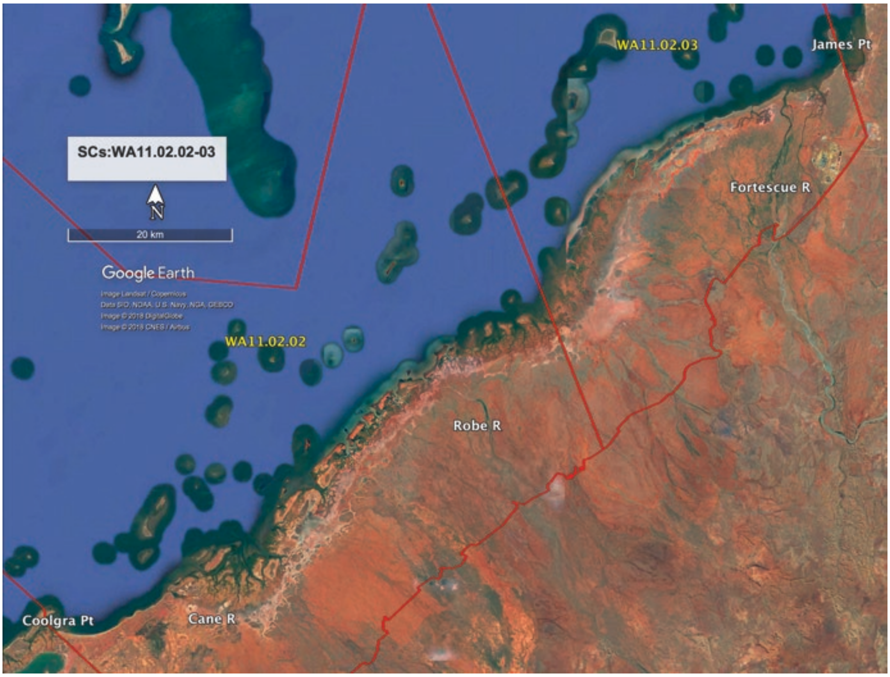

Fig. 4.4 SCs WA:11.02.02–03 Coolgra Point to James Point includes the Robe and Fortescue river deltas. (Source: Google Earth)

4.2.3.1 Rivers and Creeks

Four rivers, the larger Ashburton and Fortescue and smaller Cane and Robe (Table 3.2), flow out of the Hamersley Range across the coastal plain to episodically supply sediment and build deltas at the coast (Fig. 4.5). In addition, there are about 25 smaller streams and tidal creeks located along this section. Semeniuk (1993) mapped plan and profile sections of the Ashburton and its downdrift shore and Robe-Fortescue deltas. He found the Ashburton consists of regressive beach-foredune ridges some sitting on high tide muds, while downdrift the prograding shores are all backed by Pleistocene limestone barriers. The Robe-Fortescue have more limited Holocene sedimentation, and on the smaller Robe delta, Pleistocene limestone barriers dominate the modern shore, with Holocene beaches and sand-mud flats only occurring along parts of the Fortescue delta.

4.2.3.2 Coastal Processes

The coast is sheltered by a near continuous chain of islands and reefs that parallel the coast and extend up to 30 km offshore, together with the overall low inner shelf and nearshore gradients. These combined with the low deepwater wave energy

Fig. 4.5 (**a**) The Ashburton River mouth with its migratory barrier islands and regressive beach ridges and mangroves (WA-1665-6), (**b**) the town of Onslow sits is lee of a 9 km long regressive foredune ridge barrier WA-1669-70) and (**c**) mangrove-lined shore just south of Coolgra Point (WA-1676). (Photos: AD Short)

Table 4.4 PC:WA11.02 beach types by number and length

BS	BS	No.	%	Length (km)	%	Mean (km)	σ (km)
6	R	10	21.7	29.3	28.5	2.9	2.1
11	B + SF	8	17.4	27.2	26.4	3.4	2
12	B + TSF	23	50.0	32.5	31.6	1.4	1.5
14	B + RF	5	10.9	13.9	13.5	2.8	3.5
		46	100	102.9	100.0	–	–

[a]BS = beach states; see Table 1.2

result in low to very low waves along the coast, averaging about 0.3 m with a period of 4 s. Spring tide range increases slightly to 1.9 m at Onslow, resulting in an RTR >6 and predominately TM and TD beaches (Table 4.4).

4.2.3.3 Beaches

Beach sediments tend to be carbonate-rich, medium to coarse sand, with the majority of beaches (76%) being fronted by sand flats, tidal flats or rock flats (Table 4.4) with ten R beaches on the slightly more exposed sections. The tidal flats average 450 m in width but can extend up to 2 km.

4.2.3.4 Barriers

There are 23 barriers along this section occupying 58% of the shore. The barriers consist of regressive foredune ridge plains in the west containing up to 10 ridges and usually terminating with a splay of east trending spits, indicative of easterly sand transport. In the east the barriers are predominately barrier islands associated with the protruding Robe and Fortescue river deltas (Fig. 4.4). The barriers have a mean height of 6.4 m and range on average up to 1.36 km in width, the wider barriers associated with the regressive systems. They occupy a total area of 14,085 ha and are predominately stable (95%), with a volume of 922 M m^3, and a relatively low unit volume of 7318 m^3 m^{-1} (Table 4.3). This PC contains three SCs which are discussed below.

SC:WA11.02.01 extends from Locker Point for 66 km to Coolgra Point on Direction Island and is dominated by the large Ashburton River delta (Figs. 4.4, 4.5a). The 24 km long western side of the river mouth is a more continuous and exposed northwest-facing shore with a mix of TD and WD reflective beaches, interrupted by just two small tidal creeks, while the 10 km long eastern side of the delta extends to the new (2018) Port of Ashburton. As might be expected, this deltaic coast is dominated by beach systems, with 18 beaches occupying 62 km (63%) of the shore. The coastal gradient is steeper with no tidal flats along the central reflective section, while the backing supratidal flats narrow to 2 km. On the northern side of the river mouth is a protruding delta, with the easterly longshore transport forming a series of recurved spits trending east for 10 km to Port of Ashburton (Fig. 4.5a). The northern part of this compartment consists of a series of regressive barrier islands extending 20 km east of Onslow to Direction Island. The overall trend of sand transport is from west to east, with interruptions at each of the creek and river mouths. The beach-foredune ridge and spit systems all have an easterly bias supporting a predominately easterly transport from the Ashburton River delta and either side of Onslow. Shul et al. (2014) present a conceptual model for river supply and sediment transport for the Carnarvon-Pilbara coast. They proposed the highest rates of transport are associated with the Ashburton, with sand moving along the shore both east and west from the river mouth, with most moving east towards Entrance Point and lesser amounts continuing towards Onslow. Along the coast the transport is interrupted by tide-driven shore-normal transport through the many tidal creeks, while sand is also moving easterly on the inner shelf. Eliot and Eliot (2013) mapped changes on the Ashburton shoreline and channels as well as proposing a sediment budget for the area. Eliot and Dodson (2010) estimated sand transport rates along this compartment and found that the coast was generally prograding, owing to easterly transport of up to 105,000 m^3 $year^{-1}$ associated with the Ashburton, decreasing to the east to 5000–30,000 m^3 $year^{-1}$ nearing Onslow (Figs. 4.5b, 4.6). Sthul et al. (2014) also suggest tidal-driven transport may be moving sediment around the eastern Coolgra Point (Fig. 4.5c) and into the next compartment. This SC therefore has a positive sediment budget with major terrestrial input from the Ashburton together

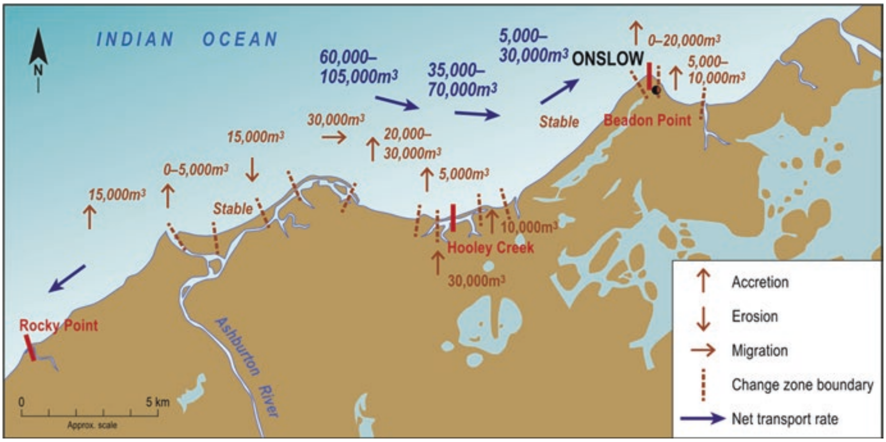

Fig. 4.6 Estimate rates of longshore transport in the Onslow region. (Source: Thom et al. 2018, based on Eliot 2013; Eliot and Eliot 2013)

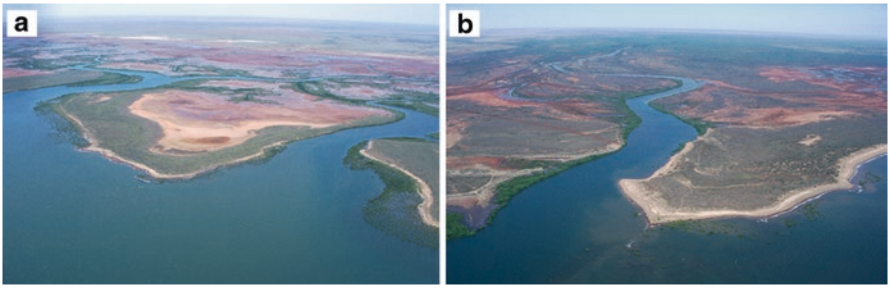

Fig. 4.7 (**a**) One of the ~12 tidal creek-distributaries that occupy the board Robe river deltaic fan, fringed by mangroves and beachrock (WA-1682) and (**b**) the Fortescue River mouth lined by a series of regressive beach ridges, foredunes and limestone barriers (WA-1685-9). (Photos: AD Short)

with carbonate supply (10%), leading to shoreline progradation and easterly sand transport and export of sand to the adjoining SC:WA11.02.02.

The northern two SCs (**WA11.02.02–11.02.03**) (Coolgra Pt-James Pt) are dominated by the small Cane and Robe rivers and larger Fortescue river deltas which fan out across the coastal plain forming two broad fan-shaped protrusions at the coast and a low gradient nearshore (Figs. 4.4 and 4.7). It is a low-energy shore sheltered by a near continuous chain of inshore islands and outer reefs, together with the very low nearshore gradients. The shoreline is composed of broad funnel-shaped mangrove-lined tidal creeks and limestone barrier islands containing narrow beaches, all backed by supratidal salt flats up to 5 km wide. Between the Robe and

Fortescue deltas is a 35 km long section entirely dominated by mangrove-lined shoreline and tidal creeks extending up to 5 km inland across the tidal flats. The Fortescue river delta is fronted by near continuous regressive barrier islands with TD beaches, separated by narrow tidal creeks. The coast is a mix of mangroves, tidal creeks and limestone barriers with 24 beaches occupying just 41 km (27%) of the coast. Sediment transport is restricted to shore-perpendicular tidal flow along the western mangrove section, with the Cane and Robe rivers essentially depositing most of their sediments across the broad outwash fan and across the coastal plain with no distinct river mouth at the shore, though no doubt during floods, sediment is deposited at the coast. Along the Fortescue delta, the sediment has contributed to the regressive barrier islands, and some is being transported east to James Point, the PC boundary. A series of elongate spits on the eastern side of James Point indicates some headland bypassing is occurring into the next PC:WA11.03.

4.2.4 Carnarvon Coast Overview

The Carnarvon subregion (PCs:WA11.01–11.02) is a low gradient coast containing some of the widest tidal flats on the Australian coast. As such all the low-lying section are already exposed to inundation by spring high tides, river flooding, tropical cyclone storm surges and occasional tsunami impacts from the north. Eliot et al. (2011) found that the entire coast is not only inherently unstable but also highly susceptible and vulnerable to present conditions as well as sea-level rise, the susceptibility decreasing to the north as gradients and tide range increase. They rate the entire coast as having moderate to high vulnerability owing to the low gradient nature of the coast, numerous tidal creeks and general instability of the beach and deltaic systems.

Rising sea level will not only physically inundate the tidal flats and migrate the shoreline inland but also initiate landward migration of the associated subtidal seagrass meadows, intertidal mangroves and supratidal flats. This migration will be most pronounced on the very low gradient eastern gulf shore, along the Ashburton, Robe and Fortescue deltaic systems, and in all inlets, bays and associated tidal flats. The northerly sediment transport is likely to increase with rising sea level deepening the nearshore and thereby lessen wave attenuation, leading to higher waves at the shore and more energy to transport sediment. This PC is not only very exposed to current threats but will be profoundly impacted by sea-level rise, together with any changes in the frequency and intensity of tropical cyclones and associated surges and flooding. Apart from the town of Onslow and Port of Ashburton, this is a largely undeveloped coast that will accommodate the above threats and changes through inundation and shoreline retreat.

4.3 Pilbara Coast

4.3.1 Introduction

The 507 km long Pilbara subregion contains two PCs (Fig. 3.1) and six SCs (Table 4.5; Fig. 4.8). It is where the ancient Pilbara bedrock reaches the coast at James Point and forms the elongate Dampier-Burrup Peninsula and Dolphin Island, together with the several large islands of the Dampier Archipelago and a number of headlands. In addition, there are numerous low Pleistocene limestone barriers and points, particularly between Cape Lambert and Beebingarra Creek. This is also where Maitland, Harding, George, Sherlock, Peawah and Yule rivers, draining the rugged Pilbara hinterland, reach the coast, with the Maitland and Harding forming regressive TD deltas. A low gradient coastal plain extends east of the Harding River to the broad fan-shaped Yule River delta and the limestone Cape Thouin, beyond which is the Turner River delta and a series of limestone barrier islands, which include Port Hedland and extend to the PC boundary at Beebingarra Creek. Semeniuk (1993) identified three major Quaternary suites along the Pilbara coast: the Pleistocene red siliciclastic sediments (alluvium, deltaic sediments and aeolian sand) that form the coastal plain, Pleistocene limestone (beachrock) that forms many of the local barriers and barrier islands and Holocene sediments contained in deltas, beaches-dunes, tidal flats and tidal embayments.

Parts of this coast have been highly developed as rail terminals and ports used to export the massive iron ore deposits located in the Pilbara hinterland (Brocx and Semeniuk 2017), together with salt farmed on the broad salt flats. Port and towns are located at Cape Preston (LPG pipeline), Dampier, Karratha, Wickham-Port Samson, Anketell (proposed near Cape Lambert), Cape Lambert, Roebourne and Port Hedland-South Hedland. The rest of the coast is dominated by large pastoral leases running cattle for export.

Table 4.5 Pilbara subregion SCs: location, beaches and length

SC[a]	Boundaries	Beach ID[b]	No. beaches	km[c]	Total km
WA11.03.01	James Pt-C Preston	1704–1708	5	4750–4770	20
WA11.03.02	C Preston-W Intercourse Is	1709–1725	17	4770–4820	50
WA11.03.03	W intercourse Is-Dolphin Is	1726–1777	52	4820–4905	85
WA11.03.04	Dolphin Is-C Lambert	1778–1831	54	4905–5015	110
WA11.04.01	C Lambert-C Cossigny	1832–1867	36	5015–5145	130
WA11.04.02	C Cossigny-Beebingarra Ck	1867–1908	41	5145–5258	112
			205		507

[a]NCCARF compartment number
[b]ABSAMP WA beach number
[c]Distance from SA/WA border

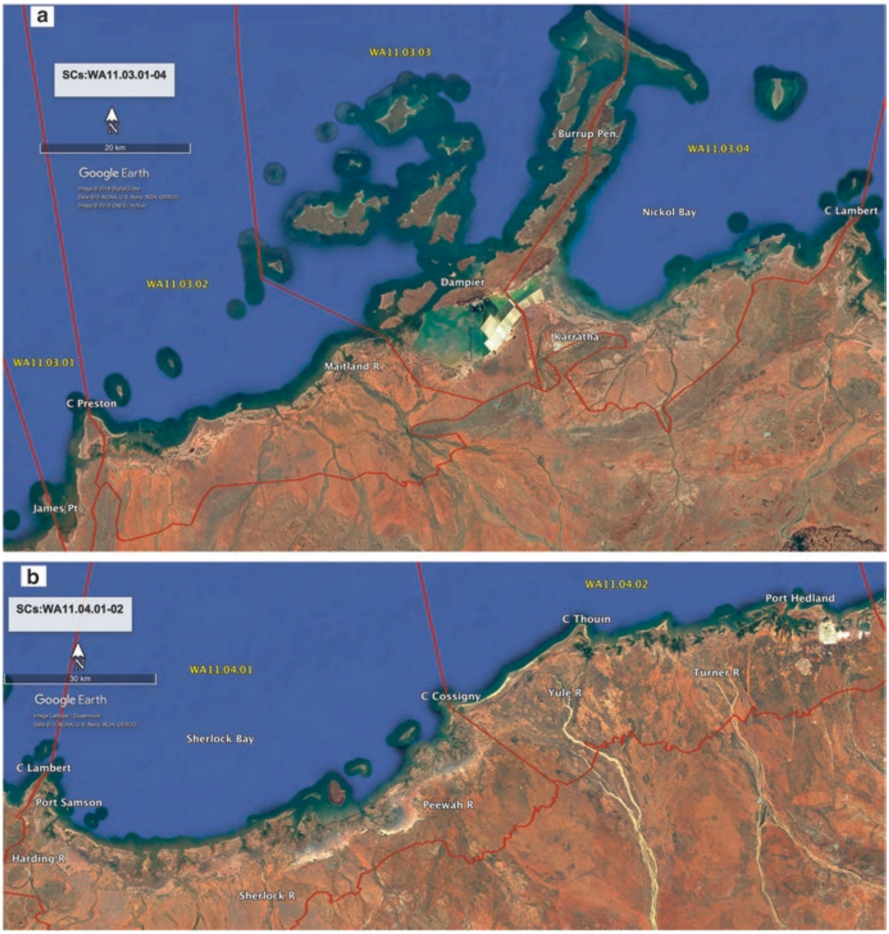

Fig. 4.8 The Pilbara subregions contains SCs WA11.03.01–04 (**a**) and WA11.04.01–02 (**b**): The region includes the prominent Dampier-Burrup Peninsula and islands and Cape Lambert and a series of rivers and deltas that have developed the coastal plain extending west to Cape Preston and east to Port Hedland. (Source: Google Earth)

4.3.1.1 Rivers and Creeks

Six rivers, the Maitland, Harding, Sherlock, Peawah, Yule and Turner (Table 3.2), flow out of the Pilbara hinterland and episodically deliver sediment to the coast. The larger Yule and Turner rivers have built fan-shaped deltas (Fig. 4.8).

4.3.1.2 Coastal Processes

Waves remain low to very low along the Pilbara coast, with much sheltering from the numerous larger bedrock islands, peninsulas and reefs in the west, combined with the low gradient shelf and inshore. Tides increase substantially from 1.9 m at Onslow to 3.7 m at Dampier, 5 m at Depuch Island and 6.8 m at Port Hedland (Table 2.3).

4.3.1.3 Beaches

Beach sands are typically moderately sorted, medium to coarse (mean = 0.56 mm), indicative of low energy beaches and carbonate rich (51%) (Table 4.6). The sand is also highly variable along the coast with considerable variation in grain size and percent carbonate (Fig. 4.9), indicating local sources are likely to dominate and

Table 4.6 Sediment characteristics on Pilbara subregion beaches (PCs:WA11.03–04)

n = 21	Carbonate %	Mean size (μm)	Sorting
Mean	50.8	0.56	0.7
σ	29.1	0.35	0.3
Max	94.9	1.5	1.2
Min	7.1	0.2	0.1

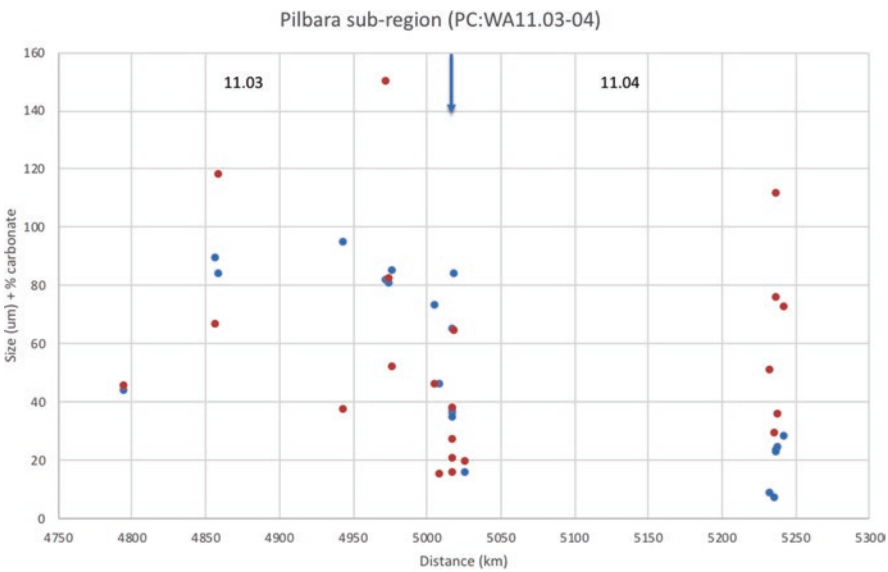

Fig. 4.9 Pilbara subregion beach sand size (μm, blue) and percent carbonate (red). Distance is kilometres from SA-WA border. PC boundary indicated by arrow; see Table 4.5 for SC boundaries

Table 4.7 Pilbara PCs (a) WA11.03 and (b) WA11.04 beach types and states by number and length (total and mean)

a. WA11.03							
BS	BS	No.	%	Length (km)	%	Mean (km)	%
6	R	4	3.1	0.7	1.16	0.18	0.1
7	R + LTT	43	33.6	15.2	25.29	0.35	0.3
11	B + SF	47	36.7	15.3	25.4	0.32	0.3
12	B + TSF	20	15.6	13.3	22.1	0.67	1
14	R + RF	14	10.9	15.65	26.04	1.12	1.9
		128	100	60.1	100	–	–

b. WA11.04							
BS	BS	No.	%	Length (km)	%	Mean (km)	%
6	R	11	14.3	8.7	9.1	0.8	0.8
7	R + LTR	5	6.5	18.1	18.9	3.6	4.9
10	B + RSR	3	3.9	3.0	3.1	1.0	1.1
11	B + SF	10	13.0	12.1	12.6	1.2	1.0
12	B + TSF	34	44.2	42.4	44.2	1.3	1.2
14	R + RF	12	15.6	7.5	7.8	0.6	0.8
15	R + CF	2	2.6	4.2	4.4	2.1	–
		77	100.0	95.98	100	–	–

longshore transport is both limited and restricted. The low waves and higher tides result in the RTR ranging from 8 to 50, with most beaches having an RTR > 12 and well into the TD domain. The 205 beaches range from 4 R cobble-boulder beaches to 48 TM R + LTT on the more exposed beaches, with the majority TD (114), together with 26 beaches fronted by rock flats (Table 4.7). However, these beaches occupy just 31% of the shore, the remainder dominated by mangrove-lined tidal flats, especially in the deeper bays together with sections of bedrock and barrier limestone. While this section has a persistent northeast trend, it is highly variable in detail owing to the influence of the bedrock, limestone, tidal creeks and the two major deltas, with the beaches averaging only 0.76 km in length and the longest 5.3 km in length.

4.3.1.4 Barriers

Holocene barriers along this subregion are a mix of barrier islands, many with Pleistocene limestone cores, usually bordered by tidal inlets and recurved spits, with either solitary to a few foredune ridges. The 48 barriers occupy 181 km of the region (36%). They range in mean width between 0.15 and 1.11 km with a mean height of 7.2 m, a total area of 14,125 ha and volume of 1066 M m^3, which represents an accumulation of 5888 m^3 m^{-1} of barrier (Table 4.8). They are largely stable with a few unstable areas of minor dune transgression and overwash totalling 900 ha (6.5%).

Table 4.8 Pilbara PC and regional barrier dimensions

WA11.03 &11.04	11.03	11.04	Pilbara
No.	22	26	48
Total length (km)	55.5	125.6	181
Mean min width	150	400	150
Mean max width	385	1110	1110
Mean height (m)	6.5	7.2	7
Area (ha)	3605	10,520	14,125
Unstable (ha)	25	875	900
Total volume (M m^3)	278	788	1066
Unit volume (m^3 m^{-1})	5008	6272	5888

4.3.2 PC:WA11.03 James Point to Cape Lambert

This PC extends for 265 km between James Point and Cape Lambert and contains four SCs (Table 4.5): the short west-facing shore between James Point and Cape Preston (WA:11.03.01); the western low energy section between Cape Preston and West Intercourse Island, with the Yanyare and Maitland river deltas occupying much of the shore (WA:11.03.02); the rocky bedrock Burrup Peninsula and the surrounding bedrock islands of the Dampier Archipelago (WA:11.03.03); and the eastern low energy muddy Nichol Bay bordered in the east by the basaltic Cape Lambert (WA:11.03.04) (Fig. 4.8a). As mentioned above wave energy is low to very low, tides range between 4 and 5 m and the beach sand is coarse carbonate-rich and highly variable longshore. The 128 beaches along this coast occupy just 22% of the shore and are a mix of TM R + LTT (25%), TD (47%) and 26% fronted by rock flats (Table 4.7a). The remainder of the coast is predominately mangrove-lined tidal sand flats in the delta-bay areas, mud flats in Nickol Bay and the bedrock on the peninsula and islands. The four SCs are discussed below.

SC:WA11.03.01 (James Point to Cape Preston) is a low energy 20 km long west-facing shore located between the ancient Proterozoic metasedimentary rocks of 30 m high James Point and 65 m high Cape Preston (Fig. 4.8a), the first high ground since Exmouth Peninsula 230 km to the southwest. Sediment is slowly moving around the protruding James Point to deposit a 2 km long terminal barrier spit on its eastern side, while at the more prominent and exposed Cape Preston, sediment is moving down both its western and eastern flanks. On its western side, the sand has built a 6 km long, up to 1.3 km wide regressive barrier containing more than 20 ridges, while on the eastern side, it has deposited a curving 7 km long barrier spits. This SC appears to be a sink receiving sand from the adjoining SCs. Based on the size of the eastern and western barriers, sand has moved into this SC from the west at a rate on the order of 300 m^3 $year^{-1}$ and down the more exposed Cape Preston at 2500 m^3 $year^{-1}$.

SC:WA11.03.01 (Cape Preston to West Intercourse Island) trends northeast from Cape Preston for 50 km to a mangrove-lined bay on the southern side of West Intercourse Island (Fig. 4.8a). The western half contains a mixture of low bedrock points and limestone barriers and steep low energy beaches fronted by tidal sand flats (B + TSF) where sediment is available and rock flats (R + RF) along the bedrock and limestone sections. The western 28 km is occupied by the Yanyare River, which flows into mangrove-lined Regnard Bay, while in the east, the Maitland River has built a protruding delta along 15 km of coast which is a mix of several tidal-dominated distributaries and ten short limestone barrier islands, with the whole system regressing over 3 km seaward at the main mouth. Semeniuk (1993) mapped the Maitland River delta and found it has an inner Pleistocene delta up to 10 km wide rimmed by low stranded limestone Pleistocene barriers. These in turn are fronted by 3 km wide mud flats containing an inner chenier dating 4.3 ka and mid-flat cheniers at 2.4 ka, with younger ridges forming the modern beach (Fig. 4.10) which are fronted by 1 km wide tidal sand flats. This SC receives sediment from the Maitland

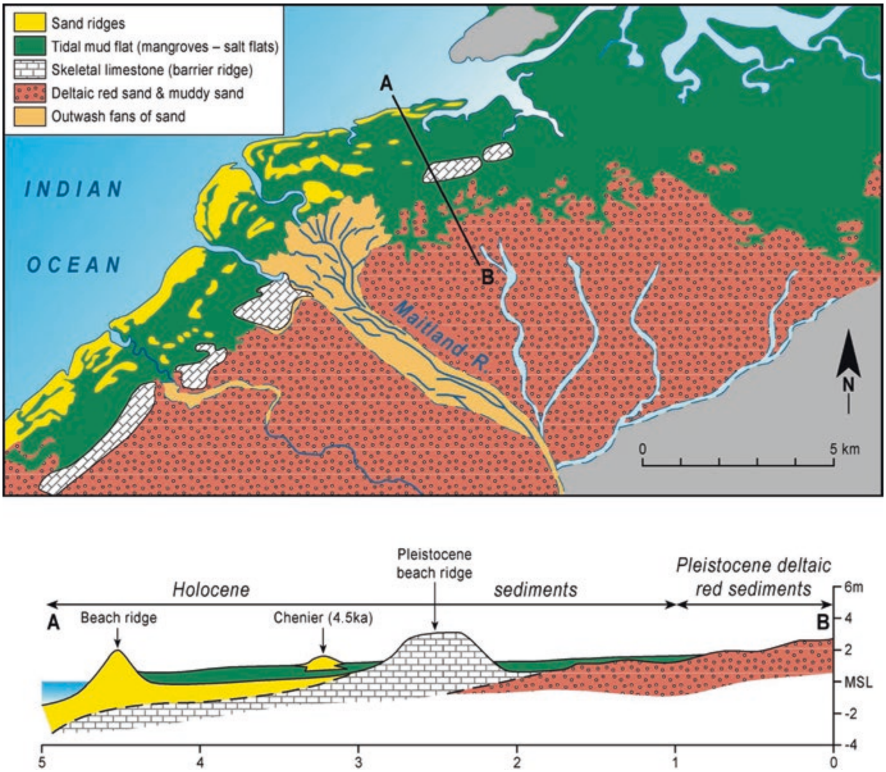

Fig. 4.10 The protruding Maitland River delta is typical of several deltas that occupy the Pilbara coastal plain consisting of an inner deltaic plain, inherited Pleistocene limestone ridges, wide mud flats and outer Holocene beaches, barriers and spits. (Source: Short and Woodroffe 2009, based on Semeniuk 1993)

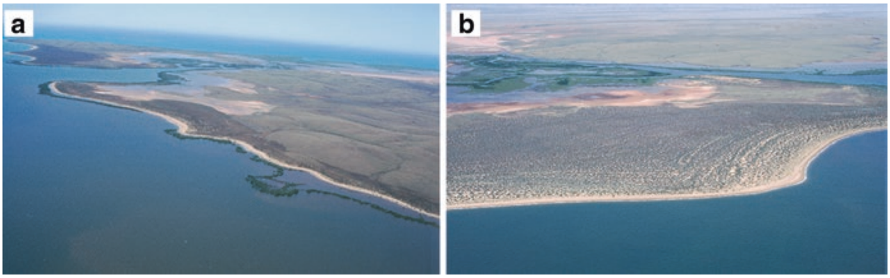

Fig. 4.11 (**a**) Low energy partly mangrove-fringed shoreline looking towards Cape Preston (WA-1705) and (**b**) up to 20 multiple beach-foredune ridges on the eastern side of Cape Preston (WA-1706-7). (Photos: AD Short)

River; however it appears to be maintained within the SC leading to the progradation of the delta but little transport to the east into the very sheltered area in lee of West Intercourse Island. There is evidence of some easterly transport in the 7 km long spit extending east of the base of Cape Preston (Fig. 4.11b) and the 3 km long Pleistocene beachrock spit in Regnard Bay, together with the minor transport extending along the eastern side of the Maitland River delta. The SCs 21 beaches occupy 38% of this section, the remainder occupied by some limestone barriers and wide mangrove-lined tidal flats (Fig. 4.11a). Many of the beaches are located on regressive barrier islands separated by small tidal creeks and backed by the supratidal salt flats.

SC:WA11.03.03 (Burrup Peninsula) contains the bedrock Burrup Peninsula and its surrounding islands. The rocky peninsula extends northwards for 50 km with an average width of 5 km. This is a bedrock-dominated coast with a predominately bedrock shore (83%) containing a series of 52 small pocket beaches averaging just 280 m in length. The southern section between West Intercourse Island and Phillip Point is sheltered by the Dampier Archipelago and the Intercourse islands which occupy much of the nearshore and substantially lower wave energy at the shore. Dampier Port and the LPG facility are located along this section, with Dampier township fronted by a series of narrow R beaches (Fig. 4.12a). The 29 beaches along the southern section are predominately TD B + SF and some TSF. North of Holden Point, and extending along the peninsula and the southern part of Dolphin Island, are 23 more exposed TM pocket beaches (R + LTT), wedged in between the dark dolerite bedrock (Fig. 4.12b). Semeniuk (1993) provides three plan views and transects across both tidal flat and embayed systems around the peninsula. All overlay or abut Pleistocene limestone, some backing onto Precambrian bedrock. The tidal flats consisted of basal shelly sand dating 3.3 ka overlain by muddy (mangroves) sand (1.4 ka) and then modern muds, while the beaches consist of shelly sand sitting atop muddy sand, i.e. cheniers. This appears to be a sheltered and closed SC containing a number of TCs. Stul et al. (2014) found no evidence of longshore transport on either side of the Peninsula.

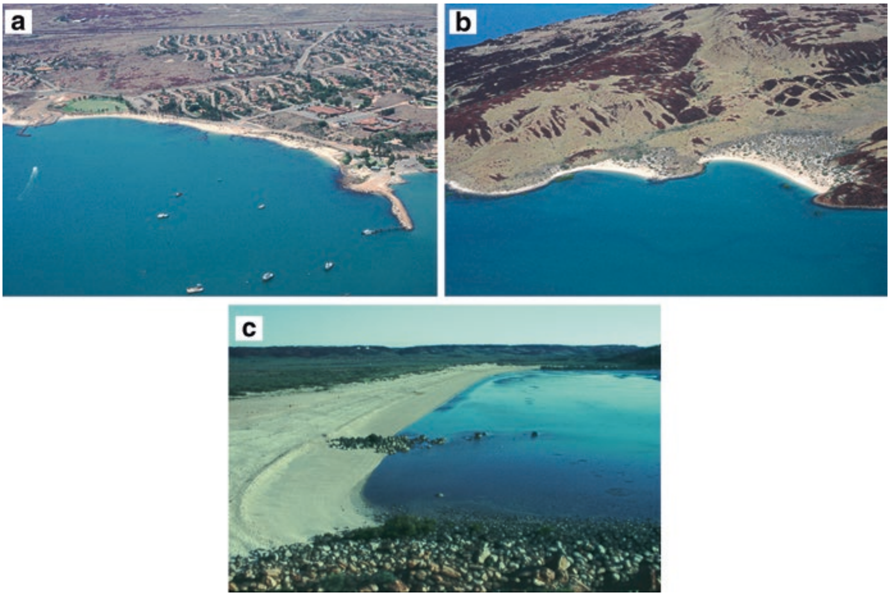

Fig. 4.12 (**a**) The township of Dampier and its sheltered reflective beaches (WA-1740-2), (**b**) two small beaches backed by vegetated sand dunes on the Burrup Peninsula (WA-1784-5) and (**c**) the steep high tide beach and exposed intertidal mud flats at Hearson Cove (WA-1796). (Photos: AD Short)

SC:WA11.03.04 (Dolphin Island to Cape Lambert) contains the 35 km wide U-shaped north-northeast facing Nickol Bay, with the Burrup Peninsula-Dolphin Island forming its western arm and Cape Lambert is eastern arm and the town of Karratha at the base of the bay. It has 110 km of shoreline commencing with the western bedrock peninsula shore which contains 19 small embayed beaches, all predominately TD B + SF with the popular Hearson Cove (WA 1796) fronted by 700 m wide mud flats (Fig. 4.12c). Just south of the cove is the start of 15 km wide, mangrove-lined mud flats of Nickol Bay with the coast extending for 56 km to Cape Lambert. The Nickol River has deposited a small delta on the inner supratidal flats and is connected to the bay by a network of tidal creeks.

This is a very low energy shore partly sheltered by the Burrup Peninsula and Dolphin and Legendre Islands. The southern shore trends east-northeast to Cape Lambert with considerable longshore variation. The first 25 km are lined by wide mangrove-fringed mud flats up to 1.5 km wide, apart from one beach (Karratha Beach (WA1797), Fig. 4.13a), with the township of Karratha on the backing slopes. Cleaverville, the popular camping area, marks the beginning of an 8 km long series of curving beachrock-controlled beaches all fronted by intertidal rock flats. These terminate at mangrove-lined Port Robinson, which is in part sheltered by Dixon Island, a 6 km long bedrock island contains six small pockets of sand. The mainland

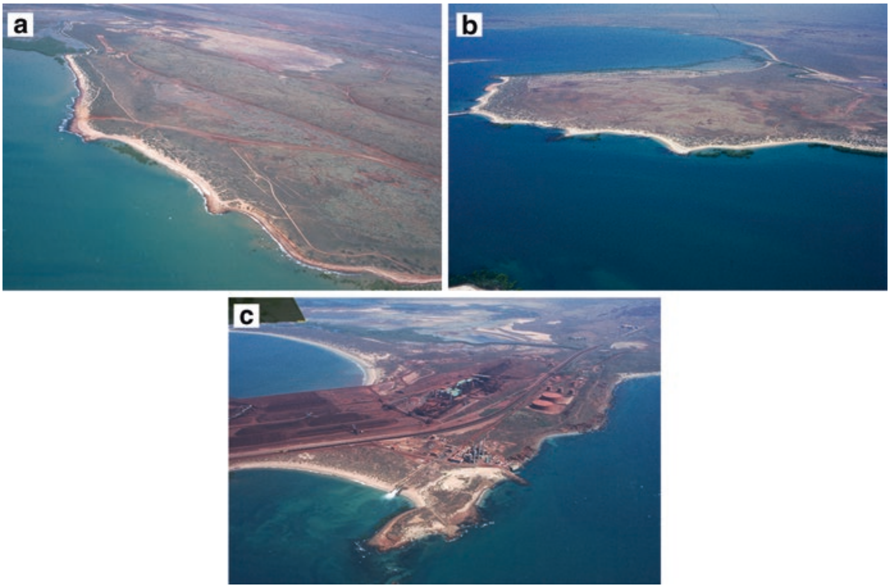

Fig. 4.13 (**a**) The low energy partly mangrove-lined beach just east of Karratha (WA-1797), (**b**) a series of crenulate beaches at Bougner Entrance (WA-1812-5) site of the proposed Anketell development and (**c**) an embayed beach at the tip of Cape Lambert (WA-1827-30) taken before the western jetty was constructed. (Photos: AD Short)

beaches resume at Bougner Entrance with a mix of small TD and TM beaches (Fig. 4.13b). The remaining beaches line the western side of Cape Lambert where there are seven near continuous curving beaches which are part of small sediment cells with sand moving down the 7 km long western side of the cape to Rocky Ridge and forming a series of south-trending recurved spits. Based on the size of the spits, they have received sand moving down the cape at a rate on the order of 2000 m^3 $year^{-1}$. The 54 beaches average 360 m in length and occupy just 17% of the shore, the remaining shore a mix of mangroves, mud flats and beachrock (limestone). Cape Lambert is the site of a major iron ore loading facility and port (Fig. 4.13c) and has loading jetties extending 2 and 3 km seaward either side of the small beach at its tip (WA 1830). The proposed town and port of Anketell is located on a low bedrock peninsula adjacent to Bougner Entrance, 10 km southwest of Cape Lambert. Stul et al. (2014) divided this SC into nine TCs and found no evidence of transport between the TCs.

4.3.2.1 PC Summary

PC 11.03 is a reasonably diverse compartment in orientation, structure and wave energy. It commences at the westernmost bedrock of the Pilbara region (James Point), contains the very prominent Dampier-Burrup-Dolphin bedrock conglomeration extending 50 km seaward, with Regnard Bay and the Maitland delta to the west and Nickol Bay and the small Nickol River to the east, terminating at the bedrock Cape Lambert. While the rivers are delivering terrestrial sediment to their deltas, there is a very limited longshore transport with most sand accumulating in the SCs and TCs. The predominately carbonate beach sand also indicates considerable local biogenic production.

4.3.3 PC:WA11.04 Cape Lambert to Beebingarra Creek

Cape Lambert lies at the tip of a 60 m high peninsula that protrudes northwards for 10 km. It marks the western boundary of an extensive coastal plain that extends east for more than 240 km to Port Hedland and 10 km beyond to Beebingarra Creek, the PC boundary. This is an increasingly TD shore with spring tide range increasing from 4.4 m at Dampier to 6.8 mm at Port Hedland. The compartment is divided into two SCs located either side of the protruding beachrock Cape Cossigny (Table 4.5; Fig. 4.8b).

SC:WA11.04.01 (Cape Lambert to Cape Cossigny) trends east of Cape Lambert as an arcuate shoreline that curves gently to the south and then east to trend for the most part east-northeast to Cape Cossigny, with 130 km of shoreline in between (Fig. 4.8). The broad 'bay' is part of a depression into which the Harding, Little Sherlock, Sherlock, Balla Balla, Peewah and larger Yule rivers flow, each fanning out across the low coastal plain to deposit their sediments on the supratidal flats in lee of a 2 km wide regressive series of both limestone and active barrier islands. Beginning at the mouth of the Sherlock River are a series of linear limestone islands and reefs that extend northeast past the 160 m high bedrock Depuch Island for 45 km to Reef Point-Cape Cossigny. The sheltered shoreline to their lee consists entirely of mangrove-lined tidal flats and creeks and kilometre-wide supratidal flats. The barriers are separated by TD tidal creeks, with the barrier beaches recurving into the creek mouths (Fig. 4.14a, b and c). The beach barriers are fronted by 1 km wide tidal sand flats and in places mangroves. Forty-one predominately TD beaches are located primarily on the barrier islands and occupy 62 km (38%) of the shore the remainder mangroves and open water.

SC:WA11.04.02 (Cape Cossigny to Port Hedland-Beebingarra Creek) extends to the east of Cape Cossigny for 112 km to Port Hedland-Beebingarra Creek (Table 4.5; Fig. 4.8b). This SC is dominated by the Yule and Turner river deltas and a series of linear dune-capped limestone barrier islands, including the Port Hedland barrier, separated and backed by extensive tidal creeks and mangrove-lined shores. The SC begins at Cape Cossigny which marks the western boundary of the Yule River delta, where one of its distributaries has built a 3 km wide protruding series of beach ridges (Fig. 4.14c) to form the cape. The delta shore extends northeast for about 40 km to the lee of the 14 m high limestone Cape Thouin, with one of its distribu-

Fig. 4.14 (**a**) Mount Beach one of the higher energy beaches on the Pilbara coast with recurved spits curving into the backing mangrove-lined bay (WA-1840-3), (**b**) multiple recurved spits near Butcher Inlet (WA-1845-6) and (**c**) recurved spit at Cape Cossigny (WA-1869). (Photos: AD Short)

taries exiting in lee of the cape. It contains a lower deltaic plain consisting of a 4 km wide series of beach-foredune ridges and flats, with the outer beaches capped by active dunes. The delta is more exposed to wave activity which has resulted in the minor easterly dune transgression extending up to 0.5 km inland, together with pronounced easterly longshore transport at Cape Thouin. The cape consists of a 10 m long spit, with a 4 km long series of migrating recurved spits on its eastern side (Fig. 4.15a). Based on the size of the cape, it has received sand from the west at a rate on the order of 10,000 m^3 $year^{-1}$. To the west are a series of about 15 TD funnel-shaped mangrove-lined tidal creeks, separated by a series of regressive barrier islands, including about ten limestone barriers and linear reefs, with recurved spits forming at the eastern end of the major islands. Within the wide tidal creeks are also located mangrove-lined barriers fronted by tidal flats up to 3 km wide.

Port Hedland is part of a series of limestone barrier islands, the port located in a larger tidal creek (Mangrove Creek) between Finucane and Port Hedland islands. Eliot et al. (2013) suggest that the reason why Mangrove Creek proved a suitable port was the lack of river and longshore transport to the Hedland coast, with the Yule located 45 km to the west and the closer Turner River delta infilling the tidal basin and yet to reach the open shoreline. Semeniuk (1996) conducted two transects across the Port Hedland barriers and found the central transect containing three regressive limestone Pleistocene barriers, with shell embedded at the base of the

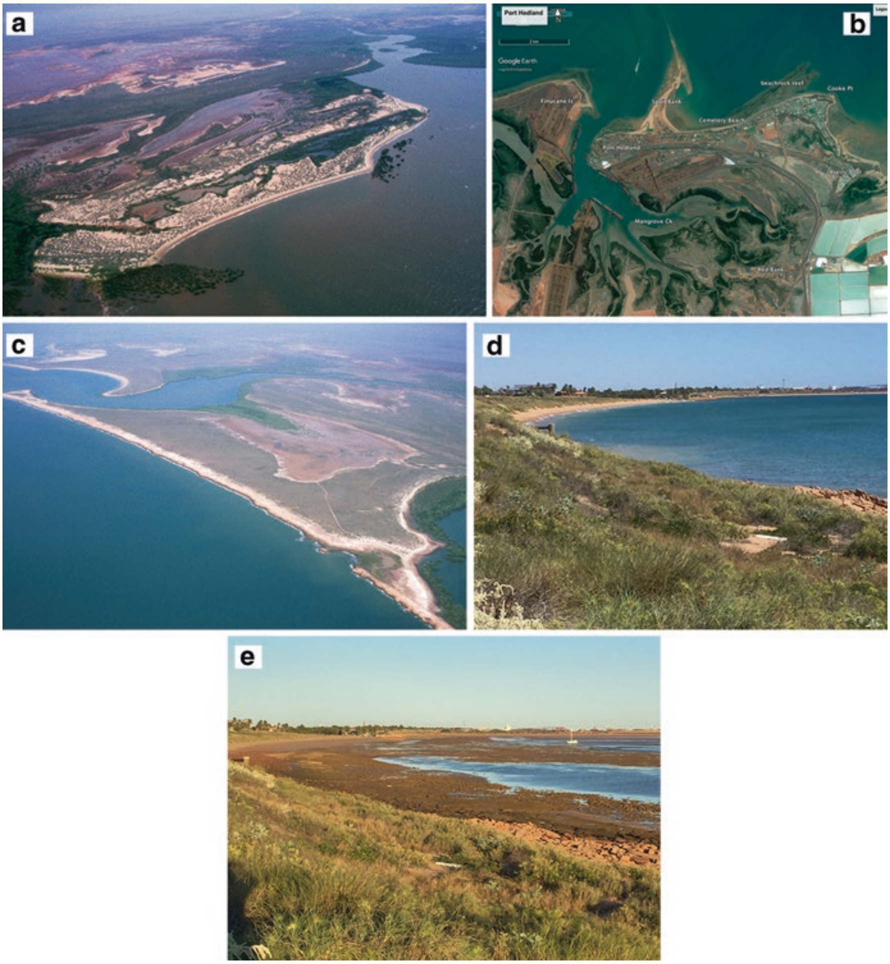

Fig. 4.15 (**a**) a series of regressive recurved spits just east of Cape Thouin (WA-1877-9) (**b**) Google image of Port Hedland showing Mangrove Creek, the town and Spoil Bank and salt ponds (Source: Google Earth), (**c**) beachrock barrier island 10 km east of Port Hedland (WA-1909) and (**d** and **e**) Cemetery Beach at high and low tide (WA-1900). (Photos: AD Short)

modern shoreline dating 6.3 ka. The modern Holocene barrier at Pretty Pool overlays a Pleistocene core and has a basal date of 1.8 ka, suggesting it may have formed after sufficient sand moved around Cooke Point.

The naturally deep Mangrove Creek was developed as a small port beginning in the 1860s. Since the 1960s it has been dredged and developed into the world's largest iron ore export port, with the town of Port Hedland occupying the 7 km long limestone core outer barrier and inner spits that recurve to the east, while salt ponds occupy part of the 5 km supratidal flats to the north (Fig. 4.15b). The main Cemetery Beach (WA 1900) at Hedland is a steep R high tide beach, fronted by coral growing on a 0.5 km wide beachrock reef (Fig. 4.15d and e) covered by a veneer of live coral. The newer town of South Hedland is located 9 km inland out of reach of storm surges. The creeks and limestone core barriers continue east of Port Hedland to Petermarer Creek (Fig. 4.15c).

Following the dredging of Mangrove Creek, Paul and Lustig (1975) found that sediment was transported from the tidal creeks into the dredged navigation channel, with only a small contribution from the Outer Harbour. Dredge spoil from the Port Hedland navigation channel was deposited to build the 2 km long spoil bank (Fig. 4.15b). Since it was constructed between 1965 and 1970, the northern tip of the bank has been slowly eroding with sand moving eastwards and shorewards as a shoreward-curving elongate sand spit. Eliot (2014) estimates that on the order of 100,000 m^3 $year^{-1}$ it is being mobilised on the bank and that the spit will eventually reach Cemetery Beach. However, the sand has not yet reached the old shoreline, and as a result of the interruption in longshore transport (on the order of a few 10,000's m^3 $year^{-1}$), the downdrift Cemetery, Cook Point and Pretty Pool beaches have been experiencing ongoing recession owing the deficit in sand supply. Eliot et al. (2013) document the range of recent shoreline changes in the Hedland area some of which may be due to the interruption is sediment supply, other to the construction of roads, salt ponds and levees. Until such time as the spit reaches the beach to naturally supply sand, or beach sand nourishment is implemented, Cemetery Beach is likely to continue to erode. In the meantime Goode St, at Cook Point, is listed as one of the two erosion 'hot spots' in the Pilbara region (DOT 2016).

Eliot (2014) also used Lidar images to identify the following features extending offshore and to the east of Port Hedland towards the De Grey River delta:

- Offshore rock ridges, likely to mark previous submerged shorelines.
- Massive underwater sandbars connected to the De Grey River delta.
- A broad, gently graded shelf with a sand and gravel layer overlying a rocky bed.
- A submerged nearshore rock platform with tidal sandbars along its edge.
- Beach barriers consisting of small coastal beachrock ridge (ramp or cliff) fronted by intertidal rock platforms and low sandy beaches and capped by rock or sand deposits, including dunes.

4.3.4 Pilbara Coast Overview

The coast of Pilbara subregion contains a mix of landform types ranging from steep rugged rocky shore of the Burrup Peninsula to the very low gradient tidal mud flats. As a consequence, its susceptibility, instability and vulnerability range from low on the steep bedrock shores to moderate on the calcarenite (limestone) barriers to high on the low gradient intertidal flats of the Maitland River delta, Nickol Bay, Sherlock Bay and Yule River delta (Table 4.9; Eliot et al. 2011). The existing threats are related to tropical cyclone storm surges and river flooding, extreme tides and occasional tsunami, all leading to inundation of the low gradient shores, all of which will

Table 4.9 Vulnerability rating for Pilbara subregion SCs

SC	Boundaries[a]	Vulnerability[b]
WA11.03.01-02	James Pt-Pelican Pt	M
WA11.03.02	Pelican Pt-W Intercourse Is	H
WA11.03.03–04	W intercourse Is-Cinders Rd	L
WA11.03.04	Cinders Rd-Cleaverville Ck	H
WA11.03.04	Cleaverville Ck-Cape Lambert	M
WA11.04.01	Cape Lambert-Cape Cossigny	H
WA11.04.02	Cape Cossigny-Cape Thouin	M
WA11.04.02	Cape Thouin-W Turner R	H
WA11.04.02	Downes Is-Beebingarra Ck	M

[a]some boundaries are based on TCs located within the SCs
[b]L, low; M, moderate; H, high
Source: Eliot et al. 2011

be exacerbated by sea-level rise. In addition, the generally north to east longshore sediment transport is likely to increase in association with the rising sea level and higher breaker wave energy. The result will be considerable instability of all low-lying shores and tidal flats, including landward migration of tide-related ecosystems, increased overwashing and recession of the beach barrier islands, exposing more limestone shores, and increased sediment transport both longshore and into the inlets and deepening bays. The net result on the open coast will be recession of the Holocene beaches, greater exposure of the limestone barriers with sediment transported both longshore and into the backing tidal creeks and flats. The towns of Dampier, Karratha, Cape Lambert and Port Hedland are all located on higher ground presently above storm surge and flood levels and have low to moderate vulnerability ratings. However, their surrounding low-lying areas will become increasing exposed to these threats.

4.4 Canning Coast (PCs:WA12.01–04)

4.4.1 Introduction

The Canning Basin subregion is defined geologically by the coastal extent of the basin, which occupies 415,000 km^2 of the northwest and extends more than 1000 km inland (Fig. 2.1). The basin containing up to 7000 m of Palaeozoic sediments deposited between 400 and 0 Ma. The sediments are a mix of fluvial, coastal and shallow marine deposits and include the Tertiary limestone (beachrock) that dominates much of the modern coast. It is generally low lying and dominated in the interior by the Great Sandy and Gibson deserts and their longitudinal desert dunes. At the coast it extends between the low beachrock Cape Thouin in the south and Point Usborne 650 km to the northeast, the first bedrock of the Kimberley region. The coastline is

1475 km long giving a crenulation ratio of 2.3. From the south it includes the widening coastal plain that extends east of Port Hedland and then merges with the long low Eighty Mile Beach that curves for 222 km north from Cape Keraudren to Cape Jaubert. There are several low (10–20 m) bedrock headlands composed of tertiary sandstones, siltstones and shales located around Cape Keraudren and between Cape Jaubert and Cape Villaret. Next is the low, wide tidal flats of Roebuck Bay and then the large low (<20 m) Dampier Peninsula extending for over 200 km northwards to Swan Island, which marks the entrance to the large mega-tidal and mud-rich King Sound. The U-shaped sound has 530 km of shoreline that terminates near Point Usborne, its northeastern tip and the beginning of the Kimberley division (Fig. 3.1). The sound's major river, the Fitzroy, enters the bottom of the sound. There is considerable beachrock throughout the region forming headlands, linear reefs, (limestone) barrier islands and integrated with many of the beaches. The subregion contains four PCs shown in Fig. 3.1.

The most comprehensive study the Canning coast was undertaken by Semeniuk (2008) who investigated the sedimentation, stratigraphy and biostratigraphy at 29 sites spread along the coast between Cape Keraudren and Beagle Bay. He identified four coastal types listed below from the most exposed to most protected:

- Rocky shore areas where Mesozoic to Tertiary bedrock and semi-indurated desert sand dunes are exposed.
- Rocky shore areas of Quaternary limestone.
- Sand-dominated flats and beaches/dunes that occur along the open coasts.
- Mud-dominated environments that occur in the various embayments, lagoons and bays.

Semeniuk recognised five distinct tracts or coastal sections, namely, from south to north: Pardoo Creek to Shoonta Hill, Eighty Mile Beach-Shoonta Hill to Desault Bay, Desault Bay to Thangoo, Roebuck Bay coast and the west coast of Dampier Peninsula. Based on field investigations, he proposed and described in detail 12 new Holocene stratigraphic units for the Canning coast followed by a model of the evolution of coastal deposits along the coast. He found the coast was flooded ~7.5 ka to an elevation ~2 m, producing an indented and jagged coastline, including exposing longitudinal desert dunes along the shore. Between 7.5 and 5 ka barriers developed on and between headlands and bays, while mud sedimentation filled protected embayments. Maximum coastal progradation occurred ~3–2 ka as sea level dropped to its present level by 2 ka, with barriers prograding up to several kilometre seawards and embayments filling with sand, as well as developing recurved entrance spits. The final stage since 2 ka has seen sea level at its present level and evidence of 'moderate' to 'marked' barrier retreat, the latter along parts of Eighty Mile Beach, while in the embayments entrance barriers have been lithified to limestone and carbonate mud has accumulated in the bays.

Eliot et al. (2011) mapped the regions sediment compartments at the PC, SC and TC level, together with the coastal processes and coastal landforms. Based on this information, Eliot et al. (2013) assessed each compartment susceptibility to change, shoreline instability and combined these to determine the compartment vulnerability to change. Some of their results are presented at the end of this chapter; however, for a detailed assessment of each compartment, the reader is referred to these comprehensive publications.

4.4.1.1 Beaches

The Canning Basin has 1475 km of shoreline between Beebingarra Creek and Point Usborne and contains 332 beaches, which average 2.3 km in length and occupy 780 km (50%) of the coast (Table 4.10), the remainder occupied by mangrove-lined mud flats, particularly in Roebuck Bay and King Sound, and sections of sandstone, red pindan and beachrock barriers, flats and reefs. Eighty Mile Beach extends discontinuously for 222 km making its one of the three longest beaches in Australia.

The Canning coast has a wide mix of beach types. In general, it has a more exposed higher energy west coast and a more sheltered east coast including most of King Sound, with mangroves and wide mud flats lining the entire southern and eastern shore of the sound. On the exposed beaches, H_b averages 0.3 m (σ = 0.2 m) with a T = 5 s (σ = 1.4 s). Tides increase from 6.8 m at Port Hedland to 9.4 m at Broome and 11.2 m at Derby, the highest in Australia. The mega-tides and low waves result in a mean RTR between 20 and 40 producing predominately TM (47%) and TD (41%) beaches with only 13 of the beaches WD R. Compared to the Carnarvon and Pilbara regions, the beaches are slightly higher energy with 45% UD (dominated by Eighty Mile Beach), 20% B + RSF and only 20% B + TSF and TMF (Table 4.10).

Beach sediment along the Canning coast is typical of the northwest division consisting of a mix of moderately well to moderately sorted, medium to coarse terrigenous and carbonate sands (Table 4.11). Also, like the other Carnarvon and Pilbara coasts, there is considerable longshore variation in sediment texture as illustrated in Fig. 4.16. Carbonate ranges from 0.5 to 99%, sand from very fine to very coarse and sorting from very well to poor. This variation both within and between

Table 4.10 Canning subregion (PC:WA12) beach types and states by number and length (mean and total)

BS	BS	no.	%	Mean (km)	σ (km)	Length (km)	%
6	R	13	3.9	0.95	0.85	12.4	1.6
7	R + LTT	13	3.9	1.5	1.6	19.7	2.5
9	UD	62	18.7	5.6	10	350.1	44.6
10	B + SR	11	3.3	0.6	0.6	6	0.8
11	B + SF	74	22.3	2.14	2.8	158.1	20.1
12	B + TSF	77	23.2	1.8	2.5	139.6	17.8
13	B + TMF	8	2.4	2	2	15.6	2.0
14	R + RF	57	17.2	1.3	1.9	76.4	9.7
15	R + CF	17	5.1	0.5	0.7	8	1.0
		332	100	2.3	5.1	780	100

Table 4.11 Beach sand characteristics of sections of the Canning Basin subregion

	PH-De Grey	Eighty Mile	N. Roebuck Bay	Dampier (E)	Dampier (W)	Canning subregion
n	7	10	10	20	12	59
Mean size (mm)	0.62	0.27	0.35	0.3	0.6	0.36
σ (mm)	0.28	0.27	0.27	0.1	0.34	0.27
Sorting	0.81	0.2	0.51	0.6	0.8	0.65
σ	0.23	0.2	0.2	0.3	0.34	0.28
Carbonate %	27	83	11	38	77	45.7
σ (%)	22	12	12	27	17	31.5

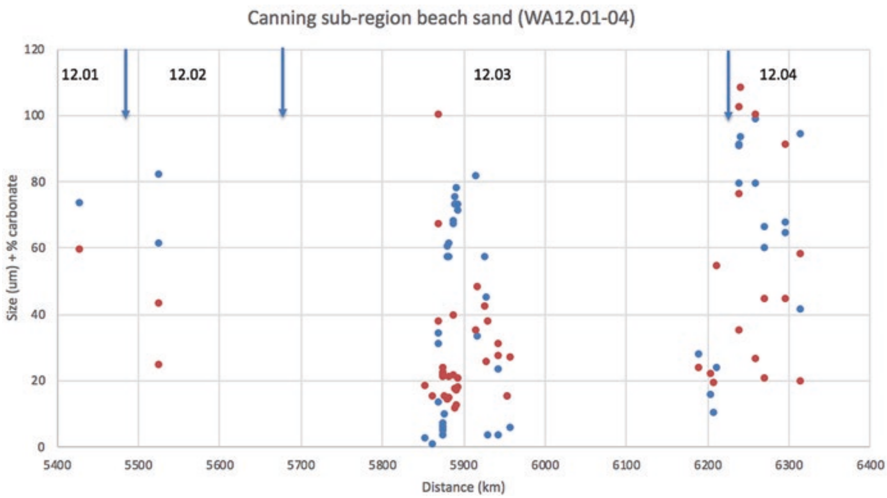

Fig. 4.16 Canning subregion beach sediments: sand size (red) and percent carbonate (blue). Distance is in kilometres from SA-WA border. PC boundaries indicated; see Table 4 12 for SC boundaries

beaches and coastal sectors (Table 4.11; Fig. 4.16) again indicates variable local sources and limited longshore transport resulting in Eliot et al. (2011) identifying 11 TCs between Beebingarra Creek and Tyron Point.

4.4.1.2 Barriers

Holocene barriers in the Canning are the longest and largest and most unstable in the division, a result of higher wave energy leading to increased sand supply and greater exposure to wave attack. The barriers occupy 647 km (44%) of the coast having a total area of 67,037 ha and volume of 6600 M m^3, which represents 10,200 m^3 m^{-1} (Table 4.12), also the highest in the division, with the per metre

Table 4.12 Canning subregion (PCs:WA12.01–04) barrier dimensions

	12.01	12.02	12.03	12.04	Total
Number	13	4	56	19	92
Total length (km)	132.1	189.7	293.1	32.5	647.2
Mean min width (m)	2000	3150	270	100	–
Mean max width (m)	325	460	300	130	–
Mean height (m)	9	10	11	6	–
Area (ha)	17,360	34,730	14,107	840	67,037
Unstable area (ha)	820	1070	6400	130	8420
Volume (M m^3)	1520	3473	1565	40	6600
Unit volume ($m^3\ m^{-1}$)	11,500	18,307	5342	1239	10,200

volume varying considerably between a high of 18,307 $m^3\ m^{-1}$ along Eighty Mile Beach to a low of 1239 $m^3\ m^{-1}$ in King Sound. The barriers are predominately moderate energy foredune ridge plains with several areas of active dune transgression. They range between 0.10 and 3.15 km in mean maximum width with a mean height between 6 and 10 m, the highest in the region. Twelve percent of the barriers are unstable most related to areas of dune instability along the higher energy sections of the western Dampier Peninsula and parts of Eighty Mile Beach.

In the remainder of this section, the Canning region is divided into its four PCs (WA12.01–12.04) and 13 SCs (WA12.01.1–12.04.4) (Table 4.13).

4.4.2 PC:WA12.01 De Grey River Delta-Shoonta Hill

PC:WA12.01 commences at Beebingarra Creek, 10 km east of Port Hedland, and extends east-northeast for 208 km to Shoonta Hill on Eighty Mile Beach. The dominating feature of this compartment is the large De Grey River delta that protrudes 25 km seawards and contrasts with the more embayed low energy Pardoo-Keraudren section (Fig. 4.17).

4.4.2.1 Rivers and Creeks

The De Grey river is the largest in the Pilbara region with a catchment of 54,752 km^2. It has built a substantial delta occupying about 100 km of the coast. It has a surface elevation of <10 m, with alluvial sediment extending to 100 m depth, indicating local submergence during the evolution of the delta (Hickman 1983). It is the only river in this PC, with most of the other ~20 small streams and tidal creeks associated with the delta, it distributaries and barrier islands and spits.

Table 4.13 The Canning subregion, PCs and SCs

PC/SC[a]	Boundaries	Beach ID[b]	No. beaches	km[c]	Total km
WA12.01.01	Beebingarra Ck-Yan Well	WA 1909–1922	14	5258–5310	52
WA12.01.02	Yan Well-Condini Landing	WA 1923–1930	8	5310–5352	42
WA12.01.03	Condini Landing-Shoonta Hill	WA 1931–1957	27	5352–5466	114
WA12.01	*De Grey river delta*		*49*		*208*
WA12.02.01	Shoonta Hill-Wallal	WA 1958–1965	8	5466–5549	83
WA12.02.02	Wallal-C. Jaubert	WA 1966–1974	9	5549–5668	119
WA12.02	*Eighty Mile Beach*		*17*		*202*
WA12.03.01	C. Jaubert-C. Villaret	WA 1975–2048	74	5668–5803	135
WA12.03.02	C. Villaret-Entrance Pt	WA 2048-K12	15	5803–5877	74
WA12.03.03	Entrance Pt-Coulomb Pt	K 12–34	22	5877–5954	77
WA12.03.04	Coulomb Pt-Swan Pt	K 35–93	50	5954–6221	267
WA12.03	*Dampier Peninsula (west)*		*170*		*553*
WA12.04.01	Swan Pt-Cornambie Pt	K 94–148	54	6221–6357	136
WA12.04.02	Cornambie Pt-Jangerie	K 149–152	4	6357–6415	58
WA12.04.03	Jangerie-Pt Torment		0	6415–6535	120
WA12.04.04	Pt Torment-Pt Usborne	K 153–155	3	6535–6746	211
WA12.04	*King Sound*		*61*		*525*
WA12	**Canning region**	Sub-total	**297**		**1475**

[a]NCCARF compartment number
[b]ABSAMP WA and Kimberley (K) beach ID
[c]Distance from SA/WA border

Fig. 4.17 PC:WA 12.01 (SCs WA12.01.01–03) occupies the Beebingarra Creek to Shootna Hill sector and is dominated by the De Grey River delta, the Pardoo embayment and the start of Eighty Mile Beach at Cape Keraudren. (Source: Google Earth)

4.4.2.2 Sediments and Coastal Processes

Beach sands are moderately-sorted, coarse sand averaging 27% carbonate (Table 4.11). The lower carbonate can be attributed to the injection of terrigenous quartz sand from the De Grey. However as indicated in Fig. 4.16, there is considerable longshore variation in size and carbonate indicating a series of sources and limited longshore connectivity, with the beach sand sourced from the De Grey as well as the inner shelf and in situ biogenetic production.

4.4.2.3 Beaches

This PC has 55 beaches, which occupy 122.4 km (59%) of the shore, the rest occupied by mangrove-lined tidal flats and some bedrock and beachrock around Cape Keraudren. By length the beaches are a mix of more exposed TM (32%) particularly on the exposed UD Eighty Mile beach section where sand is finer (0.12–0.2 mm), together with one R and three R + LTT. TD beaches account for 60% of the beach length and include sand and mud flats, the remainder fronted by beachrock flats (6%) (Table 4.14). There are 33 beaches with sand flats averaging 500 m in width and nine with mud flats averaging 800 m in width, particularly in the low energy Pardoo embayment section (Fig. 4.18c).

4.4.2.4 Barriers

There are 14 barriers in the PC which occupy 140 km (67%) of the shore, the remainder either mangroves, open water or some bedrock and limestone. Between Cooke Point (Port Hedland) and the delta are a series of five Pleistocene limestone (beachrock) barrier islands with limited Holocene sands. Either side of the delta however are extensive regressive beach-foredune ridge plains each separated by tidal creeks and the river mouth and occupying at least 100 km of the shore. To the east of the delta, the limestone islands resume together with the Cape Keraudren bedrock, beyond which begins the long Eighty Mile Beach and its primarily regressive barrier.

Table 4.14 PC:WA12.01 beach types and states by number and length (mean and total)

BS	BS	No.	%	Length (km)	%	Mean (km)	σ
1	R	1	1.8	2.4	2.0	2.4	–
7	R + LTT	3	5.5	3.3	2.7	1.1	0.9
9	UD	9	16.4	36.1	29.5	12	10.1
11	B + SF	5	9.1	26.9	22.0	5.9	3.9
12	B + TSF	23	41.8	36.7	30.0	1.7	1.9
13	B + TMF	4	7.3	9.8	8.0	2.5	2.9
14	R + RF	10	18.2	7.25	5.9	0.7	0.6
		55	100	122.4	100	–	–

Fig. 4.18 (**a**) Long recurved spit on western flank of De Grey River delta (WA 1920), (**b**) long spit encased in mangroves immediate east of De Grey River mouth (WA 1929), (**c**) 1.5 km wide tidal mud flats at Pardoo Station (WA 1945), (**d**) Cape Keraudren at the southern end of Eighty Mile Beach and (**e**) the mouth of Meetyou Creek on Eighty Mile Beach at low tide (WA 1956). (Photos: AD Short)

SC:WA12.01.01–02 contain most of the De Grey River delta with WA12.01.01 occupying its western flank and WA12.01.02 centred on the river mouth (Table 4.12, Fig. 4.17). WA12.01.01 commences at Beebingarra Creek, which is located in the centre of a series of limestone barrier islands that continue for another 4 km to the east, followed by another 4 km of very low energy sinuous east-trending spits, all indicative of easterly transport. The island and spits form the western boundary of a shallow, 15 km wide bay. On the eastern side is a 15 km long spit formed from sediment transported southwest from the De Grey River (Fig. 4.18a) and enclosing the eastern side of the bay, part of which is used for salt production. The spit marks the beginning of the De Grey River delta that continues for 50 km northeast to the river mouth and the boundary with WA12.01.02 and then another 20 km to the east to

Condini Landing where limestone barriers again occupy parts of the coast. The river has deposited a protruding fan-like coastal plain, surrounded by several kilometres of regressive beach-ridge barriers and spits, with the spits migrating both west on the western flank and east on the eastern flank (Fig. 4.18b). It is similar in plan form to the Maitland River delta (Fig. 4.10). The central main channel is a mangrove lined and funnel shaped and consists of a 15 km wide coastal plain composed of inner supratidal flats grading to the regressive barriers, beach ridges and spits. The delta has 28 km^2 of supratidal flats, 1.6 km^2 of mangroves and 12 km^2 of intertidal flats (http://www.ozcoasts.gov.au/index.jsp), the extensive flats a product of the low gradient, mega-tidal range and dry, tropical climate. The beaches lining the delta flanks tend to be longer, occupying 52% of the shore. They are entirely TD beaches with tidal sand and mud flats, with the remainder of the shore consisting of mangroves and tidal creeks.

SC:WA12.01.03 (Pardoo-Cape Keraudren) commences at Condini Landing and extends for 114 km to Shoonta Hill on Eighty Mile Beach (Fig. 4.17). It can be divided into two sections located either side of Cape Keraudren (Fig. 4.18e). The 80 km long western section begins with a 20 km long section containing three limestone barriers islands separated by tidal creeks followed by the very low energy curving Pardoo embayment which contains TD beaches fronted by tidal sand and mud flats up to 1 km wide (Fig. 4.18c), together with several tidal creeks. In the east it is bordered by a limestone barrier island tied to the coast by salt flats. Between the island and Cape Keraudren, 12 km to the west, are two mangrove-lined bays filled with 4 km wide salt flats, separated by a second limestone barrier island. The beaches and barriers show evidence of easterly transport in the form of east-trending barriers and spits, as well as creeks deflected to the east. It is however unlikely sand is moving around Cape Keraudren except in the subtidal. The beaches are entirely TD with tidal flats up to 1.5 km wide and occupy 50% of the shore, the remainder mangroves and beachrock. The protruding Cape Keraudren (Fig. 4.18d) is 14 m high and composed of Tertiary sandstones of the Bossut Formation and fringed by beach and dune calcarenite and capped by dune sand. A mangrove-filled bay occupies the western side of the cape, with two small embayed beaches on the eastern side, the second terminating at the shallow mouth of Cootenbrand Creek which meanders across the beach at low tide, filling at high tide. The cape beaches are backed by a 10 m high foredune, with slabs of beachrock littering the foreshore and continuous beachrock dominating the first beach and the separating point. The second beach is fronted by a 150 m wide LTT. The creek also marks the beginning of Eighty Mile Beach, with the first 40 km a wide TM UD beach (Fig. 4.18e) extending to the PC boundary at Shoonta Hill, a 16 m high hill that is part of an inner Holocene barrier dune system. Three creeks drain across this section of the beach, all deflected to the east, with the eastern-most creek running behind a 10 km long series of east-trending recurved spits, all indicative of easterly longshore transport. The backing barrier is a mix of regressive foredune ridges, with migratory recurved spits at the creek mouths and two sections of secondary dune transgression extending up to 500 m inland and consisting of bare transverse dunes generated by the stronger easterly winds. The ridges/dunes are backed in turn by a mix of barriers and spits and backbarrier salt flats up to 5 km wide.

4.4.2.5 PC Summary

This PC extends for 208 km between Beebingarra Creek neat Port Hedland and Shoonta Hill on Eighty Mile Beach. Sediment is moving eastwards along the Beebingarra Creek section limestone barrier islands terminating in a series of very low energy recurved spits slowly filling a large shallow bay. The De Grey River sediment is transported up to 40 km southwest along its western flank towards the same bay, which is acting as an internal sink. River sediment is also moving up to 20 km along its eastern flank, where it is interrupted by limestone barriers, points and reefs. There is evidence however that it continues to move eastwards along the Pardoo section, terminating in a very low energy 4 km long recurved spit. If sand is moving around Cape Keraudren, it will be in the subtidal rather than along the shore. The southern end of Eighty Mile Beach does show evidence of easterly transport in the form of three deflected creeks including a 10 km long series of recurved spits located 30 km east of Cape Keraudren. As the beach sands average between 60 and 95% carbonate, it is assumed much of this sediment originated in the beach and nearshore waters and has been transport both onshore and alongshore.

This PC has mixed vulnerability to inundation and sea-level rise ranging from low on the higher points like Cape Keraudren, to moderate along the limestone barriers and Eighty Mile Beach section to high on the delta and in the low Pardoo embayment.

4.4.3 PC12.02: Eighty Mile Beach

The 202 km between Shoonta Hill and Cape Jaubert is part of one long beach system, the 222 km (138 mile) long Eighty Mile Beach, which is one of Australia's three longest beaches. The system lies across the low southern section of the Canning Basin and is anchored by the sandstone Cape Keraudren (14 m) and limestone Cape Missiessy (8 m) (Fig. 4.19). The beach is predominately a TM UD beach, a product of the low-moderate waves, high tides (8–10 m) and fine (0.1–0.3 mm), well-sorted, carbonate-rich (>80%) sand. At low tide the beach merges with the nearshore and it is possible walk more than 1 km out across the rippled sand flats.

4.4.3.1 Rivers and Streams

There are no rivers along this section; however several creeks drain the backbarrier flats. Each creek mouth is deflected a few kilometre to the east to northeast indicating easterly sand transport.

Fig. 4.19 SCs:WA12.02.01–03: Eighty Mile Beach. (Source: Google Earth)

4.4.3.2 Coastal Processes and Sediments

This is a moderately exposed section of coast with waves averaging 0.5 m and tide to nearly 10 m. Beach and dune sand remain generally well-sorted fine sand high in carbonate (Table 4.11; Fig. 4.16).

4.4.3.3 Eighty Mile Beach

The entire beach is UD, usually consisting of a well-developed foredune up to a few metres high, a narrow high tide beach and very wide (100’s m+) low gradient (<1°) intertidal zone. It contains two SCs WA12.02.01-02.

SC:WA12.02.01 (Eighty Mile, south) extends along 83 km of the beach between Shoonta Hill and Wallal (Fig. 4.19), where the Eighty Mile Beach caravan park is located and the only development on the coast, apart from a few pastoral stations (Wallal, Mandora, Anna Plains and Nita Downs) usually located on higher ground a few kilometre inland. The beach initially trends east then gently curves to face west-northwest at Wallal. The low tide beach is essentially continuous, while the high tide beach interrupted by two sections of high tide beachrock/limestone totalling 10 km (Fig. 4.20a). The beach is part of a continuous outer Holocene barrier backed by interbarrier mud flats and discontinuous inner Pleistocene barriers. The Pleistocene ridges and spits form a series of embayed regressive barriers, divided by undulations in the underlying coastal plain and longitudinal dunes on its surface. As

Fig. 4.20 (**a**) Typical low beachrock bluffs found along sections of the beach (WA 1960), (**b**) the ultradissipative beach backed here by active transverse dunes (WA 1958), (**c**) the wide ultradissipative beach at Cape Missiessy (WA 1969) and (**d**) Cape Jaubert surrounded by bedrock flats and sections of beachrock (WA 1973–7). (Photos: AD Short)

the Holocene barrier prograded seaward between 3 and 2 ka, it resulted in the present more continuous beach system (Semeniuk 2008). The outer barrier consists of regressive foredune ridges and migratory spits, with some secondary dune transgression occurring along a 20 km long section with dunes extending up to 5 km inland (Fig. 4.20b). The barrier is dissected by eight creeks which are deflected to the east and drain across the beach together with the beachrock sections. Semeniuk (2008) provides stratigraphic sections for Shoonta Hill and Wallal Downs, the former consisting of Holocene dune sand overlying calcarenite, while at Wallal an inner Pleistocene barrier is separated by 200 m wide mud flats from the outer Holocene barrier which dates ~4 ka.

SC:WA12.02.02 (Eighty Mile Beach, north) commences at Wallal and extends for 105 km to the small 8 m high Cape Missiessy then continues for another 14 km of shore to the more prominent 14 m high limestone Cape Jaubert. The beach continues as a very wide (~1 km) low gradient UD intertidal beach backed by a well-developed foredune, which is cut by four creeks draining the backbarrier flats. The beach continues curving to the north, facing west-northwest at Cape Jaubert (Fig. 4.19). TM UD beaches comprises 91% of this SC, with the remainder primarily TD sand flats (Table 4.15). The high tide beach is interrupted by the several tidal creeks and groundwater seepage. In the south the beach commences at a narrow foredune systems backed by two deflected creeks, which occupy the first 30 km.

Table 4.15 PC:WA12.02 beach types and states by number and length (mean and total)

BS	BS	No.	%	Length (km)	%	Mean (km)	%
7	R + LTT	2	11.8	2.7	1.4	1.35	–
9	UD	14	82.4	174	90.3	12.4	18.8
12	B + TSF	1	5.9	16	8.3	16	–
		17	100	192.7	100	11.4	–

These are followed by a 20 km long section with no foredune and groundwater seeping from the interbarrier depression out onto the beach. Both these sections are backed by inner Holocene barriers up to 3 km inland, and in places a Pleistocene barrier located at 7 km inland and backbarrier flats extending up to 20 km inland. Semeniuk (2008) provides a transect across central Eighty Mile Beach which shows an inner barrier that marks the limit of high stand coastal retreat, separated by a 1 km wide shelly carbonate mud flats from an outer chenier (3.5 ka) and then foredune, the latter presently receding and exposing mud flats.

The northern 73 km long section runs continuously to Cape Missiessy (Fig. 4.20c) without interruption. It is also backed by the best developed regressive barrier on Eighty Mile beach, the barrier up to 3 km wide and containing up to 25 ridges. The ridges increase in spacing landward where they become discontinuous and end in recurved spits, indicating an earlier discontinuous beach and barrier, as presented by Semeniuk (2008). At Cape Missiessy sand is moving around the cape into Desault Bay to form a 3 km long, 500 m wide series of recurved spits, which overlap earlier higher sea-level ridges, which finally terminate 10 km to the north at Cape Jaubert (Fig. 4.20d).

4.4.3.4 PC Overview

Eighty Mile Beach is an exposed relatively high-energy section of the northwest coast where waves average 0.5 m and combine with the high tides (7–9 m) and fine sand to maintain the longest UD beach in Australia, if not the world. The beach is in near pristine condition and a superb natural feature. At spring high tide, the beach narrows to 20 to 30 m, with no high tide beach along sections of the southern beachrock sections and northern groundwater sector where mangroves also dot the upper beach. As the spring tides falls, it exposes a very wide, continuous gently sloping low tide sand beach, up to 2 km wide, its surface rippled by waves during the falling tide. The sediment is rich in carbonate detritus (60–80%), and a range of shells usually litters the high tide swash, making it a favourite site for shell collecting.

The beach is backed by an equally long barrier system consisting of a southern 70 km long section from Cape Keraudren to Red Hill characterised by inner and outer discontinuous foredune ridges, some of which are now covered by sand sheets and west-trending transverse dunes (Fig. 4.20b). The 133 km long northern section begins north of Red Hill has a series of widely separated discontinuous foredune ridges, interrupted by creeks with northward-migrating recurved spits, backed by a broad backbarrier depression. These converge at the beginning of the final section and form the longest foredune ridge system in Australia extending unbroken for 73 km to Cape Missiessy (Fig. 4.20c). The bedrock and beachrock of Cape Jaubert, 10 km to the north, form the northern boundary of this sector (Fig. 4.20d). The entire Eighty Mile Beach embayment represents a single TC cell that contains Holocene barriers totalling 3700 M m^3. This represents 17,000 m^3 m^{-1} of beach and a massive regional sink for predominately carbonate sands. The sand is manifest as predominately regressive Holocene (foredune ridge) barrier between 0.5 and 5 km wide.

Semeniuk (2008) noted areas of shoreline recession along the beach exposing backbarrier muds, while Eliot et al. (2011) rate the entire beach and its backing higher foredunes as having moderate vulnerability. Rising sea level should accelerate recession as well as inundation of the backbarrier flats via the many creeks. The long beach will be left to accommodate these changes with only the Wallal caravan park requiring retreat when necessary.

4.4.4 PC:WA12.03 Cape Jaubert to Dampier Peninsula (West)

PC:WA12.03 commences at Cape Jaubert and extends for 553 km north to Swan Island at the northern tip of the Dampier Peninsula (Fig. 3.1). This is largely a low-lying (~10–20 m) exposed west-facing shore, with waves averaging 0.5 m on exposed beaches. The compartment is divided into four SCs: the bedrock-controlled section between Cape Jaubert and Cape Villaret (WA12.03.01), the very low energy Roebuck Bay (WA12.03.02), the Dampier Peninsula to Coulomb Point (WA12.03.03) and then to Swan Island (WA12.03.04). Each of these is described in the following sections. This PC contains a range of development. In the south is the aboriginal community of Bidyadanga (750 population), the popular blufftop caravan parks at Port Smith and Barn Hill and the Eco Beach tourist resort, together with a couple of large pastoral leases running cattle. On the north side of Roebuck Bay is the popular and growing town of Broome (15000), one of the larger towns in the northwest, while on the northern section of the Dampier Peninsula coast is the aboriginal communities of Beagle Bay (300) and Lombadina (250) and the Cape Leveque Kooljaman tourist/wilderness resort.

4.4.4.1 Rivers and Streams

There are no rivers along this section. There are however more than 50 tidal creeks spread along the coast most linked to backbarrier depressions in the many drowned valleys, where mega-tides and strong tidal currents generate predominately broad funnel-shaped TD inlets. Most of the inlets drain completely at low tide leaving an upper narrow fringe of mangroves, backed by supratidal flats of variable width and extensive intertidal flats leading to the drainage channels and the main inlet channel.

4.4.4.2 Coastal Process and Sediment

The coast faces west and is relatively high energy with waves averaging 0.5 m on the more exposed sections. There are however several more sheltered embayments, between Cape Jaubert and Cape Latouche Treville (Geoffrey, Admiral, Lagrange and Port Smith) and the larger Roebuck Bay in the south, and Willies Creek and Carnot, Beagle and Pender bays in the north that all contain very low energy mangrove-lined TD shores. Tides are mega-tidal throughout with spring tides ranging from 9.4 m at Broome to Australia highest of 11.2 m at Derby. Sediments remain medium to coarse, carbonate-rich (80%) sand in the south, with to quartz-dominated sand along the northern shore of Roebuck Bay (12% carbonate) and the eastern Dampier Peninsula (38%), and with carbonate then increasing to average 77% on the western Dampier Peninsula beaches (Table 4.11). However, throughout there is considerable spatial variation in both sand size and percent carbonate (Fig. 4.16) indicative of the low energy environment, local sources and limited longshore sand transport.

4.4.4.3 Beaches

This is a long SC containing 170 beaches, averaging 2.2 km in length and occupying 380 km (69%) of the shore, the remainder mangrove-lined tidal flats in the major bays and sections of beachrock and exposed pindan 'bedrock'. The mega-tides and generally low waves result in a mix of TD (43%) with 28% fronted by wide sand flats averaging 1.2 km in width (σ = 1.15 km), and then TM (39%), with 35% the exposed higher energy UD, and significantly 18% fronted by intertidal rock flats of either beachrock, coral reef flats or pindan or combinations of all three (Table 4.16).

4.4.4.4 Barriers

There are 56 barriers in this PC, which occupy 293 km (52%) of the shore, the low percentage owing to the number of TD beaches with no barriers and to some of the more exposed beaches backed by pindan bluffs. The barriers that do exist are reasonably high averaging 11 m, a product of the number of transgressive dune systems

Table 4.16 PC:WA12.03 beach types and states by number and length (mean and total)

BS	BS	No.	%	Length (km)	%	Mean (km)	%
6	R	1	0.6	1.3	0.3	1.3	–
7	R + LTT	8	4.7	13.7	3.6	1.7	2.1
9	UB	45	26.5	134.4	35.4	3	3.1
11	B + SF	43	25.3	105.2	27.7	2.4	3
12	B + TSF	25	14.7	51.2	13.5	2.1	2.3
13	B + TMF	4	2.4	5.85	1.5	1.5	1.1
14	R + RF	44	25.9	68.5	18.0	1.6	2.2
		170	100	380.1	100	2.2	–

and range in width from an average minimum of 200 m to an average maximum of 900 m. They cover an area of 14,107 ha, of which 45% are unstable, also a reflection of the active transgressive dunes, particularly along parts of the west Dampier Peninsula coast. The barriers have a total volume of 1565 M m^3 and a per metre volume of 5342 m^3 m^{-1} (Table 4.12).

SC:WA12.03.01 (Cape Jaubert to Cape Villaret) commences at Cape Jaubert and extends 135 km north-northeast to Cape Villaret, the last of the sandstone headlands (Fig. 4.21). The 90 km long southern section up to Cape Latouche Treville consists of a series of low (10–20 m) protruding sandstone headlands with four partly infilled bays in between (Geoffrey, Admiral, Lagrange and Port Smith). The bays and parts of the headlands contain a mix of TM (UD) and TD sandy beaches and in some bays TD tidal creeks. Between the major headlands, the bays are infilling as the separate

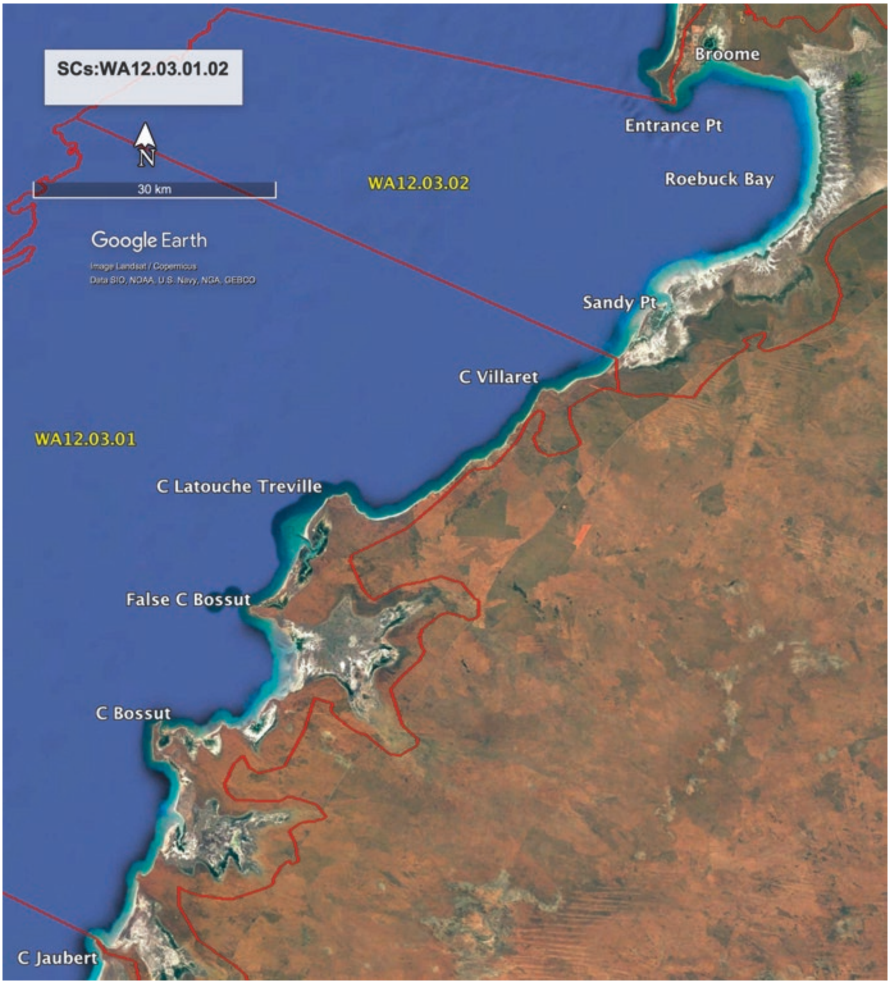

Fig. 4.21 SCs:WA12.03.01-02 contain the headlands and infilled bays in the south and the shallow Roebuck Bay in the north. (Source: Google Earth)

sediment cells. Each bay contains regressive barrier spits with prominent tidal creeks draining each embayment. The spits indicate sediment transport towards the central creek mouths implying that each bay and creeks is acting as a TC sediment sink, with little if any transport between the bays. Semeniuk (2008) investigated the Cowan Creek and Gururu Creek tidal flats and found they consisted of carbonate mud, with limestone barriers also partly blocking Cowan Creek. He also dated the sand at the base of the northern Port Smith barrier spit at 6.9 ka.

Beginning in the south, Geoffrey Bay extends for 9 km from Cape Jaubert to Cape Frezier with the beach grading from B + TSF in lee of Cape Jaubert to UD along the northern half (Fig. 4.22a). A series of foredune ridges back the beach with supratidal salt flats extending 8 km into the bay and two small creeks draining the flats. The 14 km wide Admiral Bay faces west and is similar with a central tidal creek (McKelson Creek) draining 10 km wide supratidal flats, with recurved spits extending north of Cape Duhamel to the south of the creek and regressive foredune ridges on the northern side, with both sides having an UD beach which widens to 1.3 km at spring low tide. The bay stratigraphy and the foredune ridge plain were investigated by Engel et al. (2015). They found the bay was flooded between 7.4 and 7.2 ka and colonised by mangroves. This was followed by high energy intertidal environments (~7.0 ka–4.0 ka) which aggraded into supratidal mudflats. At the same time, the foredune ridges prograded 2.5 km seaward between ~4 ka and present, assisted by a fall in sea-level and positive sediment budget. They found evidence that the sea level was ~1 m higher between ~2.1 and 0.8 ka and that it has fallen at a rate of ~1 mm yr^{-1} since 800 BP. The ridges also contain evidence of occasional high magnitude scarping/washover (storm surge) events. Cape Bossut, which forms the northern boundary, is ringed by a high tide beach fronted by wide rock flats (Fig. 4.22b). The larger 18 km wide Lagrange Bay faces north, and then west, and contains five smaller embayments each containing wide tidal flats (Fig. 4.22c) drained, respectively, by a Cape Bousset, Middle, Cowan, Lagrange and Gururu tidal creeks. Each creek is flanked by multiple recurved spits and beaches grading from the more sheltered tidal sand flats up to 2 km wide, through to the more planar sand flats on the more exposed UD, and rock flats around the northern False Cape Bousset. Port Smith is the most exposed of the bays and consists of two sets of regressive barriers that recurve into the deep central Port Smith tidal creek. The creek is a partly infilled mangrove-lined estuary which has a large tidal prism which has developed ebb tide sand shoals extending 3.5 km offshore. This is a popular fishing destination owing to a caravan park and boat ramp located in lee of the main channel.

The bays have between them received 560 M m^3 of predominately Holocene marine sand which has built embayed regressive (foredune ridge) barriers between 0.1 and 3 km wide. There are 77 beaches occupying 84% of the coast which are a mix of TM UD (45%) and TD (34%) with 19% fronted by intertidal rock flats (Table 4.17). They average 1.6 km in length (σ = 1.7 km), with the longest 9 km at Eco Beach.

North of Cape Latouche Treville is a near continuous northeast trending 30 km long section of coast containing series of 24 more exposed UD sandy beaches tied to 20–30 m high sandstone bluffs and points, which terminate at Cape Villaret, in what is called Gourdon Bay (Figs. 4.22d and e). The southern beaches (WA 2022–5) have experience minor regression and are backed by foredune/s, while most of the beaches to the north (WA 2026–45) are backed by 20–30 m high eroding and gullied sandstone bluffs, including the popular Barn Hill caravan park section.

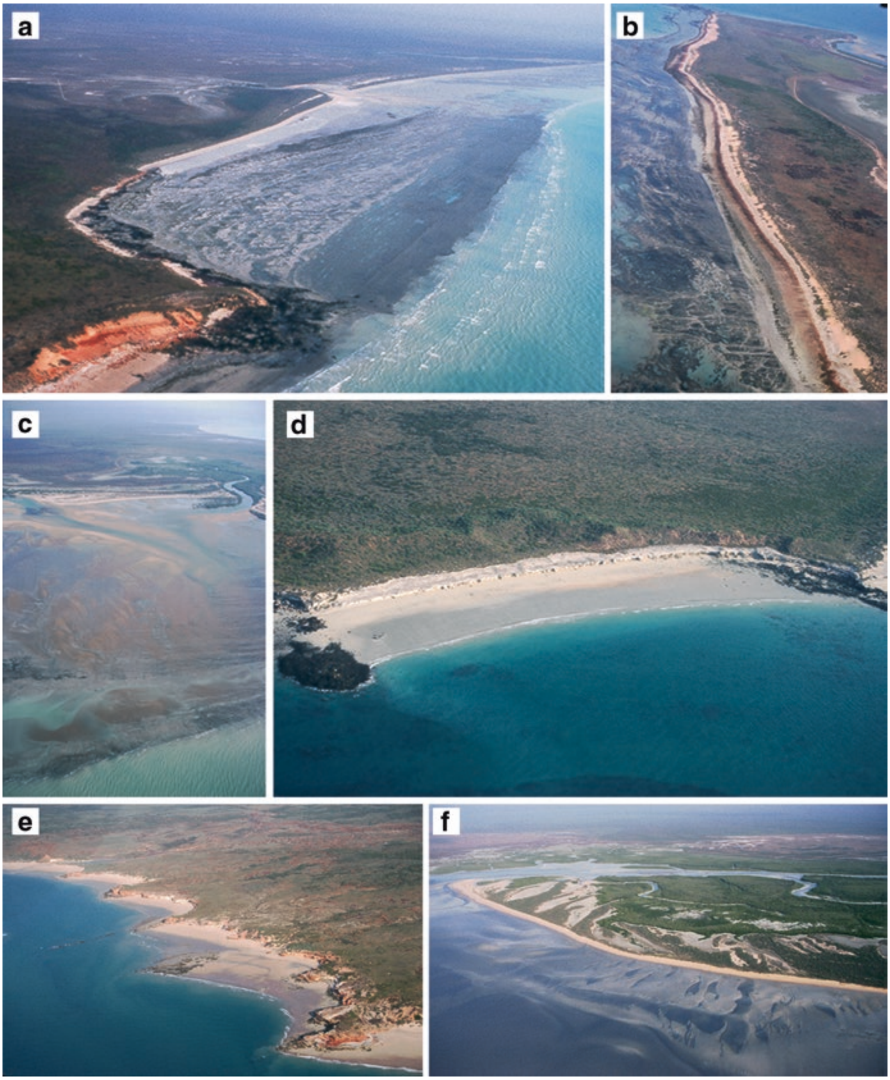

Fig. 4.22 (**a**) View south into Geofferys Bay showing the 1 km wide UD beach (WA 1978–81) (**b**) beach, beachrock and rock flats at Cape Bossut (WA 1991–2), (**c**) 1.5 km wide tidal flats at Middle Creek, La Grange Bay (WA 1995) (**d**) an embayed UD beach at Saddle Hill (WA 2020), (**e**) a series of headland bound beaches at Cape Gourdon (WA 2029–32) and (**f**) the multiple recurved spits of Sandy Point (WA 2049). (Photos: AD Short)

Sand is moving along this northern bluffed section, bypassing the subdued headland and moving around Cape Latouche Treville to ultimately feed the 12 km Sandy Point in the next SC.

SC:WA12.03.02 (Roebuck Bay) occupies the 40 km wide Roebuck Bay embayment that trends northeast and occupies a depression that some have suggested may have been a former outlet for the Fitzroy River. However, based on stratigraphic and

Table 4.17 SC:WA12.03.01 (Cape Jaubert to Cape Villaret) beach types and states by number and length (mean and total)

BS	BS	No	%	Total length (km)	%	Mean (km)	σ (km)
6	R	1	1.3	1.3	1.0	1.3	–
7	R + LTT	4	5.2	1.9	1.5	0.5	–
9	UD	29	37.7	56.2	44.6	1.9	1.8
11	B + SF	21	27.3	33.3	26.4	1.6	1.9
12	B + TSF	8	10.4	9.6	7.6	1.2	1.2
14	B + RF	14	18.2	23.8	18.9	1.7	1.2
		77	100.0	126.1	100.0	1.6	1.7

Table 4.18 Roebuck Bay (WA12.03.02) beach types and states

BS	BS	No	%	Mean (km)	σ (km)	Length (km)	%
12	B + TSF	11	91.7	1.4	1.4	15.1	99.0
14	R + RF	1	8.3	0.3	–	0.2	1.0
		12	100	1.3	1.3	15.3	100

sedimentological evidence, Semeniuk (2008) rejects this claim. The bay has 77 km of shoreline between the southern Cape Villaret and northern Entrance Point (Fig. 4.21), site of Broome port and jetty and can be divided into three sectors: the southern continuous sandy beaches between the Cape and Bush Point, the wide mangrove-lined tidal flats of Roebuck Bay and the northern pindan section containing a scattering of 12 pindan-backed beaches and their tidal sand flats (Table 4.18).

The 25 km long section from Cape Villaret to Sandy-Bush points consists of a near continuous, though curving sandy beach, containing the 9 km long Eco Beach which is backed by dune-draped bedrock, and then a 15 km long series of regressive beach ridge spits that have prograded longshore up to 5 km and seaward up to 3 km, forming a large terminal sediment sink for this coastal sector (Fig. 4.22f), which has partly infilled the southern corner of Roebuck Bay. Based on the size of the terminal Sandy-Bush points, barrier spit sand has been moving northwards into the adjoining SC at a rate on the order of 10,000 m^3 $year^{-1}$. The beach grades from UD to sand flats towards Roebuck Bay, as gradient and wave energy decrease. Semeniuk (2008) dated two shelly cheniers in the southern corner of the bay at 1.5 and 1.2 ka, the cheniers sitting atop of the carbonate mud flats.

The Roebuck Bay shoreline commences at Bush Point where the shoreline trends northeast for 10 km deep into the bay to where the 200 m wide belt of mangroves begin. The shoreline then trends north for 25 km to Crab Creek as west-facing mangrove line tidal mud flats, with the mud flats extending up to 1.5 km into the bay, while supratidal salt flats extend 10 km inland and merge with the Roebuck plain that continues inland for another 60–70 km. The tidal flats are drained by 15 tidal creeks spaced on average 1.2 km apart (Fig. 4.23a). The sides of the bays are acting as sinks for sand transported longshore from the north and south, while the tidal flats receive in situ sediment accumulation and muds. A transect though the centre of the

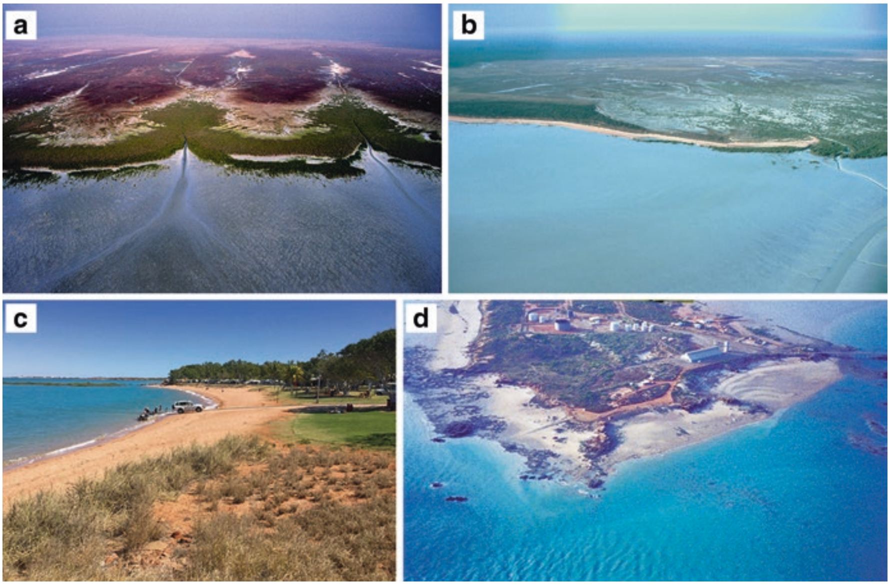

Fig. 4.23 (**a**) A section of Roebuck Bay showing the wide supratidal zone, mangrove belt and intertidal mud flats, (**b**) the long spit across Crab Creek at low tide (K 1) and extensive mud flats, (**c**) Town Beach at high tide (K 8) and (**d**) the cluster of small beaches around Entrance Point (K 11–14). (Photos: AD Short)

outer plain and flats by Semeniuk (2008) found up to 4 m of mud with a basal date of 5.1 ka. Semeniuk and Brocx (2016) suggest that Roebuck Bay represents the largest and thickest carbonate tidal deposits in the world, followed by other large deposits behind Eighty Mile Beach and in Shark Bay.

The northern sector begins at Crab Creek which marks the beginning of the Broome beaches and more sandy tidal flats. It appears that much of the sand for these beaches has been derived from erosion of the backing quartz-rich pindan bluffs and transported west towards Crab Creek where it has built a 0.7 km long series of recurved spits that extend to the mouth of the creek (Fig. 4.23b). The sand is fine, moderately sorted with carbonate content averaging a low 11% and ranging from just 0.5% to 34%. The first seven beaches (K 1–7) are wedged in between the backing 5 m high red pindan bluffs and the tidal sand-mud flats, with the mangrove-lined, 4 km wide, funnel-shaped Dampier Creek separating them from the five similar Broome beaches (K 8–12) which face west into the bay. A transect across Dampier Creek tidal flats revealed a carbonate mud sequence thickening to 5 m towards the creek, with buried mangrove roots dating at 3.4 ka (Semeniuk 2008). All the beaches are accessible by vehicle, though only the Broome beaches are developed, especially the popular Town Beach (Fig. 4.23c), which is the only erosional hot spot in the Canning region (DOT 2016). The 4.5 km long Demco Beach (K 9), which extends to Entrance Point, has sloping beachrock exposed on the beach face along its eastern half. The northern boundary at Entrance Point is the location of the Broome jetty together with three small beaches, one with a boat ramp and each containing sloping beachrock (Fig. 4.23d).

SC:WA12.03.03 (Dampier Peninsula, west) commences at Entrance Point where the coast turns out of the sheltered Roebuck Bay and heads north for 74 km to Coulomb Point (Fig. 4.24), with **SC:WA12.03.04** then trending northwest for 267 km to Swan Point the northern tip of the Peninsula and entrance to King Sound, the latter containing seven mangrove-lined bays of varying shapes and sizes, separated by sections of open coast and beaches. This is a more exposed and initially more continuous coast backed throughout by the low (~10–20 m) red pindan bluffs that comprise the entire peninsula. The beaches are a mix of higher energy sections with both TM R + LTT (5%) and UD (33%) and the more sheltered northern bays with their tidal sand and mud flats (B + SF 30%; B + TSF 14%), together with 15% fronted by intertidal rock flats (Table 4.19).

The southern SC (WA12.03.03) contains 25 near continuous beaches, which occupy 94% of the coast, the remainder the red pindan bedrock between Entrance Point and Cape Gantheaume and around Coulomb and James Price points (Fig. 4.25d), together with the open water of Willie Creek and the raised beachrock reef at Barred Creek (Cape Boileau) (Fig. 4.25c). The coast and beaches are well exposed and either R + LTT, UD or R + RF (Table 4.19). They include the famous Cable Beach at Broome, a 12 km long sweep of sand that widens to 300 m at low tide (Fig. 4.25a and b) and is one of Australia's most popular beaches for beachgoers and definitely the most popular for vehicles, with hundreds of vehicles lining the beach to watch the famous sunsets. Cape Gantheaume forms the southern boundary of the beach, the cape famous for its Cretaceous dinosaur footprints, with the beach extending north to the 1 km wide Willie Creek mouth, north of which the beaches run near continuously between the points and rocks to Cape Bertholet (located in WA12.03.04), the cape a 5 km long north-trending recurved spit that is a sink for the northward longshore sand transport. The beaches are composed of generally fine, moderately-sorted sand that is carbonate-enriched (38%, $\sigma = 27\%$), with those associated with eroding pindan lower in carbonate, while others reach 60–80% carbonate. Northerly longshore sand transport is driven by a pronounced asymmetry in the tidal currents with a net northerly drift, which in conjunction with wave orbital motion results in net northerly sand transport (Wright 1981; Wright et al. 1982). This is evident in the 1.5 km wide series of spits that have infilled the southern side of Willie Creek. Masselink and Lessa (1995) investigated the now dry Coconut Well area at the northern end of Cable Beach. They found the paleo-estuary was closed by longshore transport when sea level was about 1 m higher, roughly 2.5 ka. Semeniuk (2008) cored the Cable Beach barrier also at Coconut Well and obtained dates below the outer section of 2.1 and 1.1 ka. He also augered Willie Creek and found it is largely infilled by 2 m thick carbonate mud flats. Clifford and Semeniuk (2019) describe the Quaternary sequence stratigraphy in the Broome region, including the overlaying of the red desert quartz with the white carbonate-rich coastal sands and dunes.

SC:WA12.03.04 continues north of Coulomb Point where the coast consists of pindan 'headlands' separated by seven bays and their tidal creeks, with a number of

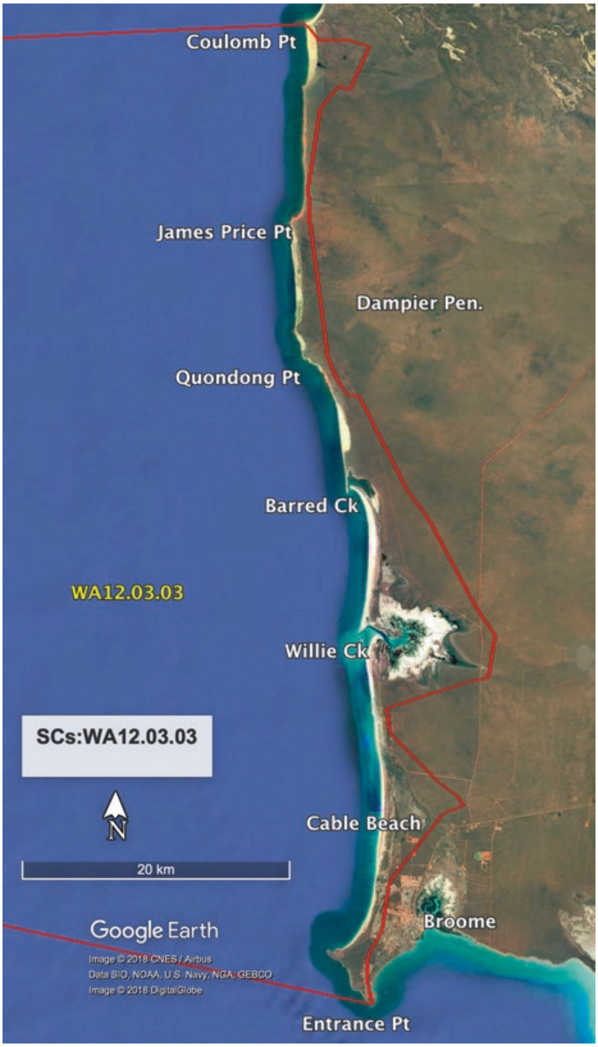

Fig. 4.24 SC:WA12.03.03: The southern coast of Dampier Peninsula trends due north from Entrance Point to Coulomb Point. (Source: Google Earth)

Table 4.19 The western Dampier Peninsula beach types and states

BS	BS	No	%	Total length (km)	%	Mean length (km)	σ (km)
7	R + LTT	4	4.9	11.8	4.9	2.9	–
9	UD	16	19.8	78.2	32.8	4.9	3.8
11	B + SF	22	27.2	71.9	30.1	3.3	3.5
12	B + TSF	6	7.4	26.5	11.1	4.4	2.9
13	B + TMF	4	4.9	5.9	2.5	1.5	1
14	R + RF	29	35.8	44.5	18.6	1.5	2.5
		81	100.0	238.8	100.0	2.9	3.3

Fig. 4.25 (**a** and **b**) Broome's Cable beach at low tide (K 19); (**c**) the jagged raised beachrock at Barred Creek (Cape Boileau); (**d**) view north from James Price Point showing the red pindan bluffs, narrow high tide beach and intertidal rock flats; (**e**) trangressive dunes either side of Coulomb Point (K34–5) and (**f**) ebb tide delta at Baldwin Creek and Low Sandy Point (left) (K 42–3). (Photos: AD Short)

long spits migrating northward into the bays (Fig. 4.26). The pindan sections tend to be fronted by sandy beaches (Fig. 4.27a, b), together with sections of beachrock and several areas of minor to moderate transgressive dunes the largest at Coulomb Point and Cape Leveque extending up to 1 km inland (Fig. 4.27c, d). Offshore the beaches are paralleled in places by submerged beachrock reefs (Cape Leveque) and exposed reefs forming natural breakwaters (Barred Creek (Fig. 4.25c), Cape Borda to Lombadina).

Beginning in the south 18 km wide Carnot Bay is partially blocked by three long narrow spits totalling 16 km in length each backed by a 3–7 km wide band of man-

Fig. 4.26 SC:WA12.03.04 trends northeast from Coulomb Point to the tip of the peninsula at Swan Point. (Source: Google Earth)

groves and supratidal flats. To the north of the bay is 18 km of beachrock-controlled beach and transgressive dunes followed by the smaller TD Baldwin Creek which has a 2 km wide barrier undergoing secondary dune transgression filling the southern half of the bay, the northern half filled with mangroves up to 2 km wide.

Between Baldwin and Camp Inlet are 12 km of beachrock-tied barriers terminating as a 4 km long spit that forms the southern entrance to the inlet. Sandy tidal shoals 2 km wide at the entrance also extend 3 km seaward, with the inlet infilled with sand shoals, mangroves and supratidal flats. The protruding Sandy Point separates it from the large funnel-shaped Beagle Bay. The bay entrance is 8.5 km wide between Sandy Point and the rocky North Head, with the bay extending 15 km inland, with the Beagle Bay community located at the head of the bay. A mix of pindan bluffs, 16 small sandy beaches and further in mangroves and tidal flats rim the bayshore. Semeniuk (2008) dated the base of the mud in the inner bay at 5.3 ka. The beaches range from higher energy UD

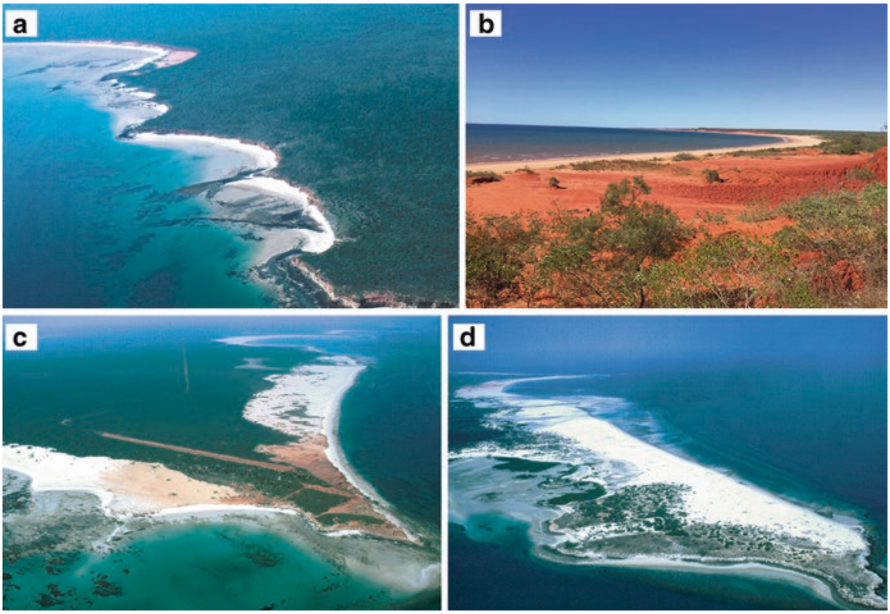

Fig. 4.27 (**a**) View south of Perpendicular Head (K 74–7), (**b**) Embalgum beach backed by red pindan (K 77) (photo VM Short), (**c**) Cape Leveque (K 88–91) and (**d**) transgressive dunes west of Swan Point (K 93–6). (Photos: AD Short)

on the southern shore grading bayward to wide B + TSF and then TMF up to 1 km wide on both side of the bay while along the outer northern shore the pindan bluffs and point and intertidal rock flats front the high tide sandy beaches.

At North Point the shoreline turns and trends north-northwest for 6 km to Emeriou Point. In between is a predominately rocky pindan shore containing a few small beaches and Trooper and Emeriou inlets. Trooper has a 1 km wide open inlet with its 700 ha bay half-filled with mangroves, the smaller Emeriou inlet has a narrow open inlet and a small 60 ha mangrove-filled inlet. Between the inlet and Emeriou Point is a curving exposed UD beach backed by 0.5 km wide bare and vegetated transgressive dunes. At Emeriou Point the shoreline turns and trends 7 km east to the steep 10 m high Perpendicular Head, followed by a curving beach and bluffs to Bell Point, in all 25 km of pindan-controlled shore containing 16 generally small beaches averaging 1 km in length (Fig. 4.27a) and ranging from longer exposed UD to several small beach backed and bordered by pindan, with some fronted by rocks, reefs and rock flats.

Bell Point forms the southern entrance to the large 10 km wide, funnel-shaped 17 km deep Pender Bay. The 7000 ha bay has three large recurved barrier spits, two bordering a 2.5 km wide inlet, with tidal sand flats extending up to 1.5 km into the open bay. Inside the spits are extensive tidal sand shoals, mangroves all backed by supratidal flats up to 1 km wide.

Cape Borda forms the northern Pender Bay entrance, where the coast again turns and trends north-northeast for 60 km to Cape Leveque, where it turns and trends northeast for another 15 km to Swan Point the tip of the Dampier Peninsula and PC boundary. In between is 75 km of coast containing a series of 13 longer curving embayed beaches (mean = 4.2 km) controlled by north-northwest trending linear beachrock reefs (including Packer Island, Lombadina Point and Chile Head) and pindan headlands, with most of the beaches backed by transgressive dunes extending a few hundred metres inland. The small Lombadina community is located on the pindan 4 km to the lee of the beachrock Lombadina Point, which is tied to the mainland by a curving sandy barrier, which forms the shoreline of Thomas Bay. At the 30 km high Cape Leveque, the red pindan is well exposed making it one of the more photogenic sections of the Australian coast. The beaches grade from UD in the more exposed locations to B + TSF in lee of the reefs. In addition, five small tidal creeks (Gilbut, Lombadina, Chile and Gnamagun) are located in lee of the reefs, while Hunter Creek splits the 13 km long sweep of sand between Cape Leveque and Swan Point in two.

4.4.4.5 PC Overview

This PCs has a more exposed west-facing coast with relatively higher waves which combined with the mega-tides to maintain a range of both TM and TD beaches. TM R + LTT and UD beaches occupy 39% of the sandy shore, the UD typified by Cable beach (Fig. 4.25a), and TD beaches with sand and some mud flats 43%, while beach with rock flats makeup 18% (Table 4.16).

The higher energy nature of this coast is also expressed in the barrier dimensions and level of instability (Table 4.12). There are 56 barriers that occupy 293 km (53%). They have an averaging height of 11.2 m and ranging in average width from 200 to 900 m. They include both regressive and transgressive systems, the transgressive dunes extending a maximum of 2.5 km inland, with 42% of the dunes unstable and migrating inland (Fig. 4.25c and Fig 4.27c, d). They have a total volume of 1565 M m^3 and a unit volume of 5342 m^3 m^{-1}.

This is a long and somewhat variable PC, unified by the mega-tide and low to moderate waves, but divided into four SC by the southern bedrock section, the low gradient Roebuck Bay embayment and the exposed but variable western shore of Dampier Peninsula. Sediment transport is likewise variable within and between the four SCs. The southern bedrock section (WA12.03.01) is dominated by four large embayment which have acted as sinks infilling as barrier-fronted shallow inlets that drain completely at low tide, with northerly sediment transport only along the northern continuous beach sections. Roebuck Bay (WA12.03.02) acts as a sediment sink with longshore sand transport along its southern and northern boundaries moving sand into the boundary regions developing cheniers and long spits, while the centre is accumulating carbonate mud and in situ sediments. The western shore of Dampier Peninsula has two parts, the southern (WA12.03.03) more continuous series of beaches and regressive and transgressive barriers bounded by pindan and beachrock points and reefs and backed by the bright red pindan as bluffs or eroding cliffs and northerly wave and tidally driven sand transport.

The northern half (W12.03.04) contains four embayments each acting as sediment sinks each generally TD funnel-shaped and infilling with carbonate sand and mud.

The PC has a range vulnerability to inundation and sea-level rise based on its cross-shore gradient. The southern SC and the western Dampier Peninsula all have low levels of vulnerability owing to their general higher elevations (>10 m), while the very low gradient Roebuck Bay and the peninsula bays are the most vulnerable.

4.4.5 PC:WA12.04: King Sound

King Sound is a large 120 km long rectangular-shaped bay approximately 5000 km^2 in area, with 525 km of shoreline. It is bounded by the low Dampier Peninsula in the west, the large funnel-shaped tide-dominated Fitzroy dominating the south, and the funnel-shaped May, Meda and Robinson rivers in the east which drain into Stokes Bay and is bordered in the northeast by the rugged linear bedrock ridges of the Leopold Range, which marks the beginning of the Kimberley Basin (Fig. 4.28). The only major development in the sound is One Arm Point community (350) on the northwestern entrance (Fig. 4.29a) and the town and port of Derby (3500) in the south. The sound contains four SCs (WA12.04.01-04) which are discussed below.

SCs:WA12.04.01–02 (Dampier Peninsula, east) extend for 186 km from Swan Point to Hoon Point at the mouth of the Fitzroy River and contains SCs:WA12.04.01–02 (Fig. 4.28). It faces east into the prevailing trade winds, but waves are limited by the 40–50 km fetch across the sound and shallow nearshore and wide tidal flats. It is also exposed to the highest tides in Australia reaching 11.2 m at Derby. There are 59 beaches located along the eastern shore, most small embayed beaches located in the two indented northern Catamaran and Cygnet bays, with mangroves dominating most of the shore to the south. The beaches occupy 25% of the shore, the remainder low pindan bluffs and mangrove-lined tidal flats (Fig. 4.29d). The beaches average 0.8 km in length (σ = 1.1 km), with the longest beaches in Disaster Bay (K 149, 6 km) (Fig. 4.29f) and along the more continuous southern mangrove shore. These lower energy beaches tend to be composed of moderately-sorted coarse, carbonate-rich (77%) sand (Table 4.11, Fig. 4.16).

The beaches range from B + RSF on some of the more exposed sections (Fig. 4.30b) to predominately B + SF and B + TSF (Table 4.20) averaging 0.5 km in width but extending up to 2.5 km wide in the south (Fig. 4.29e, f). There are also several beaches fronted by fringing reefs around Deepwater (Fig. 4.28c) and Amatangoora points. In the smaller embayments of the northern bays, there are about 20 small tidal creeks, with the beaches occupying the mouths of the small bays and mangroves lining the creeks and part of the embayments. The mangroves become more continuous south of Disaster Bay and reach up to 600 m wide near Hoon Point.

SCs:WA12.04.03–04 (Fitzroy, May, Meda and Robinson river deltas) occupies the southern and eastern shore of King Sound and contains 323 km of highly

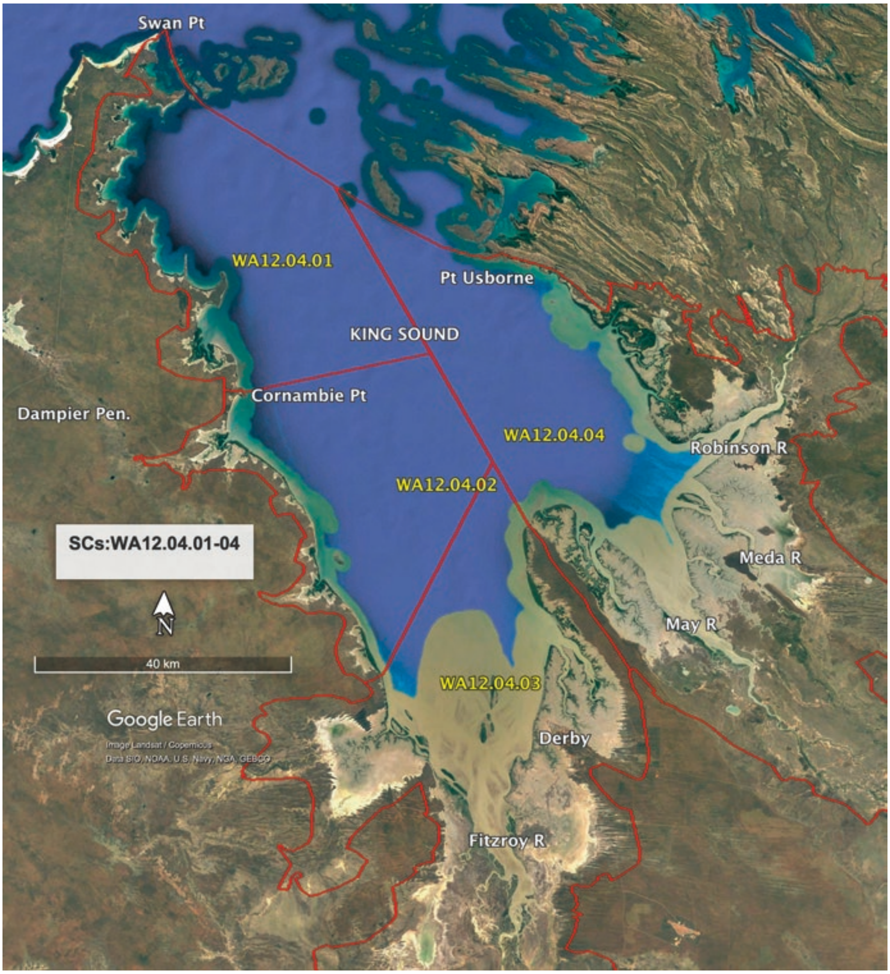

Fig. 4.28 PC:WA12.04 King Sound and its four SCs. (Source: Google Earth)

indented muddy shoreline which extends into each of the four funnel-shaped river mouths and is lined by mangroves throughout (Fig. 4.30). While there is no bedrock, the mangroves are ultimately backed by the drowned longitudinal dunes and pindan of the Canning hinterland. Derby is built on a protruding section of higher hinterland and dunes that extends close to the shore, and the reason it was chosen as at port, with Point Torment being a similar feature. The Fitzroy and the adjoining May, Meda and Robinson rivers each have the classic tide-dominated funnel-shaped river mouths (Fig. 4.30). The rivers supply sediment to the coast with the Fitzroy delivering the highest suspended sediment load in the northwest, with the fine sediment being deposited on the pro delta and tide flats of King Sound.

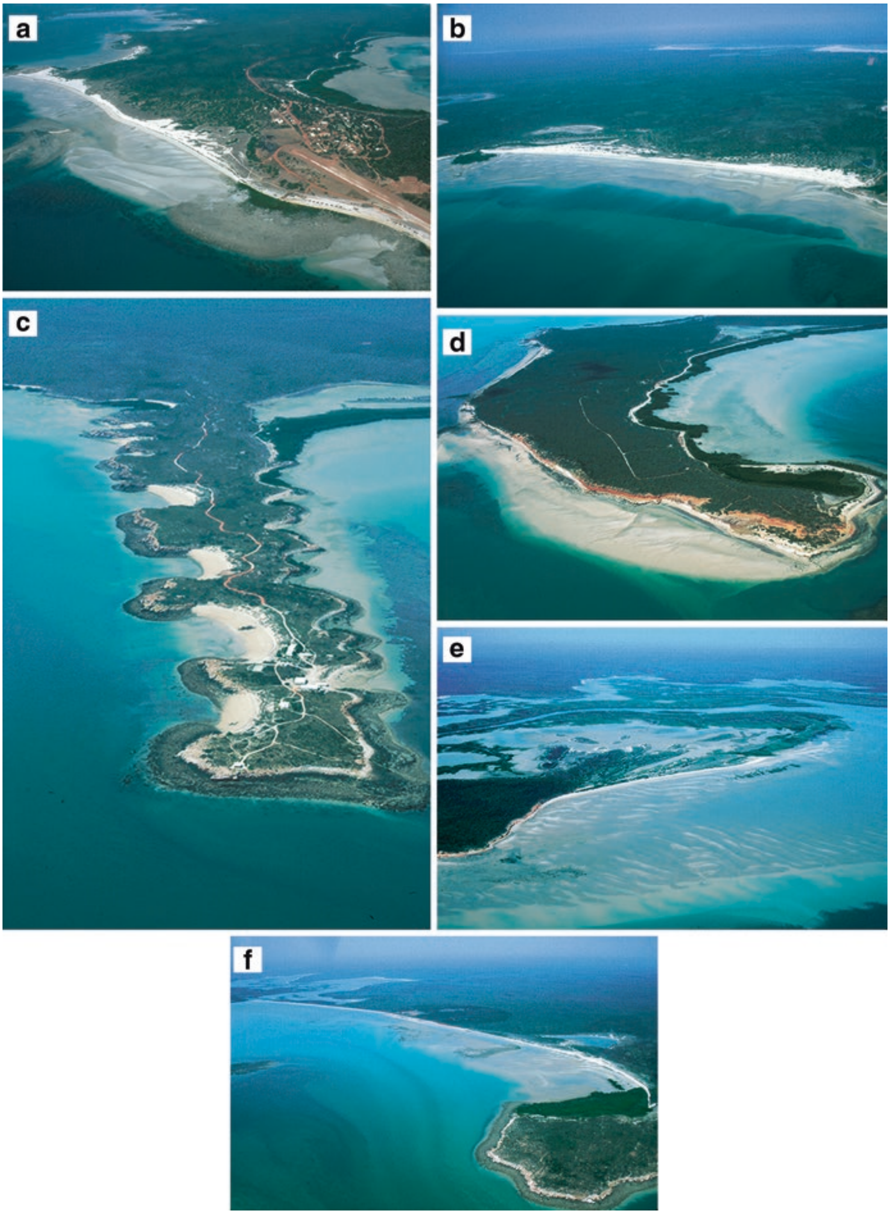

Fig. 4.29 (**a**) Middle Beach and the One Arm Point community (K 101–2), (**b**) beach with ridged sand flats north of Elephant Point (K 121), (**c**) the 4 km long Deepwater Point (K 132–8), (**d**) Cunningham Point with sand flats on the west and mangroves on the sheltered east (K 139–42), (**e**) 1–3 km wide sand flats in Goodenough Bay (K146) and (**f**) the beach and sand flats of Disaster Bay (K 149). (Photos: AD Short)

Fig. 4.30 The muddy TD funnel-shaped mouths of the Fitzroy, May, Meda and Robinson rivers. (Source: Google Earth)

Table 4.20 King Sound (PC:WA12.04) beach systems by type and length

BS	BS	No.	%	Length (km)	%	Mean (km)	σ (km)
10	B + RSF	11	18.6	6	13.0	0.7	0.6
11	B + SF	18	30.5	11.8	25.5	0.7	0.8
12	B + TSF	16	27.1	24.4	52.7	1.5	1.7
14	B + RF	3	5.1	0.5	1.0	0.1	0.1
15	B + CF	11	18.6	3.7	7.9	0.3	0.4
		59	100	46.3	100	0.8	–

Fig. 4.31 Point Usborne at the northeast entrance to King Sound contains the only pockets of sand on the eastern shore of the Sound (K 155). (Photo: AD Short)

Semeniuk (1982) provides an overview of the geomorphology of the tidal flats and Semeniuk and Brocx (2011) present an evolutionary depositional model for the Fitzroy River. The river depression was flooded by sea level ~7 ka with fine sediment begin transported into the drowned river valley and its subbasins (Jarramanga Plain, Fraser River and Doctors Creek). During the mid- to late-Holocene deltaic sedimentation resulted in a sedimentary lobe comprised of a sand-to-mud shoaling tidal sediment sequence, capped by (mangrove-covered) mud, with delta-land accretion progressing from south to north and the river channel dominated by tidally-oriented shoals. As the delta prograded prodelta mud was deposited in the central and northern parts of King Sound, as well as protected smaller subbasins. Throughout this period, the Fitzroy River deposited subaerial floodplain sediments that filled the alluvial valley tract in southern parts of King Sound and cap the deltaic sediment sequence. Today the Fitzroy delta plain is dominated by salt flats up to 15 km wide, which occupy 580 km^2, and is fringed by 30 km^2 of mangroves.

The town and port of Derby is located on a low pindan ridge which separates the Fitzroy and May river systems, the tip of the ridge providing reasonable access to deeper water for the 2 km long jetty. Most of the shore consists of extremely wide mud tidal flats up to 15 km wide, all fringed by dense mangroves and drained by numerous tidal creeks. The only beach consists of one 2.3 km long series of cheniers sitting on mangrove peats at the tip of Point Torment in the southern sound and three 50–70 m long pockets of sand out on the tip of Point Usborne (Fig. 4.31), which occupy just a tiny fraction of the shoreline.

Jennings and Coventry (1973) examined the stratigraphy and age of the Point Torment cheniers and found the sediments are a mix of coarse limestone and fine quartz and overlie mangroves peat that dated between 0.5 and 1 ka, with the cheniers appearing to be retreating over the mangroves. While there are four rivers flowing into the Sound and depositing sediment, Semeniuk (1980) also found that the mud flats between the Fitzroy River and Derby were eroding, though he provides no reason their retreat. As it is unlikely to be related the sediment budget, it may be related to change water-tide levels within the Sound. Jennings (1975) studies the longitudinal desert dunes that border the shores of King Sound and which were inundated by the Holocene sea-level transgression by 6 ka. He also provides a detailed description of the sound, its morphology, hydrodynamics, vegetation and shoreline transgression.

4.4.6 Canning Coast Overview

The Canning coast has four distinct shores: the protruding De Grey delta coast and its boundary limestone barriers and bays, the wide low beach and regressive foredune and transgressive dunes of Eighty Mile beach, the higher (~10 m) Dampier Peninsula and the very wide low gradient mangroves-lined shores of King Sound and the Fitzroy River delta. All four are presently exposed to tropical cyclone storm surge, Fitzroy River flooding in King Sound, extreme tides and occasional tsunami inundation. The De Grey delta coast has a high vulnerability rating (Table 4.21) owing to its low gradient shoreline. Semeniuk (2008) found the evidence of ongoing recession of Eighty Mile beach which Eliot et al. (2011) found has a moderate susceptibility, instability and vulnerability ranking (Table 4.21) and will remain moderate as sea level rises. The Dampier Peninsula has a low to moderate ranking owing to its generally more elevated position, apart from the tidal creeks and bays which are highly susceptible to inundation. The very low gradient shores of King Sound are highly vulnerable to present and future inundation and will retreat together with landward migration of the tide-related ecosystems. The towns of Broome and Derby are located on slightly higher ground but surrounded in part by low-lying tidal flats which will migrate landward. Sediment transport is likely to increase with sea-level rise leading to an increase in breaker wave energy and increased sedimentation in the creeks and flats of Eighty Mile Beach and accelerated northerly transport into creek and bays on the Dampier Peninsula.

Table 4.21 Vulnerability rating for Canning subregion SCs

Boundaries	SC	Vulnerability
Beebingarra Ck-Condini Landing	WA12.01.01–02	High
Condini landing-Cape Jaubert	WA12.01.03–12.02.02	Moderate
Cape Jaubert-Tyron Point	WA12.03.01	Low

Source: Eliot et al. (2011)

4.5 Pilbara Region

The Pilbara region contains a long and diverse coastline ranging from one of Australia's longest beaches to the extensive mud deposits of Roebuck Bay and King Sound. The entire coast as flooded by the PMT which came to rest about 2 m above present sea level ~7 ka followed by a fall to present level about 2 ka. The fall permitted considerable shoreline progradation as regressive chenier, beach and foredune ridges, some followed by moderate dune secondary transgression. The Carnarvon and much of the Pilbara coast is a low gradient coastal plain, while the Canning coast has the De Grey River delta and Eighty Mile Beach in the south and the large more elevated Dampier Peninsula to the north. Eliot et al. (2013) assessed the vulnerability of the Carnarvon, Pilbara and Canning coast to Cape Jaubert. As Tables 4.21 and 4.22 indicate most of the coast has a moderate to high vulnerability. The high ratings relate to the low gradient low-lying sections of coast, including the many shallow bays and tidal flats. The moderate is generally backed by higher beach, dune and barrier deposits and higher hinterland, like the pindan of Dampier Peninsula. The few low ratings are restricted to the limited higher bedrock shore, including the Burrup Peninsula.

The coast has several major sources of terrestrial sediment derived from the larger rivers and their deltas (e.g. Fortescue, Robe, Turner, De Grey, Fitzroy) which supply the adjoining downdrift shore. However away from the deltas, most of the sediment is carbonate indicating a marine origin, with the lesser quartz also derived from the shelf and in the north from local erosion of pindan. Semeniuk (2008) found parts of the coast are receding exposing backbarrier muds indicating that in some areas, there is a deficient sediment supply leading to shoreline recession.

Climate change will have a range of impacts on this coast starting with climate, as sea temperature warms and tropical systems expand southward and tropical cyclone change their frequency, intensity and tracks (Fitchett 2018). This will impact rainfall, flooding, storm surges and terrestrial sediment supply. The other major impact will be the rising sea level which will deepen the nearshore and begin to inundate the extensive tidal and supratidal flats. The deeper nearshore will enable larger waves to reach the coast leading to an increase in sediment transport which can have both positive and negative impacts on the sediment budgets and the shoreline. The inundation of the flats will be permanent as it will take centuries to millennium for the intertidal sediment to accumulate in the growing accommodation space. It will also have major impacts on all tide-dependent ecosystems as they attempt to follow the rising sea level and tides landward.

Table 4.22 Susceptibility, instability and vulnerability of the Pilbara region[a]

	Susceptibility	Instability	Vulnerability
Low	3 (9%)	4 (12%)	3 (9%)
Moderate	18 (53%)	13 (38%)	21 (61%)
High	13 (38%)	17 (34%)	10 (29%)

[a]The table covers from Locker Point to Cape Jaubert (PC:WA11.02–12.02)
Source: Eliot et al. (2013)

Most of the Pilbara division is undeveloped and likely to remain that way, and as such most of the coast will be left to accommodate the climate-induced changes with no human input, with action taken only at the nodal ports and settlements. Eliot et al. (2013) have mapped the levels of vulnerability, and so long as these are incorporated in the planning process, there is no reason for any future developments to be placed at unnecessary risk, particularly if they are sited at the existing nodes, as recommended by Brocx and Semeniuk (2017).

References

Brocx M, Semeniuk V (2017) Impacts of ports along the Pilbara Coast, Western Australia – a coastline of global geoheritage significance that services a mineral-rich hinterland. Annals Geophysics, 60, Fast Track 7, 1–13. https://doi.org/10.4401/AG-7495

Clifford P, Semeniuk V (2019) Sedimentary processes, stratigraphic sequences and middens: the link between archaeology and geoheritage–a case study from the Quaternary of the Broome region, Western Australia. Aust J Earth Sci

DOT (2016) Coastal management hotspots. Dept Transport, Perth

Eliot M (2013) Application of geomorphic frameworks to sea-level rise impact assessment. WA Pty Ltd, Damara

Eliot M (2014) Port Hedland spoil bank marina: coastal engineering assessment. Seashore Engineering Pty Ltd, Report SEO13-01-Draft B, Perth, 24 p

Eliot I, Dodson J (2010) Geoheritage features of the Onslow embayment: coastal landforms, coral reefs and wrack lines. Unpublished Report 82-04-Addendum 1: Geochronology and Other Laboratory Analyses. Damara WA Pty Ltd

Eliot M, Eliot I (2013) Interpreting estuarine change in northern Australia: physical responses to changing conditions. Hydrobiologia 708(1):3–21

Eliot I, Gozzard B, Eliot M, Stul T, McCormack G (2011) Geology, geomorphology and vulnerability of the Pilbara coast, in the shires of Ashburton, East Pilbara and Roeburne and the town of Port Hedland, Western Australia. Report 161-01, Damara WA Pty Ltd, Geol. Survey WA & WA Dept Planning, 233 p

Eliot I, Gozzard B, Eliot M, Stul T, McCormack G (2013) Geology, geomorphology and vulnerability of the Pilbara Coast, in the Shires of Ashburton, East Pilbara and Roebourne, and the town of Port Hedland, Western Australia. Damara WA Pty Ltd and Geol Survey of Western Australia, Innaloo, Western Australia, 387 p

Engel M, May SM, Scheffers A, Squire P, Pint A, Kelletat D, Brückner H (2015) Prograded foredunes of Western Australia's macrotidal coast – implications for Holocene Sea-level change and high-energy wave impacts. Earth Surface Processes Landforms 40:726–740. https://doi.org/10.1002/esp.3663

Fitchett J (2018) Recent emergence of CAT5 tropical cyclones in the South Indian Ocean. S Afr J Sci 114(11/12):#4426. 6 pages. https://doi.org/10.17159/sajs.2018/4426

Hickman AH (1983) Geology of the Pilbara black and its environs. Geol Surv Western Australia, Perth, Bull 127:266

Jennings JN (1975) Desert dunes and estuarine fill in the Fitzroy estuary (Northwest Australia). Catena 2:215–262

Jennings JN, Coventry R (1973) Structure and texture of a gravelly barrier island in the Fitzroy estuary. Mar Geol 15:145–167

Lessa G, Masselink G (1995) Evidence of a mid-Holocene Sea level highstand from the sedimentary record of a marcotidal barrier and paleoestuary system on northwestern Australia. J Coastal Res 22:100–112

May SM, Brill D, Leopold M, Callow JN, Engel M, Scheffers A, Opitz S, Norpoth M, Brückner H (2017) Chronostratigraphy and geomorphology of washover fans in the Exmouth gulf (NW Australia) – a record of tropical cyclone activity during the late Holocene. Quat Sci Rev 169:65–85. https://doi.org/10.1016/j.margeo.2017.03.005

May SM, Gelhausen H, Brill D, Callow JN, Engel M, Opitz S, Scheffers A, Joannes-Boyau R, Leopold M, Brückner H (2018) Chenier-type ridges in Giralia Bay (Exmouth gulf, Western Australia) - processes, chronostratigraphy, and significance for recording past tropical cyclones. Mar Geol 396:186–204. https://doi.org/10.1016/j.margeo.2017.03.005

Nott J (2006) Tropical cyclones and the evolution of the sedimentary coast of northern Australia. J Coastal Res 22:49–62

Paul MJ, Lustig TL (1975) Sediment movement in Port Hedland Harbour. In: 2nd Australian conference on coastal and ocean engineering, Gold Coast, pp 120–127

Semeniuk V (1980) Quaternary stratigraphy of the tidal flats king sound, Western Australia. J R Soc W Aust 63:65–78

Semeniuk V (1981a) Long term erosion on tidal flats of King Sound. Mar Geol 43:21–48

Semeniuk V (1981b) Sedimentology and the stratigraphic sequence of a tropical tidal flat, northwest Australia. Sediment Geol 29:195–221

Semeniuk V (1982) Geomorphology and the Holocene history of the tidal flats, King Sound, North-Western Australia. J Royal Soc Western Australia 65:47–68

Semeniuk V (1993) The mangroves systems of Western Australia. J Royal Soc Western Australia 76:99–122

Semeniuk V (1996) Coastal forms and quaternary processes along the arid Pilbara coast of northwestern Australia. Palaeogeogr Palaeoclimatol Palaeoecol 123:49–84

Semeniuk V (2008) Holocene sedimentation, stratigraphy, biostratigraphy, and history of the Canning coast, North-Western Australia. J Royal Soc Western Australia 91:53–148

Semeniuk V, Brocx M (2011) King Sound and the tide-dominated delta of the Fitzroy River: their geoheritage values. J Royal Soc Western Australia 94:151–160

Semeniuk V, Brocx M (2016) Roebuck Plains, North-Western Australia – a major Holocene carbonate mud deposit of international geoheritage significance. ProGEO News 1:3–9

Short AD (2005) Beaches of the Western Australian Coast: Eucla to Roebuck Bay. Sydney University Press, Sydney, 433 p

Short AD (2006) Beaches of the Northern Australia coast: the Kimberley, Northern Territory and Cape York. Sydney University Press, Sydney, 463 p

Stul T, Gozzard JR, Eliot IG and Eliot MJ (2014) Coastal sediment cells for the Pilbara region between Giralia and Beebingarra Creek, Western Australia. Report by Seashore Engineering Pty Ltd and Geological Survey of Western Australia for the Western Australian Department of Transport, Fremantle, 73 p

Thom BG, Eliot M, Eliot I, Harvey N, Rissik D, Sharples C, Short AD, Woodroffe CD (2018) National sediment compartment framework for Australian coastal management. Ocean Coast Manag 154:103–120. https://doi.org/10.1016/j.ocecoaman.2018.01.001

Wright LD (1981), Nearshore tidal currents and sand transport, macrotidal environment. GeoMarine Lett 1:173–179

Wright LD, Nielsen P, Short AD, Green MO (1982) Morphodynamics of a macrotidal beach. Mar Geol 80:97–128

Chapter 5
Kimberley-Territory Division

Abstract The Kimberley-Territory division includes the rugged Kimberley coast and the low western and northern coast of the Northern Territory (NT). This is a remote difficult-to-assess coast dominated by meso through mega-tides, low waves and a monsoonal climate, all exposed to trade winds and periodic tropical cyclones. The Kimberley coast is dominated by its deeply dissected joint-aligned geology and is a predominately steep rocky shore with small usually embayed beaches and extensive mangroves in sheltered areas. The NT coast is low with several rivers building deltas and extensive tide-dominated beaches and their wide tidal flats, with mangroves occupying all lower energy section of the coast. Barrier development is limited and usually restricted to regressive beach-foredune ridges, with a few areas of dune transgression. The chapter describes the geology, climate and coast and biological processes that have contributed to the formation of the coast.

Keywords Kimberley · Western Northern Territory · North Arnhem Land · Meso-tides · Mega-tides · Beaches · Barriers · Sediment transport · Sediment compartments

5.1 Introduction

The Kimberley-Territory division encompasses the entire Kimberley coast and the western coast and northern Arnhem Land coast of the NT. It extends for 7190 km between Point Usborne at the northeast entrance to King Sound and Cape Arnhem at the northeastern tip of the NT, taking in 24% of the Australian coast. This large section of the coast is also the least developed, least accessible and largely in a natural state. The only major city in the entire region is Darwin (population 120,000), followed by the much smaller towns of Wyndham (670) and Nhulunbuy (3000); the remaining coastal development is restricted to aboriginal communities of usually a few hundred people at Kalumburu, Wadeye, Warruwi (South Goulburn Island), Maningrida, Milingimbi and Ramingining; a scattering of very small aboriginal outstations; and handful of small land and boat-based pearling and tourist operations. Most of the coast is contained in aboriginal land, nature reserves and national parks,

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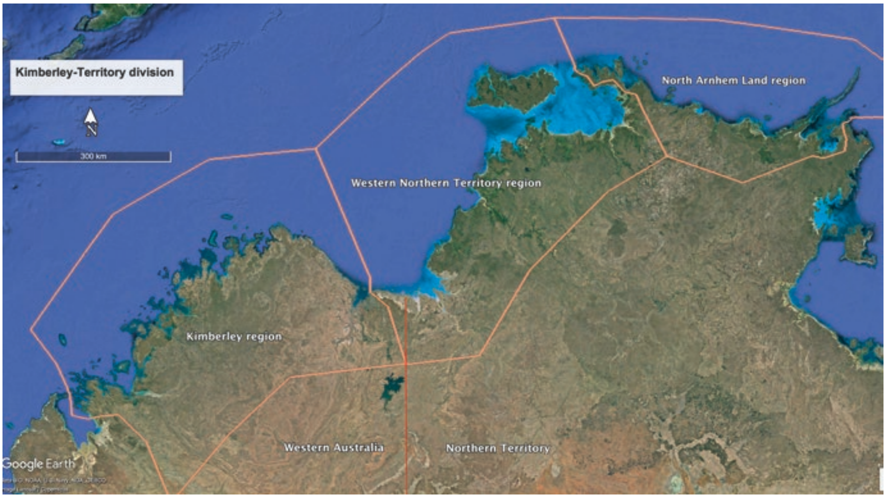

Fig. 5.1 The Kimberley-Northern Territory division and its three regions. (Source: Google Earth)

with the only extensive development of freehold land located in Darwin and the adjacent region.

In this chapter the Kimberley-Territory division is divided using the NCCARF classification into three regions: the Kimberley (WA13), the western NT (NT01) and the northern Arnhem Land coast (NT02, 03 and 04) (Fig. 5.1), which combined contain 11 PCs (Table 5.1) and 34 SCs. All except the Bathurst-Melville island compartments are presented in Chaps. 6, 7 and 8.

5.2 Geology and Geomorphology

The Kimberley-Territory division is part of the ancient northern Australian craton (Fig. 1.2) and encompasses from west to east the King Leopold Orogen, the Kimberley and Bonaparte basins, the Pine Creek Orogen, the Monkey Shoals Basin, the Arafura Basin and the small Arafura Inlier forming the eastern Cape Arnhem (Fig. 2.1). The basic geology, coastal morphology and age of each of these units are listed in Table 2.1 and are each discussed in more detail in the following sections.

5.2.1 *Kimberley Region*

The Kimberley region is bordered to the west and south by the northern boundary of the larger Canning Basin and the Fitzroy Trough, the latter occupying the coast between northern Roebuck Bay and Derby. The King Leopold Orogen surrounds

Table 5.1 Kimberley-Territory division, regions and PCs

Region/PC No.[a]	PC boundaries	Beach ID[b]	No. of beaches	km[c,d]	Total km
Kimberley					
WA13.01	Pt Usborne-Traverse Is	K 155-271	117	6746–7203	457
WA13.02	Traverse Is-Augereau is	K 272-515	244	7203–8245	1042
WA13.03	Augereau Is-C Londonderry	K 516-1102	587	8245–9434	1189
WA13.04	C Londonderry-C Domett	K1103-1345	243	9434–10,126	692
WA13.05	Cape Domett-Pearce Pt	K1346-1360	15	10,126–10,205	584
		NT 1-14	14	0–505	
WA13		Sub-total	**1220**		**3964**
West NT					
NT01.01	Pearce Pt-Gunn Point	NT 15-149	135	505–1256	751
NT01.02	Gunn Point-Cape Don	NT 150-183	34	1256–1859	603
NT01		Sub-total	**169**		**1354**
N Arnhem					
NT02.01	Bathurst-Melville Is[e]	–	*312*		
NT02.02	Cape Don-Laterite Pt	NT 184-506	323	1859–2373	514
NT02.03	Laterite Pt-Dhiprrnjura	NT 507-676	170	2373–2809	436
NT02.04	Dhiprrnjura-C Arnhem	NT677-1053	377	2809–3731	922
NT02-04		Sub-total	**870**		**1872**
		Total	**2257**		**7190**

[a]NCCARF compartment number
[b]ABSAMP beach ID (K = Kimberley, NT = Northern Territory)
[c]Distance from SA-WA border
[d]Distance from WA-NT border
[e]Bathurst and Melville islands are not discussed in this book

the southern Kimberley Basin (Fig. 2.1) and consists of Proterozoic (1800 Ma) folded sandstone and volcanics. Today these rocks form the King Leopold Range which extends to the coast between the highly indented eastern side of King Sound and Walcott Inlet and includes the offshore islands of the Buccaneer Archipelago.

The Kimberley Basin is the oldest of Western Australia's 18 sedimentary basins with rocks dating from 2000 to 400 Ma. The core of the basin, and covering the largest area, is a thick central basin sequence of sandstone, shale and basalt that was formed between 1800 and 1650 Ma and has since been subject to only minor faulting and warping. This was uplifted to form the central plateau, which has been heavily weathered and dissected along joint lines forming the prominent northwest and northeast joint-aligned drainage systems. It is surrounded in the east and south by the King Leopold and Halls Creek orogens, both remnants of mountain belts, which ceased tectonic activity by 1800 Ma. The basaltic lava of the northern Kimberley was extruded 1800 Ma onto the seafloor covering an area of 250,000 km^2. The area was also glaciated between 700 and 600 Ma.

By 400 Ma the Kimberley region had moved to the tropics and was covered by shallow seas fringed with coral reefs, which now form prominent belts of limestone, including the Napier Range and Geikie Gorge. A more southern location and glacial activity prevailed by 250 Ma. The breakup of Gondwanaland began in the northwest 180 Ma and continued counter-clockwise around the continent, with the south coast separating about 100 Ma when the continent began its northward movement. This movement and past warmer global temperatures resulted in the Kimberley having a tropical climate for the past 100 Ma, with more humid conditions prevailing until about 30 Ma when global cooling commenced. Tropical weathering of the basaltic rocks produced the aluminium-rich bauxite deposits in the northern Kimberley and the rich brown soil that fills the valleys. During this time the Prince Regent, Mitchell, Drysdale, King George, Berkeley and other smaller rivers eroded the plateau and cut deep joint-aligned gorges in the sandstone and volcanic rocks with waterfalls a common feature in the resilient rocks. Today the deeply weathered sandstone and basalts dominate much of the coast, while the deeply incised rivers and streams have produced the highly irregular coast and the numerous high bedrock islands, such as the Buccaneer and Bonaparte archipelagos.

5.2.2 Northern Territory Region

The NT can be divided geologically into the western half, consisting of Proterozoic fold belts (Pine Creek Orogen) and Monkey Shoals Basin, and the eastern half containing the Proterozoic Arafura and McArthur basins and the Arnhem Inlier (Fig. 2.1). All the rocks have been eroded down to a low peneplain and are deeply weathered and laterised. The geology of the coast, which is dominated by the basins, is described from west to east.

The *Bonaparte Basin* is a synclinal basin located on the eastern side of the Kimberley where it occupies the eastern side of Cambridge Gulf and extends east to Fog Bay in the NT. It contains a wide range of sediments up to 6000 m thick dating from the Cambrian to Quaternary (500–0 Ma).

The oldest rocks in the NT are part of the ancient northern Australian craton, represented in the territory by the *Pine Creek Orogen*, the remnants of which occupy the coast in the Darwin region. They also include the rocks of the Kakadu escarpment and outcrop along the north coast between Goulburn Island and Hall Point. The basement rocks were laid down as sedimentary rocks, which were intruded with volcanics and folded and metamorphosed between 2500 and 1800 Ma to form a mountain belt or orogen. The mountains were subsequently eroded exposing the intruded granite. Erosion of the mountains led to deposition of sedimentary layers between 2000 and 1800 Ma, followed by renewed mountain building and intrusion of granite and metamorphosis of the sedimentary rocks. These rocks were eroded and deeply weathered resulting in laterisation, followed by a renewed period of quartz-rich sedimentation by 1650 Ma. This was followed by 1500 Ma of stability.

During the Mesozoic (140 Ma), the coast was flooded, and fossiliferous sandstone and siltstone were deposited over the lowlands. The sandstones of the Arnhem Land escarpment sit on older deformed rocks consisting of the Archaean basement, folded Proterozoic sedimentary and volcanic rocks and Proterozoic granite, which have been eroded down and partially overlain with Cretaceous sandstone. The entire surface has been laterised down to 30 m depth, probably during the Jurassic about 125 Ma, and predates the Cretaceous sediments. The younger sediments and basalts have also been subsequently laterised.

The *Money Shoal Basin* is a pericratonic basin that formed after the continental breakup along the northwestern margin during the Jurassic. It covers an area of 350,000 km^2 much of which lies submerged in the Arafura Sea. In the NT, it includes the Kakadu coast, Van Diemen Gulf, Coburg Peninsula and Bathurst-Melville islands (Fig. 2.1). It consists of a relatively undeformed Middle Jurassic to Recent (140–0 Ma) basin containing up to 4500 m of sediment. The sediments consist of marine and clastic sequences overlain by carbonate sequences.

The *Arafura Basin* is a pericratonic basin 500,000 km^2 in area that extends north of the northern Arnhem Land coast into the Arafura Sea. It occupies the coast between Hall Point and Buckingham Bay and includes the Elcho-Wessel islands. The Basin contains up to 5000 m of Proterozoic to Permian (2500–250 Ma) to possibly Triassic (200 Ma) sediments, consisting of shallow marine sandstone, mudstone and some carbonates. Uplift and folding occurred during the Permo-Triassic, followed by major erosion during the Middle Triassic to Early Jurassic, which resulted in a planated surface, upon which the Money Shoal Basin sediments were deposited.

The small *Arnhem Inlier* extends along the eastern Arnhem Land coast from Melville Bay-Gove to Cape Shield. It consists of Proterozoic sediments, which have been folded and metamorphosed during the Barramundi Orogen (1860–1800 Ma).

The *McArthur Basin* is an intracratonic platform basin covering 180,000 km^2 and consisting of largely unmetamorphosed sedimentary rocks, which were deposited 1800–1400 Ma and overlie rocks of the Pine Creek Orogen. The rocks include sandstone, shale, carbonate and interbedded volcanic and intrusive igneous deposits, which reach up to 8000 m in thickness. It occupies the coast between Blue Mud Bay and the McArthur-Robinson river region and includes Groote Eylandt.

The *Carpentaria Basin* is a 560,000 km^2 north-south-trending intracratonic basin that covers most of the Gulf of Carpentaria (Fig. 2.1), with 80% located in Queensland waters. The basin was formed as a gentle intracratonic downwarp. At the coast it occupies a section of NT coast between the northern McArthur Basin centred on Arnhem Bay and the English Companys Islands in the north and Blue Mud Bay in the south. It then extends from just inside the NT border to include most of the low-lying southern and all the eastern coast of the Gulf of Carpentaria. The basin was formed in the Middle Jurassic (180 Ma) and contains Mesozoic (180–100 Ma) clastic sandstone, siltstone and conglomerate sediments up to 1800 m thick.

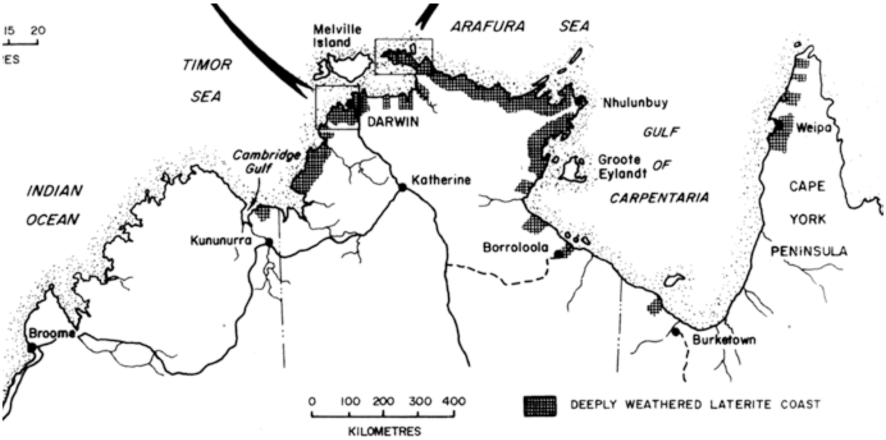

Fig. 5.2 Distribution of deeply weather strata (laterite) along the northern Australian coast. (Source: Nott 1994; reproduced with permission Journal of Geology)

5.2.3 Laterite

Tropical pedogenesis has produced extensive laterite soils across northern Australia particularly in the Cretaceous marine rocks. They outcrop along much of the coast of the NT and parts of the west and east coast of the Gulf of Carpentaria (Fig. 5.2). The bright red silicified mottled and pallid horizons are often exposed along the coast in generally low (<30 m high) eroding bluffs. As the bluffs retreat, they leave inter- to subtidal laterite reefs or platforms often covered by a veneer of cemented laterite pebbles. These reefs have a profound impact on inshore coastal processes and geomorphology affecting wave attenuation and refraction and thereby the direction and level of wave energy at the shore (Nott 1994; Young and Bryant 1998) and thereby the length, shape, orientation and type of beach. As Nott (1994) states 'The location of bays and headlands in the Darwin region has been controlled by the undulations of a resistant subsurface bed in the Cretaceous Darwin Member, and the development of a number of previously undescribed landforms such as ferricrete and saprolite rock platforms and offshore ferricrete reefs……'. The laterite is also mined for bauxite on the Gove Peninsula (Nhulunbuy) and at Weipa.

5.3 Climate

The tropical climate of northern Australia has been presented in Chap. 2, with this section focusing on the climate of the Kimberley-Territory division. Northern Australia has a tropical monsoonal climate (Aw) (Fig. 1.8) dominated by two pressure systems – the subtropical high and the equatorial low. The high dominates most of the year, and its great anti-clockwise spiral of winds generates the southeast trades across the northern half of Australia (Fig. 1.4). The high pressure and associated winds persist from April to November, with the wind velocity tending to increase into the winter period (Fig. 1.7). The trades bring some winter rain to Darwin and eastern Arnhem Land regions, while dry winter conditions dominate most of the interior and coast. During summer the intertropical convergence zone (ITCZ) shifts south and the Pilbara and Cloncurry heat lows draw in moist air from north of Australia which delivers the summer monsoonal rains. The climate consequently has hot wet summers and warm dry winters (Fig. 1.5). Wyndham located deep in Cambridge Gulf is Australia's hottest town with the mean monthly temperature exceeding 30 °C every month of the year and an average mean monthly maximum temperature of 35.9 °C. Rainfall ranges from a maximum of between 1200 and 1800 mm in the Darwin-Tiwi island regions (Darwin 1727 mm), decreasing between 900 and 1200 mm for much of the coast, with the lowest rainfall 850 mm at Wyndham (Fig. 1.5a, b). Mean summer temperatures average in the high 20s to low 30s, dropping to the mid-20s in winter (Fig. 1.5c, d). Wind direction changes with the seasons, with the moist northwest monsoons dominating during summer and the dry southeast trades in winter. Sea breeze tends to arrive during summer also from the northwest (Fig. 1.7). The entire coast is exposed to summer tropical cyclones, with their frequency increasing towards the west Kimberley coast though cyclone landfalls are rare along this section of coast (Fig. 1.6).

Creswell and Semeniuk (2011) divide the Kimberley coast into four climatic zones which range from east to west: subhumid in the Cambridge Gulf area and northeastern Kimberley coast (rainfall 800–1000 mm); humid from Cape Londonderry to Prince Regent River, centred on Port Warrender (1000–1400 mm); subhumid between Prince Regent River and Yampi Sound; and the semi-arid in the King Sound area (600–800 mm).

5.4 Coastal Processes

North Australia is bordered by the eastern Indian Ocean and southwest Pacific, which off QLD is called the Coral Sea and connected across the top by Torres Strait and the Arafura and Timor seas (Fig. 1.1). The oceanography of these seas is controlled by six factors which are discussed in Sect. 2.4.

5.4.1 Waves

Deepwater waves are generally low to moderate across the northern coast. Southern Ocean swell is precluded from the northwest coast owing to the northerly orientation of most of the coast coupled with the Coriolis effect deflecting waves to the west, together with the landlocked nature of the northern seas. The coast is therefore largely dependent on the prevailing low to moderate velocity southeast trades and summer northwest monsoonal winds, plus any accompanying sea breezes, for the generation of all waves. The wave climate is further constrained and modified by the limited fetch; the varied orientation of the coast, which results in exposed windward and sheltered lee shores; the fact that most of the trades blow offshore in this division; the generally shallow nearshore gradients, which lead to substantial wave refraction and attenuation of the breaker waves; and the high tide ranges which leads to tidal modulation of wave height throughout the day. The overall result is breaker waves which range from zero to very low to at most moderate energy on exposed east-facing shores. Section 2.4.1 discusses the wave climate across northern Australia, with a summary presented in Table 2.3.

Table 2.4 summarises the estimated breaker wave heights and period. These represent the wave height at the shore after undergoing wave refraction and attenuation and as a consequence will be lower than the deepwater seas. The highly indented and sheltered Kimberley has the lowest waves with 50% of the beaches receiving waves averaging only 0.1 m, while only 10% receive waves averaging 0.4 m and greater, with the highest waves only reaching 1 m on six beaches. Wave period averages a short 5 seconds. The NT has a modal breaker wave height of 0.3 m, with waves ranging from a low of 0.1 m to a high of 1.5 m, the latter received by only three beaches, with wave period ranging from 3 to 7 s for most of the coast.

To summarise, the Kimberley-Territory division receives low to moderate southeast deepwater waves for most of the year averaging 1–1.5 m, with periods of 4–5 sec on the few exposed beaches. The majority of beaches however receive some degree of sheltering from headlands, reefs, islands and shallow nearshore with 26% receiving breaker waves 0.1 m or less and 83% receiving waves 0.5 m or less.

5.4.2 Tides

The Kimberley region has the highest tides in Australia with Broome, Derby and Hall Point all exceeding 9 m at spring tide. The tidal wave originates in the Indian Ocean with an amphidromic point off Cape Leeuwin. It travels up the Western Australian coast arriving at Broome only 30 min after Fremantle, but then slows considerably as it propagates around the Kimberley coast arriving at Wyndham 10 h later (Fig. 2.2). The high tide ranges are due to amplification of the tide as it crosses the broad shallow northwest shelf, as well as additional resonate amplification within King Sound and Cambridge Gulf. Tides peak at Derby in King Sound (11 m) and again in Cambridge Gulf where they reach over 7 m at Wyndham.

In the NT, the tidal wave is associated with a tidal system with an amphidromic point located in the northern Arafura Sea, which propagates in a counter-clockwise direction, moving from west to east across the NT coast. In comparison to Fremantle, the tide arrives at Darwin 8 hours after Fremantle and Gove Harbour at 11 hours. The tide range is highest on the western NT coast going into Cambridge Gulf, with the spring range all greater than 6 m. It varies along the northern coast from a low of 2.4 m at Cape Croker to 4.8 m at Yabooma, dropping to 2.9 m at Gove. In the western Gulf, the spring tides range between 2 and 3 m.

Bettington et al. (2003) modelled tides in Van Diemen and Beagle Gulf and found that it enters Beagle Gulf from the west with a range of 4 m and is amplified peaking at Darwin (>5 m) and then is delayed moving through Clarence Strait to the east resulting in a delayed and reduced tide (3.5 m) at Glyde Point and Cape Hotham and the cause of the strong tidal current through the strait. A smaller (1.6 m) tide enters the gulf from the north via Cape Don, with the two tides meeting in Van Diemen Gulf.

In summary, tide range along the Kimberley and NT coasts varies from meso to Australia's highest mega-tides in Cambridge Gulf and King Sound (Fig. 1.15; Table 5.3). Figure 2.2a, b illustrates the tidal regimes around the northern Australian coast, while Table 5.2 lists the tidal characteristics of particular sites. The tides and associated tidal currents play a major role in both the coastal and nearshore and shelf oceanography. Along the coast the high tide ranges cause major oscillations in the shoreline, especially on the low gradient tidal flats which average several hundred metres between the high and low tide shorelines, while strong tidal currents are required to accommodate the tidal flows in estuaries and inlets, through topographic constrictions and across the generally shallow seafloor. The tides also modulate the breaking waves, with higher waves at high tide and lower more attenuated waves at low tide.

5.4.3 Rivers and Streams

The northwest division has a generally humid coast with annual rainfall ranging from 900 to 1800 mm, with most accompanying the summer monsoons. The summer rains feed almost 500 streams, creeks and rivers around the coast including 22 large river systems (Table 5.3). The major rivers and their impact will be discussed in Chaps. 6, 7 and 8.

5.4.4 Beaches

There are 2256 beaches along the Kimberley-Territory division coast. The Kimberley coast has the majority (1218); however they average only 0.37 km in length and occupy only 11% (452 km) of the coast (Table 5.4). The western NT has fewer (169) but longer beaches (2.08 km), which occupy 352 (26%) of the coast. Northern Arnhem Land has 869 beaches, which average 0.96 km in length and occupy 833 km (45%) of the coast. In total the beaches occupy just 23% of the division's coast, compared to an Australian average of 50%. The low percentage can be attributed to the lower wave energy required to transport sand to the shore; the dominance of steep rocky shores around the Kimberley coast with little or no accommodation

Table 5.2 Tidal characteristics of the Kimberley and Northern Territory coast (modified from Short 2006)

Location	Mean spring high tide (m)	Mean spring low tide (m)	Mean spring tide range (m)	Relative time WST of arrival 0 h = Perth − = before + = after
Kimberley:				(WST)
Broome	9.4	1.1	8.3	+0.5
Derby	11.2	1.1	10.1	+1.0
Port Warrender	7.0	0.6	6.4	+3.0
Cape Voltaire	6.5	0.9	5.4	+3.0
Hall Pt	9.2	0.4	8.8	+3.5
Napier Broome Bay	2.6	0.2	2.4	+3.5
Lesueur Island	2.8	0.1	2.7	+5.5
Cape Domett	6.9	1.4	5.5	+9.0
Lacrosse Island	5.9	1.3	4.7	+9.0
Wyndham	7.7	1.2	6.5	+10.0
Pelican Island	6.9	1.6	5.3	+10.0
Northern Territory:				(WST)
Turtle Pt	6.0	0.8	5.2	+9.5
Pearce Pt	6.6	0.8	5.8	+9.0
Daly River	6.0	0.4	5.6	+7.0
Tapa Bay	6.5	1.3	5.2	+7.5
Darwin	6.9	1.3	5.5	+8.5
Cape Hotham	4.4	1.0	3.4	+8.5
Cape Don	2.9	0.7	2.2	+8.0
Port Essington	2.6	0.5	2.1	+7.0
Cape Croker	2.4	0.5	1.9	+7.0
North Goulburn Island	2.7	0.5	2.2	+8.5
Entrance Island	3.9	1.1	2.8	+8.6
Yabooma	4.8	1.3	3.5	+10.0
Mallison Island	4.7	0.6	4.1	+9.5
Gove Harbour	2.9	0.7	2.2	+11.0

space; and the prevalence of mangroves and tidal flats in the very low energy more sheltered sections. The beaches for each region, PC and SC, are discussed in more detail in Chaps. 6, 7 and 8, while Short (2006) provides a description of all beaches in the division.

Table 5.3 Kimberley-NT division streams and rivers

Region	Larger rivers	All streams and rivers
Kimberley	8	258
Western NT	8	66
North Arnhem Land	6	160
Total	22	484

Table 5.4 Beach characteristics of the Kimberley-Territory division and its three regions

		Regions		Division
	Kimberley	Western NT	N Arnhem Land	Kimberley-Territory
Coast length (km)	3964	1354	1871	7189
No. beaches	1218	169	869	2256
Length of beaches (km)	452	352	833	1638
% beaches	11	26	45	23
Mean (km)	0.37	2.08	0.96	0.72
σ (km)	0.70	2.7	1.37	
Max (km)	10.3	19.5	14.5	14.5
Min (km)	0.02	0.1	0.03	0.02

5.5 Coastal Ecosystems

The coast of the Kimberley-Territory division provides a habitat for the four of the major tropical coastal ecosystems, namely, the dunes, mangroves, seagrass and coral reefs. Each is briefly discussed below, while Short and Woodroffe (2009) provide a more complete description.

5.5.1 Coastal Dune Vegetation

There are 2256 beaches spread around this section of coast, most of which are backed by some form of beach ridge or foredune grading up to some larger coastal dune systems. The foredunes are usually low and prone to overwashing; however, they tend to be well vegetated by a range of grasses and succulents (Fig. 2.3) moving landwards into shrubs and occasional trees including boabs (Fig. 5.3). The vegetation plays a very important role in stabilising the dunes as well as providing a habitat for a range of fauna. Creswell et al. (2011) identified 16 coastal habitats around the Kimberley coast and went on the list the key indicator species associated with each habitat. They found the main vegetation units include mangroves, shrubby chenopods (which include succulent halophytic shrubs), saline marsh, sedgelands, rushlands, dune scrub, dune grasslands and tea-tree thickets. They concluded that the spatially and temporally variable landscape, sediments/soils and hydrochemistry

Fig. 5.3 A solitary boab tree located on the low grassy foredune near Pauline Bay (K 950). (Photo: AD Short)

along the coast mean that the coastal vegetation habitats are the most complex habitats in the Kimberley region. On the beach dune systems, they found patchy vegetation with tree, shrub or low shrub/graminoid-dominated patches and a range of possible species.

5.5.2 Mangroves

The Kimberley and NT contain 5600 km^2 (49%) of Australia's mangrove systems (Table 2.9), and on both coasts mangroves dominate a significant proportion of the shoreline. In the Kimberley where 18 species of mangroves occur (Table 2.10), mangroves are particularly common in the numerous deeply embayed estuaries, river mouths and Cambridge Gulf (420 km^2). In the NT there are 30 species of mangroves along the northern coast (Table 2.10), with mangroves dominating the shoreline of the eastern Joseph Bonaparte Gulf, particularly the mouths of the Victoria (200 km^2) and Fitzmaurice rivers and parts of Van Diemen Gulf and Arnhem Bay.

Creswell and Semeniuk (2011) reviewed the Kimberley coast mangrove systems and identified 11 mangrove habitats that range from steep rocky (cliff) shores to tidal flats, tidal creeks, spits and high-tidal alluvial fans. Depending on coastal type, sedimentary setting and the local species pool, the mangroves form habitat-specific assemblages and characteristic floristic and structural zones within the mangrove formations. They concluded that the complexity of mangrove habitats and their relationship to the megascale coastal forms of this coastal setting are of international conservation significance.

5.5.3 Seagrass

Seagrass meadows occur in suitable shallow waters right around the Kimberley-Territory coast with 13 tropical species recorded (Table 2.11). The meadows are also a source of carbonate detritus for the beach systems.

5.5.4 Coral Reefs

Coral reefs are found right around the northern Australia coast extending from Ningaloo in the west to the southern GBR in the east (Table 2.13). Along the east Kimberley coast, they occur as offshore atolls and reefs as well as numerous fringing reefs, fringing both the rocky shore and many of the small beaches. Along the NT coast, the reefs are most prevalent along the northern coast including the north coast of the Tiwi (Bathurst-Melville) islands, Cobourg Peninsula, many of the offshore islands and peninsulas and Cape Arnhem and Groote Eylandt in the east. There are 148 beaches fronted by fringing reefs along the Kimberley coast (Fig. 2.4) and 65 along the western NT and north Arnhem Land coast. The fringing reefs are also a major source of carbonate detritus and sand for the adjoining beach systems.

Turtles and crocodiles are also common along the coast, with the turtles nesting on many of the beaches where they leave evidence in the form of nesting hollows and tracks. Saltwater crocodiles inhabit the entire coast and are commonly seen resting on the beaches, particularly beaches adjacent to creeks or estuaries. An overview of the Kimberley saltwater crocodile population and its habitat is given by Semeniuk et al. (2011) and the NT crocodile management by Letnic (2004).

5.6 Summary

The Kimberley-Territory division is the longest, most diverse and least developed on the Australian coast, with the steep, rugged and indented Kimberley coast contrasting with the low more continuous NT coast. The division covers 24% of the Australian coast and contains 22% of the beach systems, most in the rugged and indented Kimberley region. However, as the beaches have a mean length of just 0.72 km, they occupy just 23% of the coast. This is a tropical monsoonal coast with meso- to mega-tides and generally low to very low waves, resulting in a dominance of TD beaches, estuaries and river mouths. The coast is supplied by 22 larger rivers and ~500 smaller streams, with all the larger rivers flooding during the summer wet and delivering large volumes of suspended and bedload sediment to the coast, which have built deltas at their mouths. However as will be seen in Chaps. 6, 7 and 8, most of this sediment is deposited in the subtidal zone, with little deposited as onshore barriers. The reason for this is the lack of wave energy to transport it to the shore and wind energy to move it into dunes, with most of the dominant trades blowing offshore. As a consequence, despite the abundance of terrigenous sediment supplied to the coast, more than half of the beach sands are carbonate in origin, also reflecting the tropic location and sources including fringing coral reefs. The following three chapters (6, 7 and 8) discuss in more detail the three coastal regions in this division: the Kimberley, western NT and north Arnhem Land.

References

Bettington SH, Cummings SH, Imrie JA (2003) Modelling of tides in Van Diemen and Beagle Gulfs, Northern Territory, Australia. Coast and Ports Australasian conference 2003, Auckland, 8 p

Creswell ID, Semeniuk V (2011) Mangroves of the Kimberley coast: ecological patterns in a tropical ria coast setting. J R Soc West Aust 94:213–237

Creswell ID, Bridgwater P, Semeniuk V (2011) The habitats and vegetation of the Kimberley region. J Roy Soc West Aust 94:197–206

Letnic M (2004) Crocodile management in the Northern Territory of Australia. In: Crocodiles, proceedings of the 17th working meeting of the crocodile specialists group, IUCN, the World Conservation Union, Gland, Switzerland/Cambridge UK, pp 4–12

Nott J (1994) The influence of deep weathering on coastal landscape and landform development in the monsoonal tropics of northern Australia. J Geol 102:509–522

Semeniuk V, Manolis C, Webb GJW, Mawson PR (2011) The saltwater crocodile, Crocodylus porosus Schneider, 1801, in the Kimberley coastal region. J R Soc West Aust 94:407–416

Short AD (2006) Beaches of the northern Australia coast: the Kimberley, Northern Territory and Cape York. Sydney University Press, Sydney, 463 p

Short AD, Woodroffe CD (2009) The coast of Australia. Cambridge University Press, Melbourne, 288 p

Young RW, Bryant EA (1998) Morphology and process on the lateritic coastline near Darwin, northern Australia. Zeitschrift für Geomorphologie NF 42:97–107

Chapter 6
Kimberley Region

Abstract The rugged Kimberley coast extends for 3964 km as a predominately steep rocky coast dissected by joint-aligned creeks and rivers which form a highly crenulate shoreline, with very limited accommodation space and beaches and river restricted to usually deep embayments. It has a monsoonal climate with several moderate-sized rivers delivering sediment to the coast during summer floods. However, carbonate sediment still comprises 50% of the coastal sediment, the material derived from both the inner shelf and fringing coral reefs. Tides range from meso to mega, and waves are low to very low resulting in a dominance of small tide-dominated beaches and their wide tidal flats, with mangroves occupying all lower energy sections of the shore and the many bays and inlets. Sediment transport is extremely limited, and barriers predominately small regressive beach-foredune ridge plains, with just one areas of moderate dune transgression. The chapter describes the processes, beaches, barriers and sediment transport of the Kimberley coast, all set within a framework of hierarchical sediment compartments.

Keywords Kimberley · Meso-tides · Mega-tides · Monsoons · Beaches · Barriers

6.1 Introduction

The Kimberley coast occupies the northern section of WA and unlike the rest of the state has a highly irregular coastline. The irregularity is a product of three factors – geology, denudation and sea level. The geology provides the structure, general orientation and joint alignment; the long period of denudation has denuded the landscape primarily along the joints with the drainage system eroding deep, narrow linear valleys following the lineaments aligned roughly 20° and 330°; finally, the flooding of the lower reaches of these valleys by the PMT leads to formation of the linear coastal bays, estuaries and island chains. While the direct distance between the regional boundaries at Point Usborne and Pearce Point is 690 km, the shoreline length is 3964 km, a crenulation ratio of 5.7 indicating the extremely indented nature of the coast. The geology not only dominates the structure but also forms 88% of the shoreline as either rocky shore or mangrove-fringed rocky shore. Tyler (1996) provides the

A. D. Short, *Australian Coastal Systems*, Coastal Research Library 32,
https://doi.org/10.1007/978-3-030-14294-0_6

detailed geology of the Kimberley region, and Scott (2018) provides a layman's guide to the Kimberley geology, its evolution and selected coastal environments. Brocx and Semeniuk (2011) discuss the geoheritage significance of the Kimberley coast and argue that much is of international significance, particularly its drowned indented 'ria' valleys in a tropical monsoonal setting. They identified 11 basic landform patterns along the Kimberley coast ranging from simple straight rocky shores through to large funnel-shaped gulfs and all dependent of the geology and its structure.

The tropical climate also makes a significant contribution to the nature of the coast enabling the growth of coral reefs, which fringe many of the headlands and 8% of the small beach systems, together with the extensive tropical mangrove systems that occupy most of the sheltered embayments and estuaries. Creswell and Semeniuk (2011) found the Kimberley mangroves grow in a wide range of habitats ranging from rocky cliff shores to tidal flats and that they form habitat-specific assemblages. They concluded the Kimberley mangroves are of international conservation significance.

The Kimberley region contains five PCs and 14 SCs (Table 6.1 and Fig. 6.1). It has a total shoreline length of 3964 km containing 1220 beaches, which have an average length of just 0.37 km, the shortest regional length in Australia. They also occupy just 452 km or 11% of the coast, with just 25% backed by a barrier system,

Table 6.1 The Kimberley region (WA13), PCs and SCs boundaries and dimensions

Comp.[a]	Boundaries	Beach ID[b]	No. beaches	km[c]	Total km
WA13.01.01	Pt Usborne-Nares Pt	K 155-244	90	6746–7014	268
WA13.01.02	Nares Pt-Shoal Bay	K 245-271	27	7014–7203	189
WA13.01			*117*		*457*
WA13.02.01	Shoal Bay-Battery Pt	K 272-359	88	7203–7547	344
WA13.02.02	Battery Pt-C. Wellington	K 360-390	31	7547–7860	313
WA13.02.03	C. Wellington-Augereau Is	K 391-515	125	7860–8245	385
WA13.02			*244*		*1042*
WA13.03.01	Augereau Is-Davidson Pt	K 516-647	132	8245–8472	227
WA13.03.02	Davidson Pt-C. Bougainville	K 648-868	221	8472–8920	448
WA13.03.03	C. Bougainville-Anjo	K 869-986	118	8920–9162	242
WA13.03.04	Anjo-C. Londonderry	K 986-1102	116	9162–9434	272
WA13.03			*587*		*1189*
WA13.04.01	C. Londonderry-C.Bernier	K 1103-1244	142	9434–9600	166
WA13.04.02	C. Bernier-Thurburn Bluff	K 1245-1319	75	9600–9760	160
WA13.04.03	Thurburn Bluff C. Domett	K 1320-1345	26	9760–10,126	366
WA13.04			*243*		*692*
WA13.05.01	C. Domett-Turtle Pt	K 1346-1360	15	10,126–10,205	79
		NT 1-2	2	1–120	120
WA13.05.02	Turtle Pt-Pearce Pt	NT 3-14	12	120–505	385
WA13.05			*29*		*584*
WA13	**Kimberley region**	Sub-total	**1220**		**3964**

[a]NCCARF compartment number
[b]ABSAMP beach ID (K = Kimberley)
[c]Distance clockwise from State borders

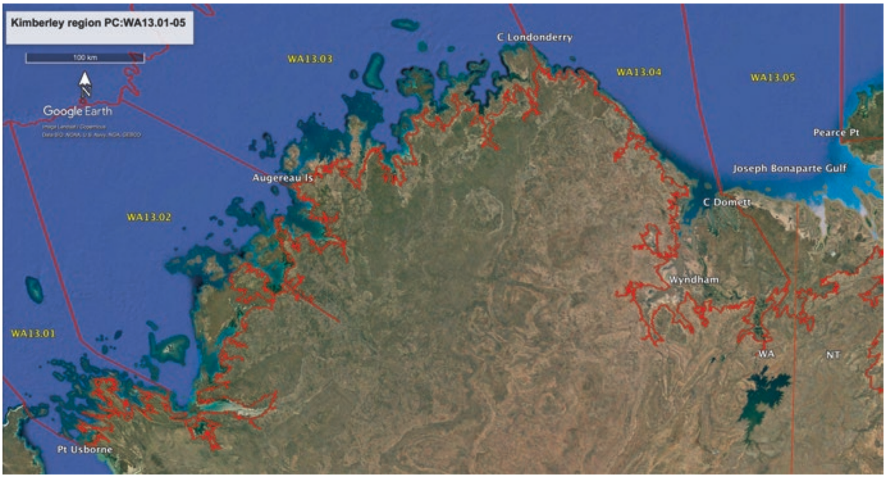

Fig. 6.1 Kimberley region PCs WA:13.01–13.05. (Source: Google Earth)

the smallest proportion of beaches and barriers in Australia's 23 regions. All of this reflects the dominance of the generally steep rocky shore, which precludes accommodation space, combined with the low energy waves, which only supplies low volumes of sand to some of the coast. Winds also tend to be offshore, with dune transgression limited to one location where they blow longshore.

6.1.1 Rivers and Streams

Eight moderate-sized rivers reach the Kimberley coast with the largest, the Ord, having a catchment of 103,900 km^2 and the largest river flow in the Kimberley at 9448 GL year^{-1}. This is followed in terms of catchment area by the Victoria (81,216 km^2), Drysdale (15,106 km^2), King Edward (9002 km^2), Fitzmaurice (8522 km^2), Berkeley (5149 km^2), Prince Regent (4964 km^2) and the King George (2776 km^2). In addition, there are over 250 smaller streams and creeks draining the hinterland and estuaries. All the upland rivers and streams are highly seasonal, with low to no flow during the winter dry, and high flow and flooding during the summer wet. Some individual rivers are discussed in the following sections.

6.1.2 Beaches and Sediments

The Kimberley beaches tend to be short and embayed, located either in gaps in the rocky shoreline or in the many small deeply incised valleys that reach the coast which results in an average embayment ratio of 0.67. They face every orientation

Table 6.2 Kimberley beach-dune sand characteristics

	Dune	HT swash	LT swash	2–6 m depth
n	114	131	124	57
Mean size (mm)	0.39	0.76	0.84	0.48
σ	0.16	0.88	0.67	0.53
Sorting	0.58	0.8	0.93	1.03
σ	0.19	0.36	0.32	0.44
% carbonate	50	58	62	45
σ	34	33	32	30

with a mean of 197° (σ = 125°), again reflecting the overriding control of the bedrock in determining where beaches form and what direction they face. Their sediments are a mix of local carbonate derived from the fringing reefs, seagrass meadows and other sources and terrigenous material deposited during and following the PMT together that delivered to the coast by some of the streams and rivers. As Table 6.2 indicates, sediments immediately seawards of the beaches are composed of poorly sorted, medium sand averaging 45% carbonate. The low tide beaches contain moderately sorted, coarse carbonate-rich (62%) sand. Moving up onto the high tide beach, carbonate remains high (58%), while the sand remains coarse and moderately sorted. The beaches tend to be moderately steep (mean slope = 6.1°) and narrow (mean width = 20 m). The low backing dunes-overwash areas contain the finest material (medium sand), which is moderately well-sorted with 50% carbonate. The typical beach material is therefore generally coarse, moderately to poorly sorted and carbonate-rich, which is typical of low energy tropical Australian beaches (Short and Woodroffe 2009).

Semeniuk (2011) found the Kimberley coast sediments had a '.. multitude of primary materials, provenances, and processes … superimposed on coastal settings that include large exposed embayments, smaller exposed embayments, protected embayments, coastal ravines, archipelago coasts, and straight coasts, that have varying orientation in relation to oceanographic aspect. As a result, the array of coastal sedimentary patterns and stratigraphic packages in the Kimberley region is considerable'. Terrigenous sediment has been derived from reworked regolith during the sea-level transgression and since the stillstand from the numerous streams and major rivers where it is redistributed by wave and tidal currents and in some locations by wind.

Semeniuk identified ten sources of biogenic materials ranging from gravel to mud in size including:

1. Coral reefs.
2. Calcareous algal reefs.
3. Calcareous algal encrustations.
4. Coral gravel and coarse sand transported shorewards by wave action along high energy coasts to form coral gravel deposits as spits, cheniers and beaches.

5. Oyster and barnacle skeletons as gravel and coarse sand derived from rocky shores and transported alongshore and shorewards by wave action along high energy coasts to form shell gravel deposits as spits, cheniers and beaches.
6. Benthic molluscs that inhabit tidal and subtidal sand and mud substrates.
7. Benthic and epibiotic foraminifera of tidal and subtidal environments that contribute particles to the sand deposits.
8. Diatoms in tidal environments that contribute mid-sized skeletons.
9. Plant material as leaves (detritus), branches and logs.
10. Plant material as in situ roots and trunks embedded in the mid- to high-tidal mud deposits. In the intertidal zone, these sediments are cemented to form beachrock, which in exposed locations are eroded into slabs and deposited as boulder beaches.

Semeniuk also proposed a series of stratigraphic packages ranging from boulder beaches to mud flats.

Figure 6.2 illustrates the considerable longshore variation in beach sand size (0.01–5.0 mm) and percent carbonate (0–100%), indicative of local sediment sources contributing to each small TC, with little or no longshore sediment transport or exchange between the beach systems. The dune sand, while finer, remains medium (predominately 0.2–0.6 mm), with carbonate ranging from 0% to 100%.

The beaches are predominately embayed and TD (72%), with 7% TM, 12.5% fronted by fringing coral reefs and 8% by intertidal rock flats and just 1% WD R (Table 6.3). They have a high tide beach slope averaging a moderately steep 6.1° and ranging with grain size from 1° to 18°. The high tide beach is relatively narrow (mean = 20 m) and usually grades into a wide low gradient intertidal sand flat (mean = 142 m) ranging from 10 to 1500 m wide and/or mud flats (mean = 368 m) ranging from 50 to 2000 m wide (Table 6.4). There are 14 B + RSF that have an average of 7.6 ridges ($\sigma = 2.5$), with 12 the maximum number observed, very close to the Australian average of 7.2 ridges ($\sigma = 4.6$) (Short 2006). There are 289 R + RF with flats averaging 149 m in width ($\sigma = 122$ m) ranging from 5 to 500 m and 148 R + CF with a mean flat width of 350 m ($\sigma = 488$ m) and range from 10 to 8000 m.

The dimensions of the beaches in each of the five PCs are listed in Table 6.5. The beaches average less than 0.5 km in length, except in PC:WA13.05 which is associated with the Victoria River delta. Short (2006) provides a description of each beach, and Short (2011) provides an overview of the Kimberley beach and barrier systems. The coast and the PCs are discussed in the following sections. The SCs are not discussed specifically, as in other sections of this book, owing to the dominance of the bedrock and lack of beaches, barriers and associated sediment transport within the PCs and SCs, apart from PC:WA13.05.

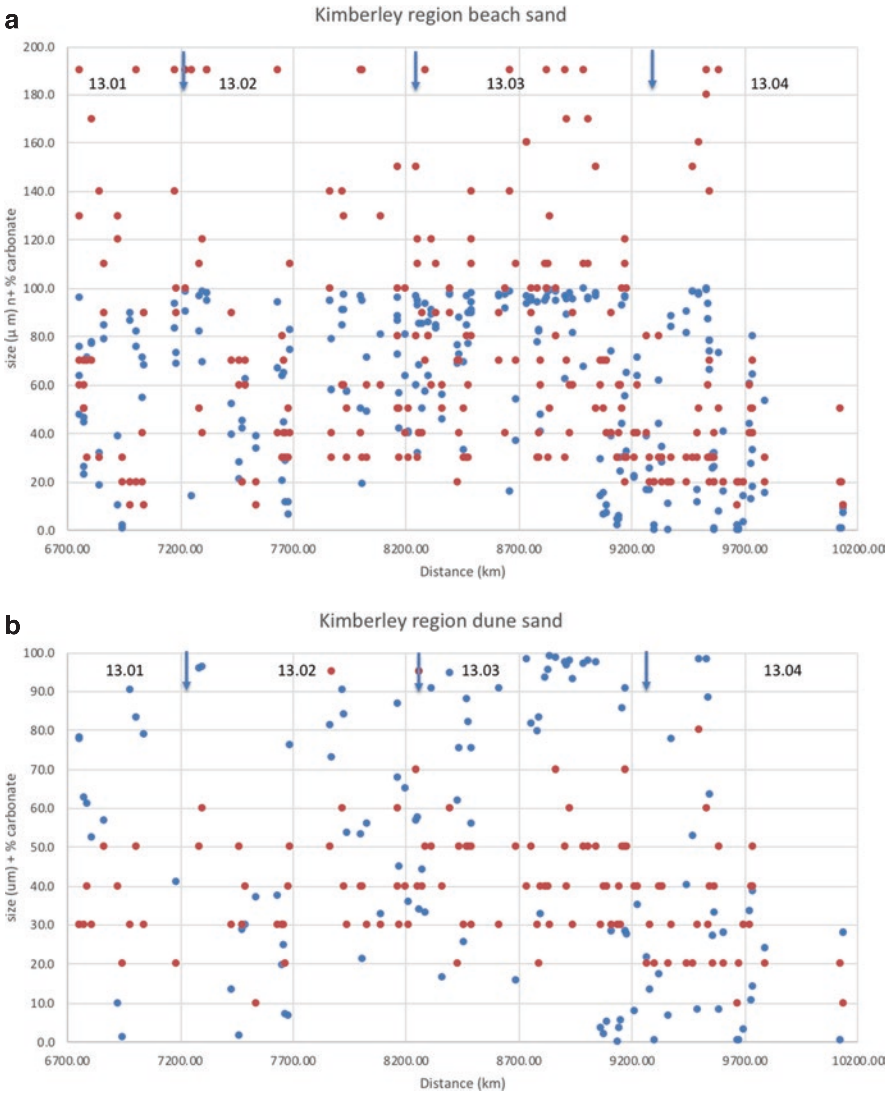

Fig. 6.2 Kimberley region (**a**) swash and (**b**) dune sand size (μm, red) and percent carbonate (blue). PC boundaries indicated by arrows. Distance from SA-WA border

6.2 PC:WA13.01 Point Usborne to Traverse Island

PC:WA13.01 extends along a very rugged and indented section of coast between Point Usborne and Shoal Bay and contains two SCs (WA13.01.01–02) (Fig. 6.3). At Point Usborne there is a dramatic change in the coast as the wide low mud flats of King Sound are replaced by the rugged folded rocks of the King Leopold Range. The range continues offshore trending northwest (300°) as the Buccaneer

Table 6.3 Kimberley region (WA13) beach states and types

BS	BS	No.	%	Total length (km)	%	Mean length (km)	σ (km)
6	R	12	1	4.1	0.9	0.34	0.15
7	R + LTT	18	1.5	13.7	3.0	0.76	0.5
8	R + LTR	3	0.2	7.1	1.6	2.4	1.4
9	UD	6	0.4	9	2.0	1.5	1.3
10	B + RSR	14	1.2	6.8	1.5	0.5	0.4
11	B + SF	377	31	98	21.7	0.26	0.3
12	B + TSF	390	32	145	32.1	0.37	0.5
13	B + TMF	106	8.7	74.4	16.4	0.7	1.8
14	R + RF	144	11.8	56.7	12.5	0.4	0.4
15	R + CF	148	12.2	37.6	8.3	0.25	0.2
		1218	100.0	452.4	100.0	0.37	0.70

Table 6.4 Some characteristics of Kimberley region beaches

Kimberley	n	Mean	σ	Aust. mean[a]	Min	Max
Orientation (deg)	1220	197	125	–	0	360
Embaymentisation	1220	0.7	0.3		0.1	1.0
Gradient (deg)	1220	6.1	1.1	–	0.1	18
Beach width (m)	1220	20	23	–	1	300
Sand ridges (m)	13	7.6	2.5	7.2	4	12
Sand flats (m)	835	142	185	485	10	1500
Mud flats (m)	207	368	327	410	50	2000
Rock flats (m)	144	149	122	–	5	500
Coral flats (m)	148	350	488	495	10	8000

[a]Source: Short (2006)

Table 6.5 Dimensions of Kimberley primary compartments

Sectors	13.01	13.02	13.03	13.04	13.05	Kimberley
Length coast (km)	457	1042	1189	692	584	3964
Beach length (km)	16.1	46.6	206.7	105.6	77.5	452.5
No. beaches	117	244	586	244	29	1220
% beaches	3.5	4.5	17.4	15.2	13.2	11.4
Mean length (km)	0.09	0.19	0.35	0.43	2.67	0.37
σ (km)	1.63	0.21	0.42	0.49	2.91	0.39
Max (km)	0.5	1.3	4.5	4.0	10.3	4.5
Min (km)	0.05	0.02	0.02	0.05	0.10	0.02

Archipelago, which contains 800 rugged bedrock islands up to 100 m high. These extend across the mouth of King Sound and up to 40 km seawards and include the larger Cockatoo and Koolan islands. The irregularity of the coast is indicated by the fact that this compartment contains 457 km of open coastline, while the direct distance between Point Usborne and Shoal Bay is just 76 km, representing a crenulation ratio of 6. The coast for the most part is rocky or has mangrove-fringed rocks,

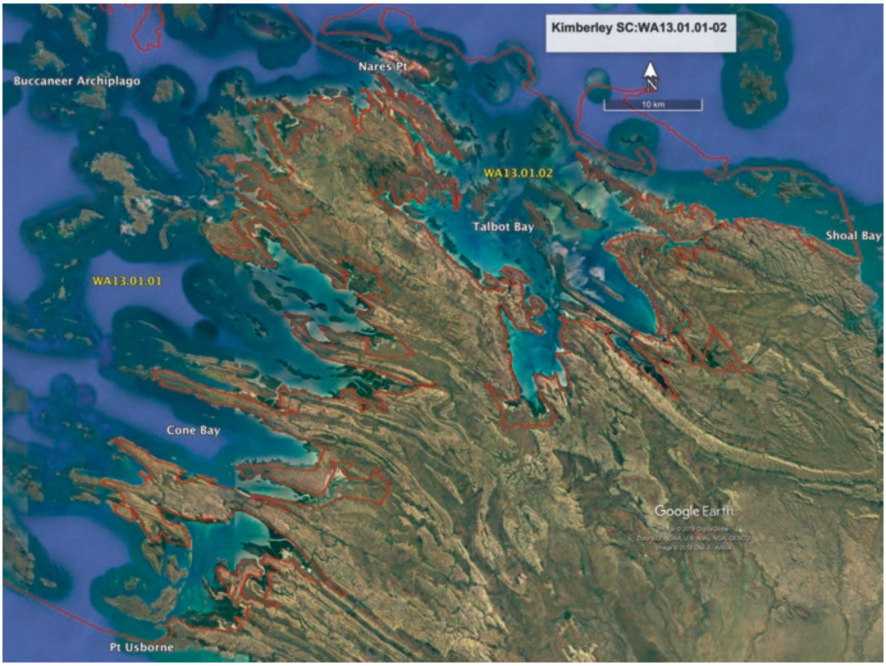

Fig. 6.3 Kimberley PC:WA13.01 and its two SCs:WA13.01.0–.02 are dominated by the drowned linear ranges of the King Leopold Range. (Source: Google Earth)

with just occasional pockets of sand forming the beaches and occupying only 3.5% of the shore, the lowest of any Australian PC. The rocks are predominately Proterozoic sandstones, which rise steeply to elevations of between 20 and 100 m, and then continue up to 200 m high on the backing dissected plateau. Apart from a fishing camp in Cone Bay, there is no development or vehicle access to the mainland coast. On the adjoining Cockatoo and Koolan islands, located just north of Nares Point, iron ore has been mined episodically since the 1950s and as of 2019 was still operational. The mine maintains mining camps on each island.

6.2.1 *Beaches and Sediments*

This PC has a total of 115 beaches, which occupy just 16.5 km or 3.5% of the shoreline. Most of the beaches are located where wave energy is highest on or towards the outer western end of ten rocky northwest-trending peninsulas. The bays between the peninsulas have either steep rocky shore or mangroves-lined wherever there is substrate available (Fig 6.4a). The beaches are all TD, with half the beaches fronted by tidal sand flats (48%) (Fig 6.4a–c), followed by tidal mud flats (25%) and fringing coral reefs (26%) (Table 6.6). They have an average length of 0.14 km (σ = 0.1 km),

Fig. 6.4 PC:WA13.01 is dominated by the linear, folded Proterozoic sandstone ridges of the King Leopold Range and small pockets of sand shown here at: (**a**) Faint Point (K-175–178); (**b**) in Cone Bay (K-204–205); (**c**) Dunvert Island (K-218–219); and (**d**) Silica Beach on Hidden Island (K-223) which is composed of 98% white quartz (silica) sand. (Photos: AD Short)

Table 6.6 Kimberley region PC:WA13.01 beach types and states

BS	BS	No.	%	Length (km)	%	Mean (km)	σ (km)
12	B + TSF	55	47.8	8	49.5	0.14	0.08
13	B + TMF	29	25.2	3.4	21.1	0.12	0.08
14	R + RF	1	0.9	0.1	0.9	0.15	–
15	R + CF	30	26.1	4.6	28.5	0.15	0.1
		115	100	16.1	100	0.14	

with the longest just 0.5 km. As indicated by Figs. 6.3 and 6.4, the coast is predominately rocky, with the small beaches of variable orientation occurring in small indentations or valleys in the more exposed rocky sections, while mangroves tend to spread along the sheltered and embayed sections of shore. About 20 streams drain to the coast but no major rivers.

The beach and dune sediment characteristics are listed in Table 6.7. The beaches are generally composed of moderately sorted, coarse (mean = 0.8 mm), carbonate-rich sand, while the dunes sands are moderately well-sorted, medium sand (mean = 0.33 mm), with the same proportion of carbonate detritus. The longshore variation in the PCs beach and dune sand characteristics is shown in Fig. 6.2. It displays the extreme variation in sediment texture between beaches, typical of the

Table 6.7 Kimberley region PCs: swash zone and dune sand characteristics

Region	13.01	13.02	13.03	13.04	13.05
Swash (HT&LT)					
n	22	71	113	46	3
Mean size (mm)	0.8	1.0	0.8	0.5	0.2
σ	0.5	1.0	0.7	0.6	0.04
Sorting	0.9	0.8	0.9	0.7	0.4
σ	0.3	0.3	0.3	0.4	0.04
% carbonate	53	66	67	42	5
σ	30	26	32	37	3
Dune					
n	9	31	51	21	1
Mean size (mm)	0.3	0.4	0.4	0.3	0.1
σ	0.1	0.2	0.1	0.2	–
Sorting	0.6	0.6	0.6	0.5	0.4
σ	0.2	0.1	0.2	0.2	–
% carbonate	55	51	57	32	28
σ	30	28	36	31	–

Table 6.8 Kimberley region (WA13) and PCs: WA13.01–05 barrier dimensions

PC	WA13.01	WA13.02	WA13.03	WA13.04	WA13.05	WA13
No. barriers	8	33	174	11	95	**321**
Length	1.95	12.4	106.5	92.5	64.3	**278**
Mean min. Width (m)	80	60	80	420	85	**–**
Mean max. Width (m)	120	100	160	1300	190	**–**
Mean height (m)	4	3.2	3.6	4.4	4.3	**–**
Area (ha)	13.5	94.5	2164.3	4400	1773.5	**8446**
Unstable (ha)	0	0	94	70	554	**718**
Total vol (M m^3)	0.52	3.3	78.1	225.5	205.9	**513.3**
Unit vol ($m^3\ m^{-1}$)	264	268	733	2438	3201	**1848**

Kimberley coast, and confirms both the local source of the beach sand and the lack of exchange between beaches, with most beaches operating as separate TCs, with small and finite amounts of sand available for each cell.

6.2.2 *Barriers*

Eight of the beaches are backed by small barrier systems, with an average area of just 1.7 ha (Table 6.8). They range in width from 80 to 120 m, a low mean height of 4 m and a unit volume of just 264 $m^3\ m^{-1}$, the lowest for any PC in Australia (Appendix 34.2). These dimensions further confirm the low energy nature of this coast and the low volumes of sediment delivered to the shore. In addition, because of the low waves and generally offshore winds, dune development is minimal, with most beaches consisting of the beach and at most a low overwashed back beach, while the few barriers consist of a single to a few low vegetated beach and/or low foredune ridges.

6.3 PC:WA13.02 Traverse Island to Augereau Island

PC:WA13.02 extends from Shoal Bay to Augereau Island and is dominated by five large rocky inlets (Walcott Inlet, Doubtful Bay, Camden Harbour, St Georges Basin and Prince Frederick Harbour) separated by large rocky peninsulas (Fig. 6.5). It has

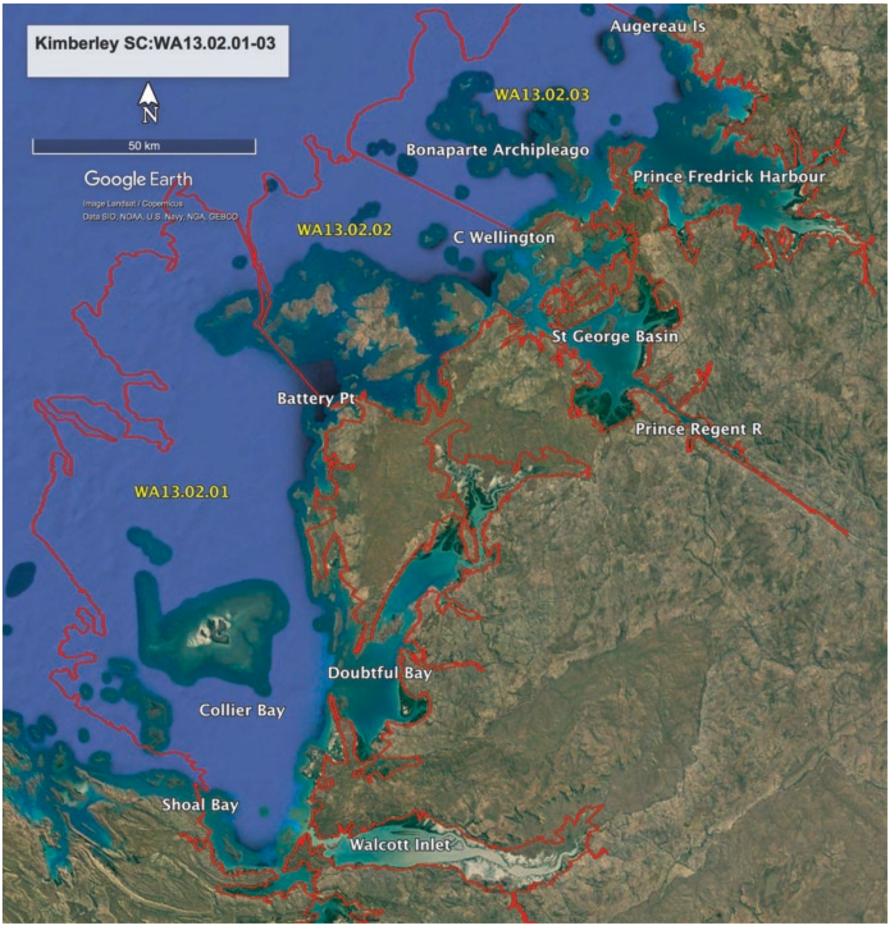

Fig. 6.5 PC:WA13.02 and its three SCsWA13.02.01–03. (Source: Google Earth)

1042 km shoreline with a crenulation ration of 5.2, reflecting the highly indented nature of the rocky shore. Several large bedrock islands extend seawards of Camden Harbour including Augustus and Darcy islands, and the Coronation Islands extend for 40 km seawards of Port Nelson. The geology is either the Proterozoic sandstone, siltstones and conglomerates of the Kimberley Basin or basic volcanics. Joint lines running to the northwest and northeast control the drainage pattern, particularly on the sedimentary rocks, with the Prince Regent River running directly northwest for 130 km (Fig. 6.5). Along the shore the rocky slopes rise steeply to between 20 and 100 m and then rise up to 250 m on the heavily dissected plateau. The only development in this area is the Kuri Bay pearl farm, together with some vessel-based pearl farms and tourist ventures. There is no vehicle access to the coast.

6.3.1 Rivers and Streams

About 25 small streams flow to the coast together with the Calder, Charnley and Isdell rivers (combined catchment = 12,732 km^2) which flow into Walcott Inlet, where their sediments have developed a bedrock-controlled, TD funnel-shaped delta, with 58 km^3 of mangroves. The larger Prince Regent river (49 64 km^2) flows into bedrock-controlled St Georges Basin (Fig. 6.5), where it has deposited sediment in two subbasins, which support 180 km^2 of mangroves.

6.3.2 Beaches and Sediments

There are a total of 245 beaches along this PC averaging just 0.19 m in length with a total length of 46.5 km, which represents just 4.5% of the coast. The beaches are composed of moderately well-sorted, carbonate-rich (mean 66%), coarse sand, which fines to medium sand in the dunes (Table 6.7). Figure 6.2 indicated the considerable longshore variation in both grain size and percent carbonate, reflecting the localised nature of the sediment sources and lack of exchange between the beaches.

The combination of high tides, low waves and often sheltered locations results in a dominance of TD beaches (78%), together with 17% fronted by rock flats and just four more exposed TM beaches (1.6%) (Table 6.9). The short length of the beaches is a result of the geological control, with beaches being generally restricted to the base of narrow bays and river valleys as illustrated in Fig. 6.6. Figure 6.7 shows a storm-deposited cobble beach (Fig. 6.7a); a narrow sandy high tide beach (Fig. 6.7b) with rocks seawards and landwards; a typical high tide beach with overwash debris (Fig. 6.7c); and a steep high tide beach and 300 m wide tidal sand flats (Fig. 6.7d) illustrating the considerable variation in the nature of the beaches.

Table 6.9 Kimberley PC:WA13.02 beach types and states

BS	BS	No.	%	Length (km)	%	Mean (km)	σ (km)
7	R + LTT	3	1.2	2.2	4.7	0.7	0.55
9	UD	1	0.4	1.3	2.8	1.3	–
11	B + SF	93	38.0	14.8	31.8	0.16	0.18
12	B + TSF	64	26.1	11.5	24.7	0.18	0.16
13	B + TMF	33	13.5	5.4	11.6	0.16	0.19
14	R + RF	42	17.1	10.5	22.6	0.25	0.2
15	R + CF	9	3.7	0.8	1.7	0.09	0.06
		245	100	46.5	100		

6.3.3 Barriers

There are 33 barrier systems backing 13% of the beaches, with a total length of just 12.4 km (27% by length), indicating the barriers only occur on the longer and more exposed beaches (mean = 0.37 km) (Table 6.8). They typically average 60–100 m in backshore width and 3.2 m in height, with most consisting of low beach ridges, and include a few tombolos (Fig. 6.6b, c). They have a total area of 94.5 ha and volume of 3.3 M m^3, which represents 268 m^3 m^{-1}, which together with compartment 13.02 is one of the lowest PC barrier volumes in Australia.

6.4 PC:WA13.03 Augereau Island to Cape Londonderry

PC:WA13.03 occupies the northwestern section of the Kimberley region between Augereau Island and Cape Londonderry (Fig. 6.7). The 1189 km of shoreline faces northwest, with the Bonaparte Archipelago paralleling most of the coast and its several hundred generally small islands extending up to 50 km offshore. The predominately rocky shore contains four major bays (Montague Sound, Admiralty Gulf, Vansittart Bay and Napier Broome Bay), each separated by large peninsulas capped by Cape Voltaire, Cape Bougainville and Cape Londonderry (Fig. 6.8), the capes rising to between 10 and 50 m in height. The rocks are predominately Proterozoic sandstones, with the northern Cape Bougainville and Cape Londonderry composed of laterised Proterozoic basalt. The coast has a crenulation ratio of 5.3, reflecting its highly indented nature. Beaches comprise 17% of the shore, the remainder rocky on the open coast and mangrove-lined rocky shore in the more sheltered sections and bays. There is 4WD vehicle access to the coast at Crystal Head (K 1023) and via Kalumburu to the landing at beach K 1023, with Kalumburu (population 460) the only settlement near the coast, together with the 'Kimberley Coastal Camp' tourist camp at beach K 719.

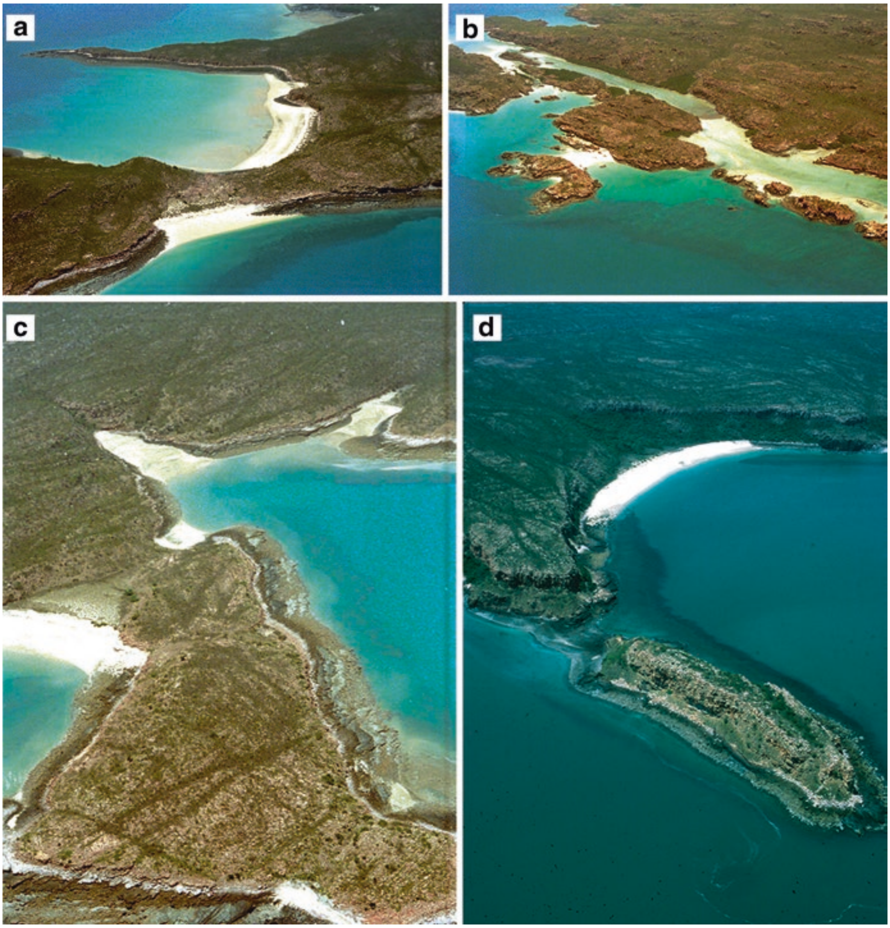

Fig. 6.6 Aerial views of PC:WA13.02 beaches: (**a**) K 368 and 370 at High Bluff, both fronted with sand flats then fringing reef; (**b**) K 510 on Augereau Island a 100 m long patch of sand connected to the mainland by sand flats; (**c**) K 388-391 a series of pocket beaches with variable orientation on Cape Wellington; and (**d**) one of the more exposed beaches at Cape Brewster (K 397). (Photos: AD Short)

6.4.1 Rivers and Streams

This PC has ~140 streams and two larger rivers draining to the coast. The King Edward (9002 km^2) and Drysdale (15,106 km^2) rivers both flow into the large Napier Broome Bay, the King Edward at its base and the Drysdale on its eastern side. The King Edward has a classic funnel-shaped tide-dominated delta which has partly infilled the bedrock bays and which is largely covered in mangroves. The Drysdale flows through a supratidal deltaic plain into a curving mangrove-lined bays.

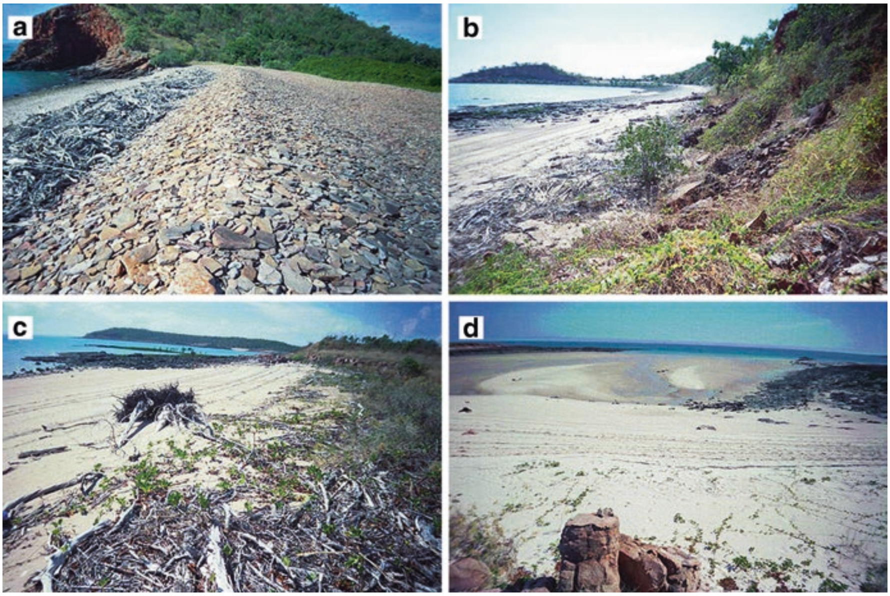

Fig. 6.7 PC:WA13.02 beaches: (**a**) storm-deposited cobble beach (K 286); (**b**) beach K 297 wedged between rocky slopes and a beachrock foreshore; (**c**) sandy high tide beach and overwash debris (K 302); and (**d**) steep high tide beach with 100 m wide tidal sand flats at Freshwater Cove (K 330). (Photos AD Short)

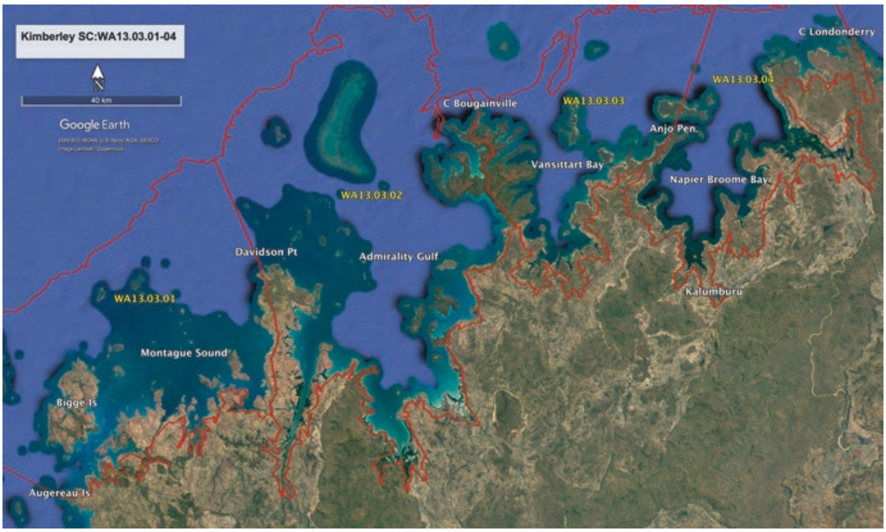

Fig. 6.8 PC:WA13.03 and its four SCs WA13.03.01–03. (Source: Google Earth)

6.4.2 Beaches and Sediments

PC:WA13.03 contains 587 beaches that have an average length of 0.35 km and occupy 17.5% of the shore an order of magnitude greater than PCs WA13.01 and 13.02. There are 20 more exposed TM beaches occupying 8.6 km of the shore, with the majority (153 km 74%) TD, with 22% fronted by either rock flats or fringing coral reefs (Table 6.10).

The beaches are composed of moderately sorted, coarse, carbonate-rich sand, while the backing foredune/overwash is slightly finer with medium sand (Table 6.7). Figure 6.2 illustrates the longshore variation in grain size and percent carbonate, with considerable variation between beaches, again reflecting the predominance of locally sourced sediment and the lack of exchange between the many small bedrock-bound TCs (Fig. 6.9a, b and d). There is however evidence of some longshore sand transport in the presence of several spits and recurved spits (Fig. 6.10c), some up to 2.5 km long located on the more exposed Cape Talbot (Fig. 6.10d).

6.4.3 Barriers

This PC has 174 barriers the largest number of beaches and barriers for the west Kimberley region, with 30% of the beach backed by a barrier system. They are however predominately a single low beach ridge-foredune, with a few regressive barriers/spits (Figs 6.9a and 6.10c). They average 0.6 km in length and 90–160 m in width with a low average elevation of 3.6 m. They have an area of 2164 ha, with a total volume of 78 M m^3, which represents 733 m^3 m^{-1} of beach (Table 6.8), substantially more than PC:WA13.01 and 13.02, but still very low by Australian barrier standards, and the barriers of the east Kimberley.

Table 6.10 Kimberley PC:WA13.03 beach types and states

BS	BS	No.	%	Length (km)	%	Mean (km)	σ (km)
6	R	1	0.2	0.08	0.0	0.08	–
7	R + LTT	10	1.7	5.2	2.5	0.52	0.34
10	UD	9	1.5	3.4	1.6	0.38	0.29
11	B + SF	277	47.2	81.5	39.4	0.29	0.34
12	B + TSF	168	28.6	65.4	31.6	0.39	0.51
13	B + TMF	16	2.7	6	2.9	0.38	0.32
14	R + RF	64	10.9	33.7	16.3	0.53	0.54
15	R + CF	42	7.2	11.5	5.6	0.27	0.26
		587	100	206.78	100		

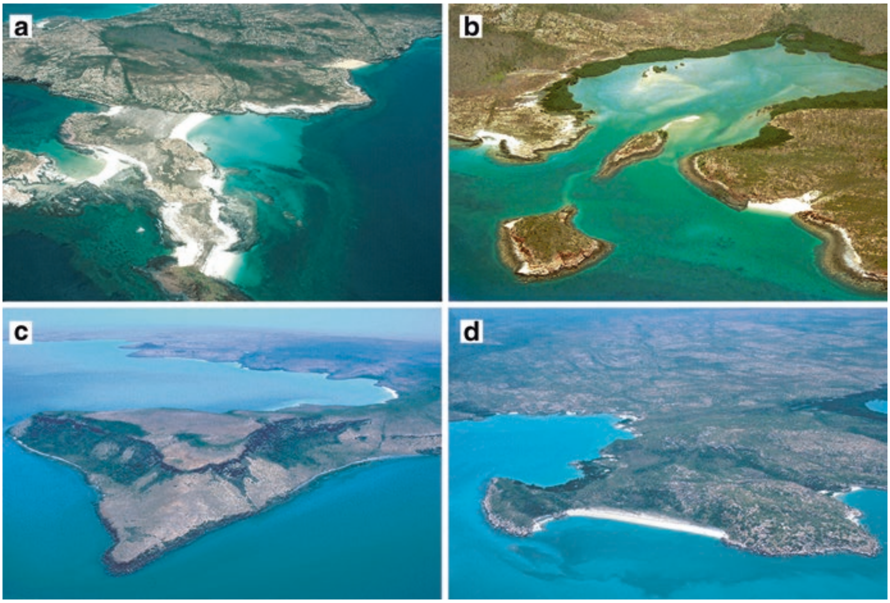

Fig. 6.9 PC:WA13.03: (**a**) Cape Voltaire (foreground) is linked to the mainland by a series of tombolos (K 642-7); (**b**) beaches K 657-8 lie either side of a mangrove-lined bay; (**c**) Crystal Head is 190 m high and composed of Proterozoic basalt; and (**d**) beach K 756 lies deep in Admiralty Gulf. (Photos: AD Short)

Fig. 6.10 PC:WA13.03: (**a**) Flat-topped Cape Bougainville is composed of Proterozoic basalt (K 878-80); (**b**) beaches K 978-80 lie either side of a low mangrove-lined bedrock point; (**c**) the road from Kalumburu leads to the landing at beach K-1023 located at the base of a 2 km long recurved spit; (**d**) Cape Talbot is a low sandstone point with a 700 m wide regressive barrier (K 1072) to the south and 2.6 km long spit (foreground K 1074) to the north, both two of the larger barrier systems in this compartment. (Photos: AD Short)

6.5 PC:WA13.04 Cape Londonderry to Cape Domett

Cape Londonderry at 13°64′ S is the northernmost tip of Western Australia and the Kimberley region. At the cape the nature of the coast changes from the highly irregular indented rocky coast of the western Kimberley, to a straighter southeast-trending coast of the eastern Kimberley (Figs. 6.11 and 6.12) roughly paralleling the 330° lineament. The coast can be divided into three parts. The relative straight section from Cape Londonderry to Cape Dussejour with a crenulation ratio of 2.1(SCs:WA13.04.01–02); the funnel-shaped 20 km wide 70 km long Cambridge Gulf (SC:WA13.04.03); and the predominately sedimentary section between the low bedrock of Cape Domett (WA) and the Northern Territory's (NT) Pearce Point, occupied by the large Keep, Victoria and Fitzmaurice river deltas and their extensive salt flats in places up to 50 km wide (PC:WA13.05, Fig. 6.12). The geology however remains dominated by the horizontally bedded Proterozoic sandstones as far as Cape Dussejour. Along the coast the sandstone rises to between 10 and 120 m, rising inland to the heavily dissected plateau to between 100 and 150 m high. Cape Dussejour abuts the Bonaparte Basin and Cambridge Gulf, with the low Cape Domett on the eastern side of the gulf composed of Devonian sandstones and

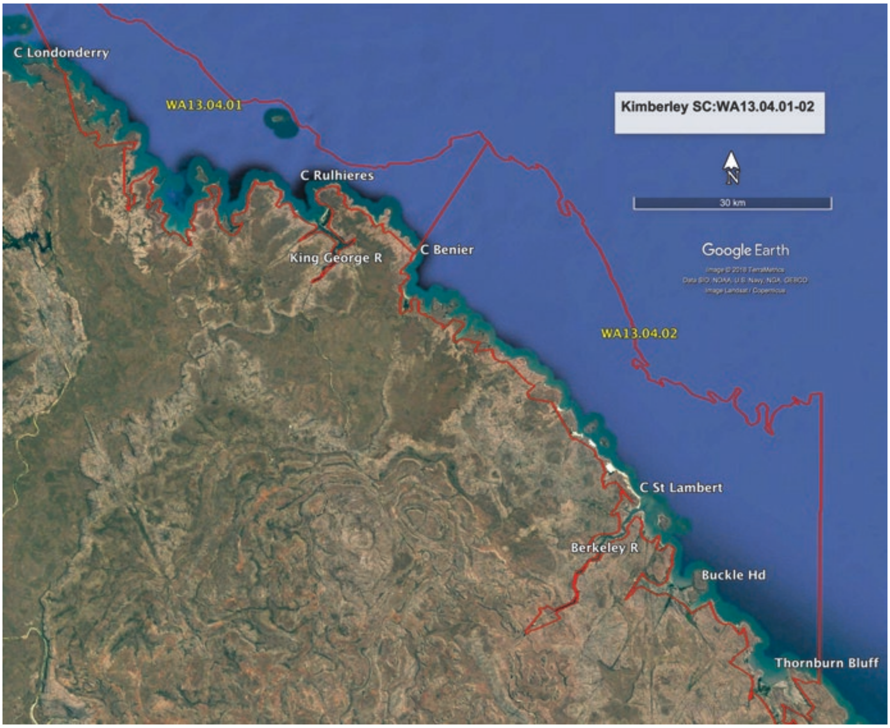

Fig. 6.11 SCs:13.04.01–02 Cape Londonderry to Thornburn Head. (Source: Google Earth)

Fig. 6.12 SCs:WA13.04.03 and 13.05.01-02 occupy the coast of Joseph Bonaparte Gulf which is feed by the Ord, Keep, Victoria and Fitzmaurice rivers. (Source: Google Earth)

conglomerates, the two capes forming the entrance to the gulf. Further east into the NT, the basin is composed of Permian sedimentary rocks with the shoreline dominated by tidal flats.

The only development on the coast is fly-in tourist resorts at Faraway Bay and Berkeley River and the town and port of Wyndham, located 90 km deep into Cambridge Gulf. The only vehicle access to the coast is at Wyndham.

6.5.1 Rivers and Streams

Approximately 70 streams drain to the coast together with three rivers. The smaller King George and Berkeley rivers reach the coast at Koolama Bay and Cape St Lambert, respectively (Fig. 6.11), both carrying sand eroded from the sandstone plateau. The King George (2776 km^2) lies 5 km inside the bay in lee of Cape Ruhlieres and is sheltered from the trade wind and waves. Its sediments have been reworked by occasional storm waves into a 1.2 km wide series of beach-foredune ridges on the eastern side of its mouth (Fig. 6.13a), with tidal sand flats extending into the 3.5 km into the drowned U-shaped valley. The Berkeley River (5149 km^2) flows into a more exposed east-facing location. Its sandy bedload is deposited in its broad mouth, rearranged into linear shoals by the tides (Fig. 6.13b), then worked

Fig. 6.13 PC:WA13.04 coast and beaches: (**a**) The King George River flows out of its bedrock valley and has deposited a series of sand ridges at its mouth; (**b**) the Berkeley River has deposited sand shoals at its broad mouth; and (**c**) part of the extensive Ord River mangrove-fringed salt flats. (Photos: AD Short)

onshore by the waves and to the west by the trade winds supplying sand to the Cape St Lambert transgressive dune field, the largest dune field and one of the largest barriers in the Kimberley region. The sandy nature and exposed location of both rivers preclude the development of extensive tidal flats, with mangroves occupying only 3 and 1.5 km^2, respectively.

The large Ord River (82,213 km^2) flows into the base of the 90 km long Cambridge Gulf (Fig. 6.12) delivering the largest river flow in the Kimberley region and a substantial suspended load, which contributes to the extensive tidal flats that have filled a substantial portion of the lower gulf. The Ord River delta has 420 km^2 of mangroves and a massive 1386 km^2 of supratidal salt flats (Fig. 6.13c).

Coleman and Wright (1978) investigated sedimentation in the Ord River delta and found

'Near the coast, prograding shorelines are characterized by extensive mangrove successional sequences and scattered thin beach-ridge deposits. In the interfluve regions and farther inland along the coast, tidal-plain sedimentation has given rise to extensive flats that are bare of vegetation at approximately the high spring tide level. Evaporites, algal-layered silts and clays, and massive sandy deposits form the bulk of these tidal-flat sediments. Sinuous tidal channels, displaying low width/depth ratios and characterized by a progressive tide wave, are found throughout the coastal tidal-flat region'. 'In the lower Ord River, linear, elongate tidal ridges within and seaward of the channel form the major sand deposits of the delta'.

Thom et al. (1975) describe the mangrove ecology of the Cambridge Gulf and Ord River including the evolution of the extensive mud flats, which is dominated by vertical accretion and lateral progradation, the latter also investigated by Wright et al. (1972). Lees (1992a) studied the recent terrigenous sedimentation in Joseph Bonaparte Gulf and found a seaward fining lobe of sand extending 80 km seawards of the entrance to Cambridge Gulf. This would correspond to the low carbonate (>1%) quartz-rich beach sand located either side of the gulf entrance. More recently Anderson et al. (2011) conducted high-resolution multibeam maps and collected seabed samples in eastern Joseph Bonaparte Gulf.

6.5.2 Beaches and Sediments

PC:WA13.04 has 243 beaches, which occupy 105.5 km (15%) of the 692 km long sector. The majority of the coast faces east-northeast exposing it to the trade wind and waves. The higher wave and wind energy is reflected in the presence of 11 WD R beaches and 11 TM beaches; however TD and particularly B + TSF continue to dominate at 120 (49%) (Table 6.11 and Fig. 6.14b and c). What is interesting is the increase in beaches fronted by rock flats (34) and fringing coral reefs (67) in all 42% (Fig. 6.14a). Some of the highest energy beaches are found at Cape St Lambert where waves reach 1 m maintaining a R + LTR beach, which is in turn backed by the largest transgressive dune field in the Kimberley, the dunes extending parallel to the shore for up to 1.5 km (Fig. 6.14d). Between Observation Head and Cape Dussejour is a 20 km section of cobble boulders all fronted by rock flats (Fig. 6.15d), and at the cape, the exposed beach has a well-developed series of six intertidal sand ridges (B + RSF) (Fig. 6.15e). However, the numerous headland, rock and reefs tend to lower waves to 0.5 m or less on most beaches maintaining the dominance of the TD beaches, particularly fronted by tidal sand flats (Fig. 6.15a–c, e).

Table 6.11 Kimberley PC:WA13.04 beach types and states

BS	BS	No.	%	Length (km)	%	Mean (km)	σ (km)
6	R	11	4.5	4	3.8	0.36	0.14
7	R + LTT	5	2.1	6.3	6.0	1.26	0.47
8	R + LTR	3	1.2	7.1	6.7	2.37	1.42
9	UD	3	1.2	3	2.8	1.0	1.47
10	B + RSF	4	1.6	2.8	2.7	0.7	0.53
11	B + SF	7	2.9	1.7	1.6	0.24	0.12
12	B + TSF	92	37.9	43.6	41.3	0.47	0.47
13	B + TMF	17	7.0	6.2	5.9	0.36	0.54
14	R + RF	34	14.0	10.1	9.6	0.3	0.18
15	R + CF	67	27.6	20.6	19.6	0.31	0.23
		243	100	105.4	100		

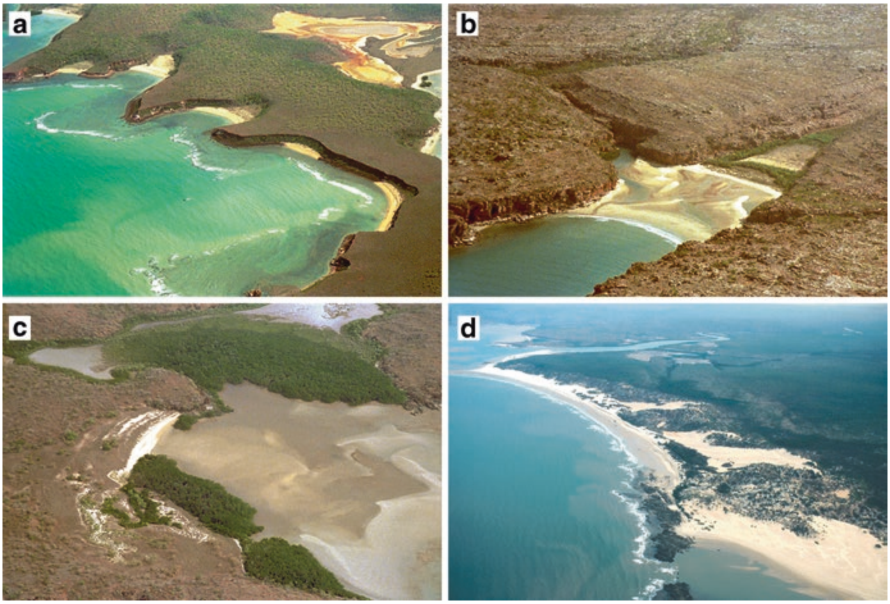

Fig. 6.14 PC:WA13.04 coast and beaches: (**a**) beaches fronted by fringing coral reefs just east of Cape Londonderry (K 1119-1123); (**b**) beach K 1215 occupies the mouth of a NE-trending valley, with tidal sand flats exposed here at low tide; (**c**) a sheltered B + TMF fringed by mangroves (K 1252); and (**d**) R + LTR beaches backed by transgressive dunes at Cape St Lambert (K 1281-1282) are the largest in the Kimberley, the sand derived from the adjacent Berkeley River (K 1283). (Photos: AD Short)

Nott (2006) also noted the common occurrence of gravel-boulder ridges along the east Kimberley coast, including those of the western side of Cambridge Gulf (Fig. 6.15d), and found some sequences contained up to nine parallel ridges. He found that the ridges on La Crosse Island located at the entrance to Cambridge Gulf dated from 5 ka to recent indicating that they are regularly overtopped and reworked by tropical cyclone storm surges.

Cape Dussejour marks the western entrance to the large Cambridge Gulf, which extends over 100 km to the south and has 740 km of shoreline (Fig. 6.12), with the small town and port of Wyndham located 90 km into the gulf. The gulf has a 9 m tide range at Wyndham and a shoreline dominated by mangroves-lined tidal mud flats, backed by extensive salt flats. The only beaches are a few cheniers on low muddy Barnett Point towards the mouth (K 1336-7). The compartment terminates at the low rocky Cape Domett, which is surrounded by TD beaches, all fronted by rock flats (Fig. 6.15f).

Sediments along PC:WA13.04 are predominately moderately sorted, coarse sand averaging 31% carbonate on the beaches, fining slightly to medium in the backing low foredunes (Table 6.7). There is considerable longshore variation in size and carbonate percentage as indicated in Fig. 6.2. This again is due to the usually small

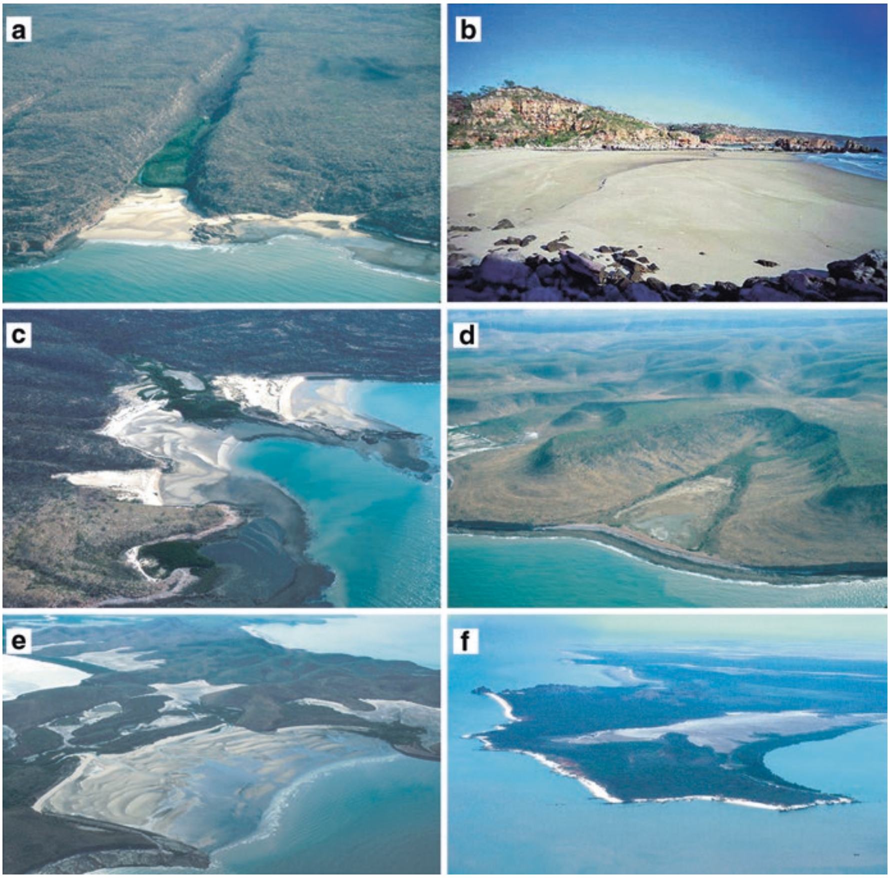

Fig. 6.15 PC:WA13.04 coast and beaches: (**a**) beach K 1296 lies at the mouth of a 25 km long straight northeast-trending valley, its tidal sand flats are also shown in (**b**); (**c**) beaches K 1297-9 are typical of the small embayed beaches of variable orientation, adjoining a mangrove-lined creek with their intertidal sand flats exposed; (**d**) boulder beach K 1322 below Observation Hill is typical of this 20 km long section of boulder–dominated shoreline; (**e**) beach K 1332-3 at Cape Dussejour is a more exposed beach with ridge intertidal sand flats; (**f**) Cape Domett at the northeast entrance to Cambridge Gulf (K-1338-45). (Photos: AD Short)

bedrock-controlled TCs, which inhibit sediment exchange between compartments. The only section of longshore sand transport is along the 10 km of coast west of the Berkeley River where it supplied the beaches (K 1280–1284) and dunes of Cape St Lambert. This system is composed of fine quartz sand, with <1% carbonate, delivered by the updrift Berkeley River. Lees et al. (1992) found there have been three episodes of dune transgression at Cape St Lambert starting 5 ka when offshore sand deposits were reworked onshore. This was followed by sand from the Berkeley River around 3 ka, then 1.5 ka and the most recent beginning around 0.8 ka.

6.5.3 Barriers

PC:WA13.04 has just 11 barriers; however they tend to be larger than the average Kimberley barrier, averaging 8.4 km in length and from 0.43 to 1.3 km in width, with a mean height of 4.4 m. They are predominately low regressive beach ridge-foredune plains, with the one active dune sheet at Cape St Lambert (Fig. 6.14d). They cover an area of 4400 ha, with a total volume of 225 M m^3, the largest in the Kimberley, and a unit volume of 2438 m^3 m^{-1} (Table 6.8).

6.6 PC:WA13.05 Cape Domett (WA) to Pearce Point (NT)

The easternmost of the Kimberley compartments extends for 584 km from Cape Domett, WA, to Pearce Point in the NT (Fig. 6.12); the two low bedrock boundaries are the only bedrocks in the entire compartment. This PC is a low depositional coastline dominated by wide low tidal flats and mangroves with the large Keep, Victoria and Fitzmaurice rivers developing broad funnel-shaped mouths along its 500 km long eastern section. The PC commences at Cape Domett a 12 m high sandstone and conglomerate point (Fig. 6.15f) that lies at the western tip of a 15 km long section of bedrock that forms the eastern boundary of Cambridge Gulf. Once the bedrock terminates, there is 523 km of sand and muddy shoreline until Fossil Head is reached, with two more headlands between here and Pearce Point 28 km to the northwest (Fig. 6.16d). There is no development on the coast with the only vehicle access at Cape Domett and at Fossil Head where there is a runway and four houses.

6.6.1 Rivers and Streams

The Keep, Victoria and Fitzmaurice rivers enter the eastern end of the compartment together with 15 smaller streams and tidal creeks (Fig. 6.12). The Keep is relatively small with a catchment of 7495 km^2, while the Victoria has the largest catchment at 81,216 km^2, and the Fitzmaurice just 8522 km^2. All three are classic funnel-shaped TD deltas with entrances up to 15 km wide. The Victoria river delta has 533 km^2 of supratidal salt flats, fringed by 200 km^2 of mangroves, while the Keep has 56 km^2 of mangroves and the Fitzmaurice 27 km^2.

6.6.2 Beaches and Sediments

The PC is dominated by the mud supplied by the river systems, with very low wave energy which drops to zero in the east and the tides which reach 6.6 m. All the beaches are either TM or TD (Table 6.12), and the three rivers and all the adjacent

Table 6.12 Kimberley PC:WA13.05 beach types and states

BS	BS	No.	%	Length (km)	%	Mean (km)	σ (km)
9	UD	2	6.9	4.7	6.1	3.35	–
10	B + RSF	1	3.4	0.6	0.8	0.6	–
12	B + TSF	11	37.9	16.5	21.3	1.5	1.7
13	B + TMF	12	41.4	54.4	70.2	4.5	3.4
14	R + RF	3	10.3	1.3	1.7	0.43	0.23
		29	100	77.5	100		

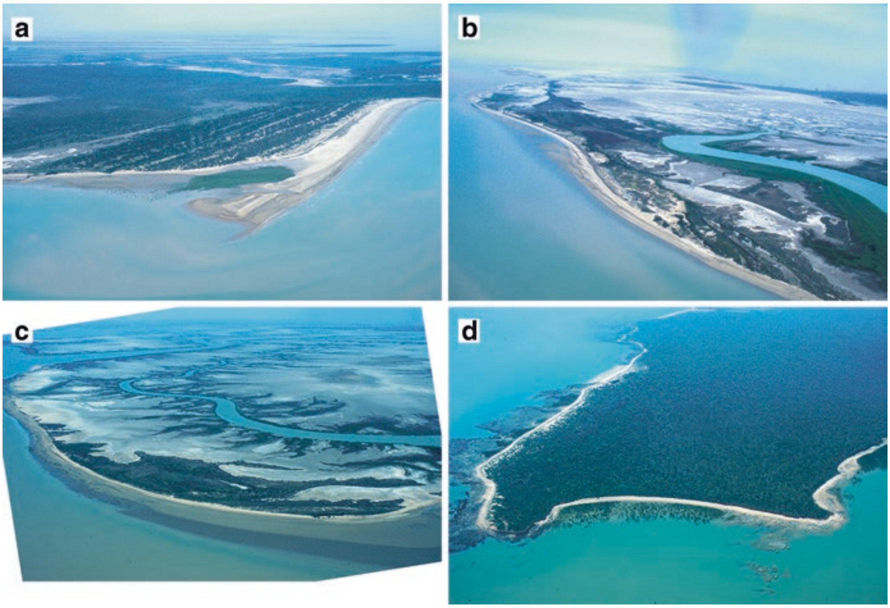

Fig. 6.16 PC:WA13.05 coast and beaches (**a**) 3 km long beach (K 1351) is backed by a 3.7 km wide series of about 20 beach-foredune ridges; (**b**) Pelican Island (K 1354) is backed by a 1 km wide series of older islands which have been dated by Lees (1992b); (**c**) NT 2 is a chenier that recurves into tidal creeks at either end of the 9 km long beach; and (**d**) the PC boundary at Pearce Point is a low siltstone headland surrounded by beaches (NT 12-15), rock flats and mangroves. (Photos: AD Short)

tidal creeks are TD. Beaches occupy 77.5 km (13%) of the shoreline, the remainder predominately mangrove-fringed tidal mud flats, open water channels and the bed-rock at either end. The beaches are also predominately B + TMF (70%), followed by B + TSF (21%), with a few TM sandy beaches around the more exposed Cape Domett (Table 6.12 and Fig. 6.15f). The mud flats average 400 m in width, while the sand flats extend on average for 490 m, with several beaches consisting of sand flats grading seawards into mud flats.

6.6.3 Barriers

There are 11 barrier systems along the southern and northern shores of this compartment. The southern barriers between Cape Domett and Pelican Island were initially regressive beach-foredune ridges (Fig. 6.16a), transforming to cheniers once the muddy tidal flats are encountered (Fig. 6.16b and c). Lees (1992b) dated the cheniers on Pelican Island (K 1354-5) and found that five chenier ridges, composed of sand and silty sand overlying mud flats, formed during a 1000-year period between 2.02 and 1.21 ka, which he suggests was during a dry period with reduce mud input from the Victoria River. The northern barriers between Fossil Head and Pearce Point (Fig. 6.16d) all consist of low beach ridges. The barriers have a total volume of 206 M m^3, with a unit volume of 3201 m^3 m^{-1}, the latter the largest in the Kimberley region. The larger size is due to the extensive regressive barrier east of Cape Domett (Fig. 6.16a).

6.7 Regional Overview

The Kimberley coast is dominated by its ancient dissected geology which provides a highly indented, steep and rugged shore, one that was flooded by the PMT to produce numerous drowned usually linear valleys and estuaries, separated by rocky cliffed shorelines. Waves are low and tides meso to mega. Several moderate to large rivers flow into these valleys partly infilling them and interacting with the tides to maintain TD estuaries and deltas. On the open coast, hundreds of small TD beaches are usually located at the mouths of small valleys and in indentations in rocky shore. The high tides, low waves and generally offshore trades have produced TD beaches usually backed by low small beach-foredune ridge barriers, with only one area of moderate dune transgression. As a consequence, barrier volumes are the lowest on the Australian coast, with most river sediment being deposited subtidally and reworked by tidal currents rather than waves. Short (2011) found that of the 1360 Kimberley beach systems, he investigated only 361 contained a backing barrier, of which 256 contained low beach ridges and just 36 had higher foredunes. In terms of stability, 260 appeared stable, 32 were regressive and 69 transgressive, indicating a high degree of shoreline stability particularly when coupled with the rocky shore.

This coast is largely in a natural state with much located in aboriginal land and national parks and essentially all undeveloped. Most is rocky shore and the beaches largely appear stable. Rising sea level will have variable impact, rising slowly up the rocky shore and causing slow retreat through overwashing of the many small low beaches. It will however have major impacts on the extensive low gradient inter- to supratidal areas which will be inundated, thereby greatly expanding the habitat for mangroves and returning tidal flats to the ‘big swamp’ phase when extensive mangrove forests covered the now elevated flats. Given the location and nature of the coast, it will be however left to accommodate these changes.

References

Anderson TJ and Others (2011) Seabed environments of the eastern Joseph Bonaparte Gulf, northern Australia: GA0325/Sol5117 – port-survey report. Geoscience Australia Record 2011.08, 61 p

Brocx M, Semeniuk V (2011) The global geoheritage significance of the Kimberley coast. J R Soc West Aust 94:57–88

Coleman JM, Wright LD (1978) Sedimentation in an arid macrotidal alluvial river system: Ord River, Western Australia. J Geol 86:621–642

Creswell ID, Semeniuk V (2011) Mangroves of the Kimberley Coast: ecological patterns in a tropical ria coast setting. J R Soc West Aust 94:213–247

Lees BG (1992a) Recent terrigenous sedimentation in Joseph Bonaparte Gulf, northern Australia. Mar Geol 103:199–203

Lees BG (1992b) The development of a chenier sequence on the Victoria Delta, Joseph Bonaparte Gulf, northern Australia. Mar Geol 103:215–224

Lees BG, Yanchou L, Price DM (1992) Thermoluminescence dating of dunes at Cape St Lambert, East Kimberley, northwestern Australia. Mar Geol 106:131–139

Nott JF (2006) Tropical cyclones and the evolution of the sedimentary coast of northern Australia. J Coast Res 22:49–62

Scott AW (2018) Australia's Kimberley coast – its landscape, biodiversity and human history. Axiom Pulb, Adelaide, 344 p

Semeniuk V (2011) Stratigraphic patterns in coastal sediment sequences in the Kimberley region, Western Australia: products of coastal form, oceanographic setting, sedimentary suites, sediment supply, and biogenesis. J R Soc West Aust 94:133–150

Short AD (2006) Beaches of the northern Australia coast: the Kimberley, Northern Territory and Cape York. Sydney University Press, Sydney, 463pp

Short AD (2011) Kimberley beach and barrier systems: an overview. J R Soc West Aust 94:19–30

Short AD, Woodroffe CD (2009) The coast of Australia. Cambridge University Press, Melbourne, 288 p

Thom BG, Wright LD, Coleman JM (1975) Mangrove ecology and deltaic-estuarine geomorphology: Cambridge Gulf-Ord river, Western Australia. J Ecol 63:203–232

Tyler I (1996) Geology and landforms of the Kimberley. Department of Conservation Land Management, Perth

Wright LD, Coleman JM, Thom BG (1972) Emerged tidal flats in the Ord River estuary, Western Australia. Search 3:339–341

Chapter 7
Western Northern Territory Region

Abstract The western Northern Territory coast includes both its western shore and northern Arnhem Land coast, in all 1354 km of coast. This is a lee coast with the prevailing southeast trades blowing predominately offshore. Waves are low to at best moderate, and tides meso to mega all set in a tropical monsoonal climate exposed to seasonal tropical cyclones. Several moderate-sized rivers flow to the coast delivering bed load; however half the coastal sediment is carbonate in origin derived from the shoreface. The generally low waves and high tides maintain predominately tide-dominated beaches with wide tidal flats, backed by low regressive beach-foredune ridge barrier and some cheniers with mangroves dominating the low energy shores, estuaries and river mouths. Dune transgression is restricted to a few more exposed east-facing shores. The chapter describes the processes, beaches, barriers and sediment transport of the western and northern Territory coast, all set within a framework of sediment compartments.

Keywords Northern Territory · Arnhem Land · Monsoons · Meso-tide · Mega-tide · Beaches · Barriers · Sediment transport · Sediment compartments

7.1 Introduction

The western NT coast faces northwest into the Timor Sea and extends for 1354 km between Pearce Point and Cape Don. It consists of a series of open bays between Pearce Point and Cape Hotham, followed by the large U-shaped Van Diemen Gulf, which is bordered on its northern side by the irregular Coburg Peninsula and Bathurst-Melville (Tiwi) islands (Fig. 7.1). Tides are macro (6–6.9 m) along the west coast dropping to meso (2.9 m) by Cape Don. Waves remain low to very low throughout. The coast contains 169 beaches which occupy 29% of the shore, mainly between Point Pearce and Darwin, with the remainder made up of mangroves covered mud flats, particularly in the bays and Van Diemen Gulf, and usually low laterite bluffs, with the highest point just 12 m at Cape Don. The majority of the coast is low and less than 10 m high, and much of it is composed of Cretaceous through

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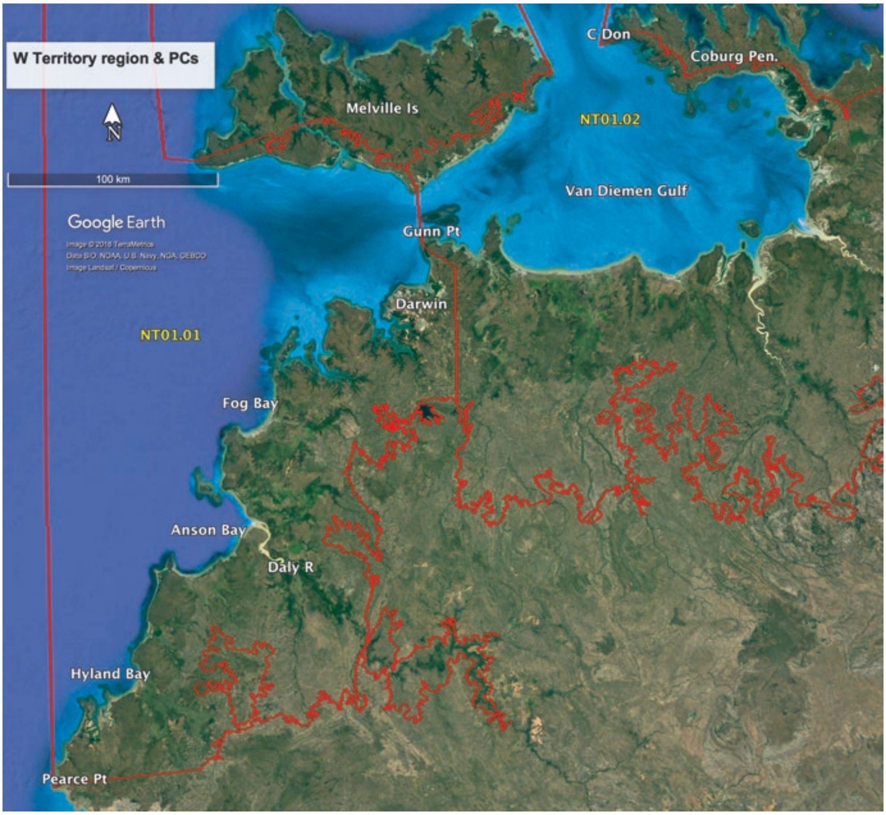

Fig. 7.1 The western Northern Territory region extends from Point Pearce to Cape Don and contains PCs:NT01.01 and 02. (Source: Google Earth)

recent sediments, the older material usually laterised and exposed as rocky points, flats and reefs.

This is the most developed and accessible region in the Kimberley-Territory division, with Darwin located in the centre and roads leading to Wadeye in the south, Stingray Head and the Cox Peninsula west of Darwin and Shoal Bay, Gunn Point and Kakadu to the east and the Coburg Peninsula to the north, all within a 250 km radius from Darwin.

The region is divided into two PCs – the west coast (NT01.01) between Point Pearce and Darwin and Van Diemen Gulf (NT01.02) (Fig. 7.1), which combined contain ten SCs (Table 7.1). The two PCs are quite distinct, the western NT01.01 is reasonably exposed to the Timor Sea with sandy beaches, laterite bluffs, and one large and one small river flowing into bays, while NT01.02 is largely landlocked within Van Diemen Gulf and has a predominately mangrove-lined muddy shore with five moderate-sized rivers draining into its southern shore. The PCs are discussed in the following sections.

Table 7.1 The western Northern Territory region (NT01), PCs and SCs

Comp.[a]	Boundaries	Beach ID[b]	No. beaches	km[c]	Total km
NT01.01.01	Pearce Pt-C ford	NT 15-64	50	505–702	197
NT01.01.02	C ford-Dundee Beach (N)	NT 65-103	39	702–885	183
NT01.01.03	Dundee Beach (N)-Charles Pt	NT 104-110	7	885–1051	166
NT01.01.04	Charles Pt-Gunn Pt	NT 111-149	39	1051–1256	205
NT01.01.05	S Bathurst & Melville Is[d]	–	–	–	–
NT01.01			*135*		*751*
NT01.02.01	Gunn Pt-C Hotham	NT 150-155	6	1256–1323	67
NT01.02.02	C Hotham-Pt Stuart	NT 156-161	6	1323–1411	88
NT01.02.03	Pt-Stuart-Pt Farewell	NT 162-166	5	1411–1593	182
NT01.02.04	Pt Farewell-Waragil Pt	NT 167-178	12	1593–1771	178
NT01.02.05	Waragil Pt-C Don	NT 179-183	5	1771–1859	88
NT01.02			*34*		*603*
NT01-04	**W Northern Territory**	Total	**169**		**1354**

[a]NCCARF compartment number
[b]ABSAMP beach ID
[c]Distance from WA/NT border
[d]Not included

7.2 PC:NT01.01 Pearce Point to Gunn Point

The western PC:NT01.01 trends north-northeast from Pearce Point for 739 km to Gunn Point, located 30 km northeast of Darwin city (Fig. 7.1). The entire compartment has macro-tides (6–6.9 m) and generally low to very low waves, with the trades largely blowing offshore and only the summer northwest winds delivering low to moderate waves, together with the very occasional tropical cyclone. The compartment is divided into five SCs (Table 7.1), four of which are described below.

7.2.1 Rivers and Creeks

The western shore is drained by about 50 small rivers and streams and the larger Moyle (3835 km^2) and Daly (54,776 km^2) rivers which drain the Pine Creek region. The smaller Moyle has a largely aggraded floodplain and an infilled a barrier estuary at its mouth, maintaining a channel across 1.5 km wide tidal flats to reach the sea. The Daly is the largest of the region's rivers and has a TD funnel-shaped channel grading into a sinuous mangrove-lined river channel that extends 66 km inland. Its deltaic plain is fringed by mangroves but dominated by salt marsh and salt flats.

7.2.2 Sediment and Processes

PC:NT01.01 beaches are composed of generally medium (0.45 mm), moderately sorted, carbonate-rich sand (40–60%, Table 7.2), typical of tropical lower energy TD Australian beaches (Short 2006a). However, there is considerable longshore variation with size ranging from 0.1 to 1 mm and carbonate from 5 to 100% with a general increase in carbonate to the north, as indicated in Fig. 7.2. While the carbonate sediments are derived from the adjacent marine environment, most likely from winnowing of the extensive sand and mud flats, the terrigenous sand and mud has been delivered either from the shelf or directly from the streams and rivers that flow to the coast and from erosion of the laterite bluffs.

Table 7.2 PC:NT01.01 beach sand characteristics

W Northern Territory	NT01.01
Swash (HT&LT)	
n	38
Mean size (mm)	0.45
σ (mm)	0.3
Sorting	0.82
σ (sorting)	0.22
% carbonate	42
σ (%)	28

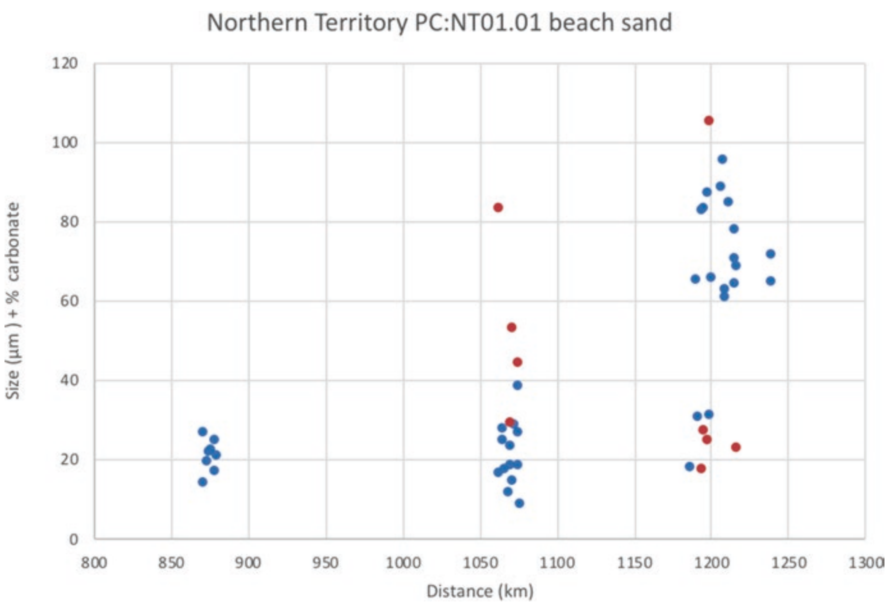

Fig. 7.2 PC:NT01.01 beach sediment characteristics. Carbonate: blue (%); size: red (µm). Distance from WA/NT border

7.2.3 Beaches

The beaches along the western PC:NT01.01 region face west into the Timor Sea with a mean orientation of 222°, and many are well exposed to the low to moderate seas, with an embayment ration of 0.85 (Table 7.3). They occupy 40% of the shore, the remainder primarily mangrove-fringed tidal sand and mud flats averaging 374 m in width and exposed low laterite bluffs. The level of beach exposure is indicated by the high proportion of TM beaches (35.4% by length), though TD (52.3%), and in particular B + TMF (26.5%) dominate (Table 7.4). The impact of the many laterite bluffs and their associated rock flats and reefs is reflected in the presence of R + RF (12.3%) which occur on the usually exposed bluffs. The TM beaches tend to occur on the straighter more exposed sections of shore, with the TD and in particular the B + TMF in the bays. Overall the high tide beaches are narrow (mean = 6 m) and moderately steep (mean = 4°) (Table 7.3). See Short (2006b) for a description of all the NT beach systems.

Table 7.3 Some characteristics of the western NT beaches (PCs:NT01.01-02)

	n	Mean	*σ*	Min	Max
Orientation (deg)	169	215	114	1	358
Embayment ratio	169	0.85	0.19	0.1	1.0
Gradient (deg)	169	4.05	1.15	2	9
Beach width (m)	160	5.9	2.1	2	10
Sand ridges	5	3.5	1.7	2	7
Sand/mud flats (m)	195	374	277	50	1500

Source: Short (2006b)

Table 7.4 Western NT PC:NT01.01 beach types and states

BS	BS	No.	%	Length (km)	%	Mean (km)	σ (km)
7	R + LTT	26	19.3	52.3	17.7	2.0	2.0
8	R + LTR	1	0.7	5.1	1.7	5.1	–
9	UD	9	6.7	47.4	16.0	5.3	5.9
10	B + RSR	5	3.7	10.8	3.6	2.2	1.6
11	B + SF	31	23.0	58.5	19.8	1.9	2.4
12	B + TSF	9	6.7	7.2	2.4	0.8	1.1
13	B + TMF	25	18.5	78.4	26.5	3.1	3.1
14	R + RF	29	21.5	36.5	12.3	1.1	1.0
		135	100	296.2	100	2.2	–

7.2.4 Sand Transport

There is evidence of sand transport along some beaches and the base of the bluffs, around some of the minor bluff points and into the major bays; however, there appears to be little if any transport between the bays. The coast rather consists of a series of embayed TCs (Yelcher Beach, Munda Beach, Port Keats, Hyland Bay, Anson Bay, Fog Bay), all with onshore carbonate input and the larger barrier estuaries also receiving terrigenous input from the creeks and rivers. Sediment therefore appears to be derived from three potential sources – onshore, longshore and terrigenous. Onshore transport is indicated by the high carbonate content (42%, Table 7.2) the carbonate derived from the tidal flats and shallow nearshore. Terrigenous sediment is supplied during the wet by the creeks and rivers delivering sediment to the barrier estuaries and directly to the coastal zone, including a substantial supply of mud that has deposited extensive mud flats in the estuaries and some of the bays and in front of 26% of the beaches. In addition, some sand is being eroded from the exposed bluffs and transported longshore. There is substantial evidence of northerly longshore transport based on the orientation of the ridges and their recurved spits. There is also evidence of both northerly and southerly longshore transport into the bays, indicated by migratory sand waves and spits moving around both north and south boundary headlands. The spits usually converge on and recurve into the creek/river mouths which tend to occupy the centre of the beaches/bays.

7.2.5 Barrier Systems

There are a total of 43 barriers, which occupy 206 km of coast (16%). They are predominately beach ridges, low foredune/ridges and recurved spits in the bays and at the creek mouths, with just seven areas of minor to moderate dune transgression on 2% of the total barriers. They have a low mean height of ~3 m but range on average from 25 to 880 m in width, with the large Anson Bay barrier 3.3 km wide and capped by 30 ridges (Table 7.4). They cover a total area of 16,348 ha and are essentially stable (98%), with a total volume of 531 M m^3 and per meter volume of 2582 m^3 m^{-1} (Table 7.5).

7.2.6 SC:NT01.01.01 Pearce Point–Cape Ford

SC:NT01.01.01 extends for 197 km from Pearce Point to Cape Ford. It trends to the north-northeast trend, broken by three larger bays (Port Keats, Hyland, Yallet Creek) and several smaller embayments (Fig. 7.3). In the south the sheltered Port Keats contains two TD funnel-shaped arms, fringed by mangroves and backed by wide salt flats and feed by a series of tidal creeks (Fig. 7.4a). Hyland Bay has a 20 km

Table 7.5 Western NT regional and PC barrier dimensions

	NT01.01	NT01.02	W NT
No.	43	15	58
Total length (km)	206	50.8	256.8
Mean width (m)	250–880	90–400	–
Mean height (m)	3.4	3	–
Area (ha)	16,348	4842	21,190
Unstable (ha)	310	0	310
Total volume (M m^3)	531	145	677
Unit volume ($m^3\ m^{-1}$)	2582	2859	2636

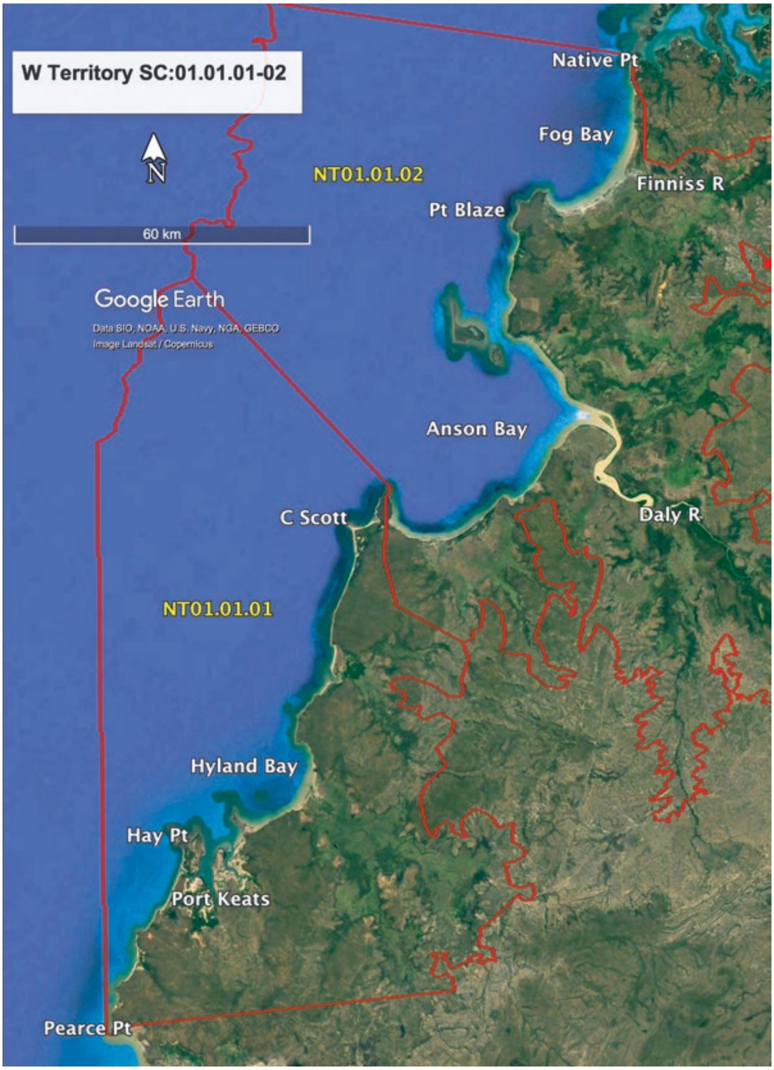

Fig. 7.3 Western NT SCs:NT01.01.01-02 Pearce Point to Gunn Point. (Source: Google Earth)

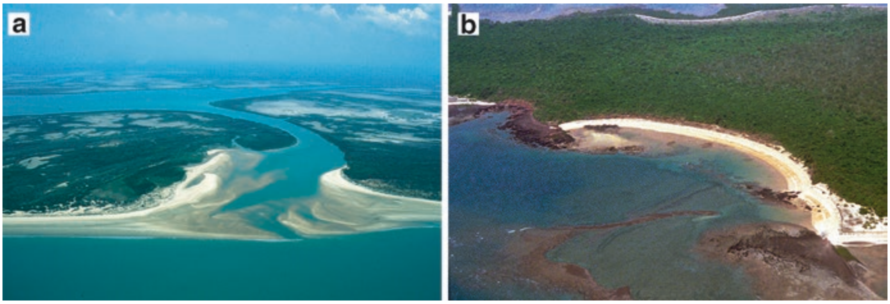

Fig. 7.4 (**a**) Munda beach (right) is separated from Dorcherty Island (left) by a dynamic inlet (NT 25–6) that connects with Port Keats; (**b**) a typical small embayed beach between laterite points and reefs on Cape Hay (NT 62). (Photos: AD Short)

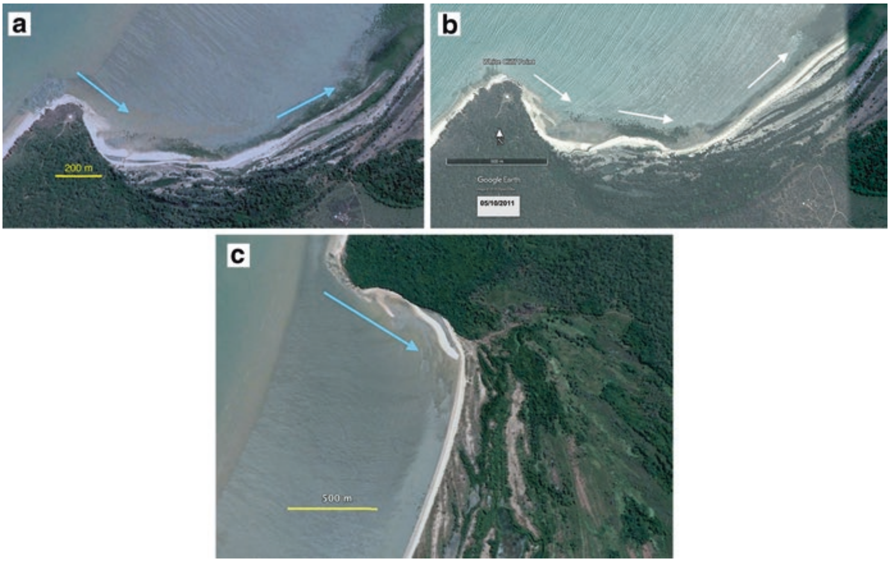

Fig. 7.5 Migratory sand wave-spits at White Cliff Point (NT 42) shown in (**a**) 2003 and (**b**) 2011. Also note the northwesterly wave direction in the 2011 image and 1 km wide mud flats exposed in 2003; (**c**) southerly migrating sand waves on the northern side of Hyland Bay (NT 43) which have delivered sand to build the 3 km wide series regressive beach ridges to the south and the 1 km wide mud flats. (Source: Google Earth)

wide entrance between Tree Point and Cape Dombey, with bluffs and beaches occupying most of the curving shore, while the small Moyle River built a broad V-shaped delta including a 5 km wide series of spits that now form the central bay shoreline, where it is fronted by mangroves and 2 km wide mud flats. Sand is being transported into the bay from the north and south, bypassing the headlands and moving longshore as migratory supratidal sand wave-spits (Fig. 7.5). On the southern side of the river floodplain, this sand has built the 5 km wide series of ~30 beach ridge-spits out to the modern spits show in Fig. 7.5a, b. The spits have an area of 800 ha, which assuming each is 2 m thick represents ~16 M m^3 of sand. If the spit has accumulated over the past 6 ka, this represents a northerly longshore transport rate of ~2500 m^3 year^{-1}, which seems reasonable for a low energy section of coast.

The 10 km wide bay that extends south of Dooley Point has been largely filled by a 3 km wide series of about 25 beach-foredune ridge-spits and recurved spits at the central river mouth. Both Hyland and Yallet Creek bays and a few smaller embayments have central tidal creeks with regressive barriers and spits extending off each side towards the creek mouth (Fig. 7.4a), suggesting a balanced sediment transport, with perhaps a slight bias to the north. This suggests that transport is largely contained within each of the bays/embayments forming closed TCs, with no net longshore or inter-bay sediment transport. Between the bays low laterite bluffs, headland and reefs occupy the shore, many of the bluffs fronted by beaches (Fig. 7.4b), but some actively eroding. Sediment is being sourced from three locations: the nearshore (carbonate and terrestrial), longshore including erosion of the bluffs and via the streams and rivers.

7.2.7 SC:NT01.01.02 Cape Ford–Dundee Beach

SC:NT01.01.02 consists of two larger bays (Anson and Fog) separated by the 20 km of bluffs between Channel Point and Point Blaze (Fig. 7.3). It extends for 183 km between Cape Ford and the northern end of Dundee Beach at Native Point and contains 39 beaches, which occupy 113 km (62%) of the shore. There are a several R + LTT and one UD (26%) on the more exposed parts of southern Anson Bay and along the northern Dundee Beach section, with TD B + SF, B + TSF and B + TMF dominating in the bays (54%), with several R + RF (18%) associated with laterite flats extending off the bluffs and points.

Anson Bay is the largest of the west coast bays, with a 35 km wide entrance between Cape Ford and Channel Point. The Daly River flows into the centre of the bay where it has deposited a TD funnel-shaped delta, with the delta shoreline and northern bay shore, lined with mangroves, while a regressive barrier (Fig. 7.6a) then bluff-backed beaches line the central-southern bay shore. Chappell (1993) investigated the lower Daly River and found the estuarine plain contains more sediment that can be attributed to the river and proposed onshore transport during the sea-level transgression (~6 ka) to account for the extra volume. The plain was covered by an extensive mid-Holocene mangrove swamp which was then replaced by supratidal salt flats as vertical sedimentation occurred between 6 and 5 ka throughout the estuarine plain.

The northern Fog Bay commences in the south at Point Jenny and then spirals northwards for 30 km to Dundee Beach and Native Point, with the shoreline grading from mangrove-fringed cheniers in the sheltered south to foredune ridges and then low beach-fronted eroding laterite bluffs in the north. The waterfront Dundee Beach subdivision is located along 6 km of these bluffs. This is one of the few coastal developments, outside of Darwin, in the NT.

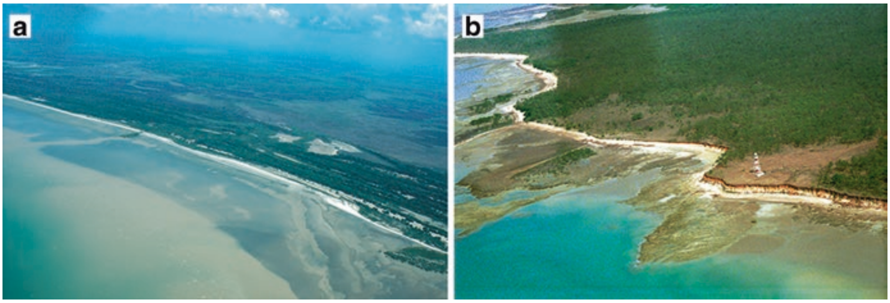

Fig. 7.6 (**a**) Regressive barrier on the southern shores of Anson Bay fronted by 300 m wide mud flats (NT 71) and (**b**) Charles Point at the tip of the Cox Peninsula sits on eroding bluffs with beaches fronted by rock flats below (NT 113). (Photos: A D Short)

It appears that northwest waves are slowly moving sand southwards along the Dundee Beach shore towards Fog Bay with the Fog Bay spits also indicating south transport. The Finniss River sediments are probably being deposited in the extensive upper deltaic plain and sheltered southern half of the bay.

7.2.8 SC:NT01.01.03 and 04 Dundee Beach–Gunn Point

The northern two SCs (NT01.01.03 and 04) contain three large TD funnel-shaped north-facing bays (Boyne Harbor, Port Darwin, Shoal Bay) separated by the low Cox and Darwin peninsulas, resulting in an irregular (crenulation ratio = 4.1) low energy TD coast with beaches only on the outer more exposed shore of the Cox (Fig. 7.6b) and Darwin peninsulas and the outer Shoal Bay shore, with mangrove-lined mud flats dominating the bay shores (Fig. 7.7). The SCs have 166 and 205 km of shoreline, respectively.

The Boyne Harbor SC has seven beaches, which occupy just 6 km (4%) of this predominately muddy shore. The Darwin SC has 39 beaches occupying 50 km (24%), the remainder also predominately mud flats. The beaches are a mix of TM on the more exposed Cox and Darwin peninsulas (R + LTT 15%), with the remainder TD (82%), with B + SF (51%) dominating.

Boyne Harbor has a broad 25 km wide mouth, cluttered by a series of low islands and coral reefs and extends 40 km inland. Port Darwin has a 5 km wide bedrock-controlled entrance which opens into a large 1220 km^2 mangrove-lined harbour containing four major arms that extend up to 35 km inland. The harbour has maximum tides up to 7 m and currents to 1.5 m s^{-1} (Heron and Prytz 1999). Nott (2003) found that in the Darwin region sea level stabilised ~6.5 ka at an elevation ~2.5 m above present (Nott 1996). The inundation of the coastal plains was followed by the big swamp mangrove phase, then by vertical accretion of the tidal flats. He found Darwin itself sits on deeply weather Cretaceous sediments that form lateritic crusts and soils, and when eroded from laterite bluffs, flats and reefs.

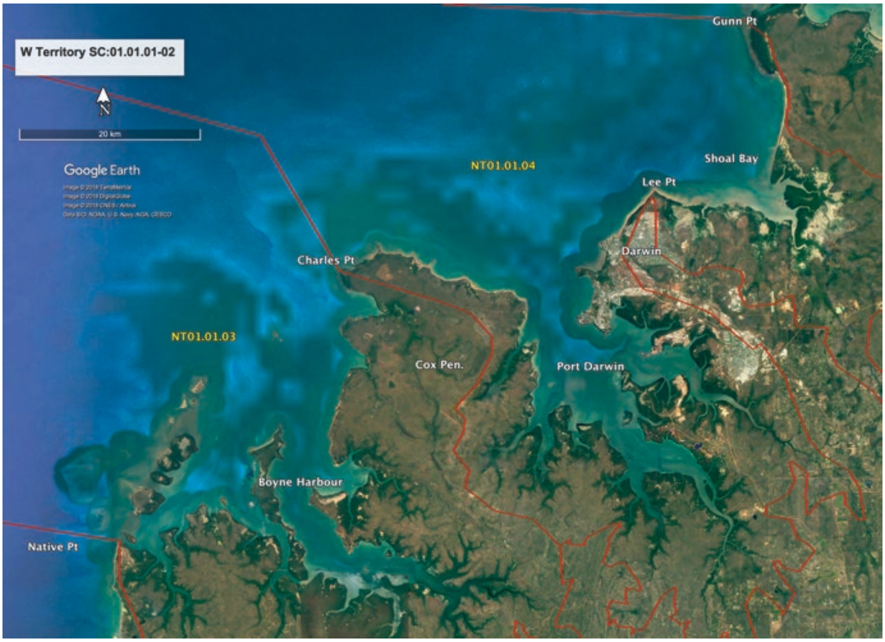

Fig. 7.7 Western NT SCs:NT01.01.03-04 is centred on Boyne and Darwin harbours. (Source: Google Earth)

Semeniuk (1985) conducted a detail investigation of the mangroves and their habitats in Port Darwin. He found the tidal flats were a wedge of mud deposited over terrestrial lowlands following the sea-level transgression, with the shoreline containing eight broad mangrove assemblages ranging from tidal flats to rocky shore. The city of Darwin is located along its eastern shores. Shoal Bay lies to the east of the Darwin Peninsula and consists of a 20 km wide V-shaped bay between Lee and Gunn points. All three bays are accumulating mud deposited in the extensive intertidal mud flats as there are no significant rivers or streams flowing into the bays, the mud must be sourced from the marine environment, as suggested by Chappell and Woodroffe (1994) for the Daly, Mary and Alligator rivers. They found that the transport is driven by shorter duration but higher velocity flood tides, with the marine mud accumulating on the tidal flats which are covered in mangroves until they aggrade above high tide.

The Darwin peninsula is surrounded by 13 beaches which occupy 14 km (40%) of the peninsula shoreline. Around Darwin city they are a series of short embayed beaches bordered and backed by the ~10 m high bluffs of the peninsula. North of Rapid Creek is 6.5 km long Casuarina Beach (NT146-7) which extends to the low sandy Lee Point, the western boundary of Shoal Bay. One of Darwinn's former beaches, Cullen Bay (NT 136), has been developed into an enclosed marina with a new artificial beach on the outer wall, and an artificial beach and wave machine have also been constructed in the old Darwin harbour precinct. Sand is moving along the northern Darwin coast around Lee Point into Shoal Bay and down Camerons Beach (NT 148), where it has built a 6 km long, 1 km wide series of beach ridge-spits, and from the east down the Shoal Bay beach (NT 149) which includes a 6 km long south-trending spit. All three bays are TC sediment sinks with no exchange between the bay and adjacent shoreline.

7.3 PC01.02 Van Diemen Gulf

The Van Diemen Gulf PC:NT01.02 is an almost completely enclosed gulf 180 km long and up to 110 km wide, with an area of ~5300 km^2 and linked by two 25 km wide openings to the Timor Sea. It has boundaries at Gunn Point and Cape Don linked by 603 km of shoreline. It is bordered by the low Proterozoic laterised coastal lowlands in the south which are drained by a series of rivers that have deposited a wide coastal plain. Higher relief Cretaceous sedimentary rocks of the Coburg Peninsula form the east-northeast boundary, with a series of mangrove-lined tidal creeks occupying most of the eastern shore. A 25 km wide opening separates the peninsula from Melville and Bathurst islands which form the northwest boundary (Fig. 7.8). Six small- to moderate-sized rivers (Adelaide, Mary, Wildman and the West, South and East Alligator; Fig. 7.8) flow into the gulf and deliver an abundance

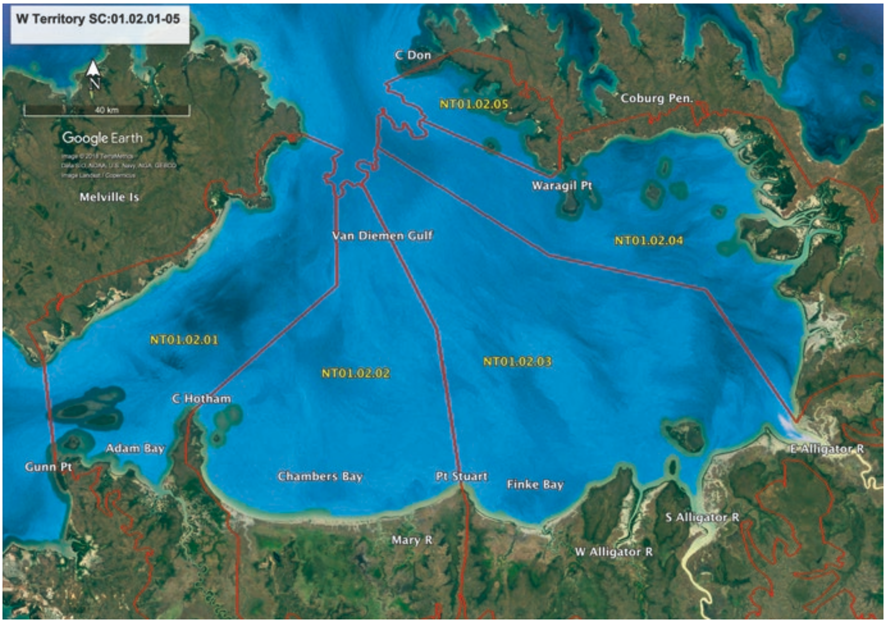

Fig. 7.8 Van Diemen Gulf – PC:NT01.02 and its five SCs. (Source: Google Earth)

of fine sediments that, combined with marine mud, have developed a coastal plain up to 30 km wide in the south and east. Wave energy is low to very low, particularly along the east and south shores, while tides decrease from 7 m at Darwin to 2.9 m at Cape Don.

The gulf shoreline is contained in five SCs (NT01.02.01-05). The south coast consists of three north-facing bays, beginning in the east the 25 km wide V-shaped Adam Bay at the base of which is the funnel-shaped TD Adelaide River (7216 km^2); the open 66 km wide Chambers Bay with its muddy shoreline fringed by mangroves and backed by the wide coastal plain including the Mary River; and Finke Bay, a similar but smaller (37 km wide) open mud and mangrove-lined bay which receives the Wildman River (2476 km^2). The east coast is dominated by the south by the 50 m wide northwest-facing Boucaut Bay into which flow the funnel-shaped West (2228 km^2), South (13,539 km^2) and East Alligator (9078 km^2) rivers. The western rivers drain the laterite lowlands, while the eastern rivers rise in the Arnhem Land Plateau 100–200 km to the south before crossing the lowlands to reach the coastal plain.

The highly sinuous Adelaide River has the longest estuarine component (69 km) and flows via a funnel-shaped lower reaches into Adam Bay, where it has the largest area of mangroves, salt marsh and salt flats. The West, South and East Alligator rivers flow into the southeast corner of the gulf, with each having classic TD funnel-shaped entrances grading into a sinuous river course. Their deltaic plains are dominated by salt marsh, salt flats and fringed by mangroves. Winn et al. (2006) investigated saltwater intrusion into a section of the East Alligator River floodplain and found it was causing a large increase in bare saline mud flats, while the *Melaleuca* forest was retreating.

The 100 km long eastern shore between the East Alligator River and the bedrock base of the Coburg Peninsula is entirely mud flats and mangroves and contains large mangrove-lined tidal creeks extending up to 20 km inland. The northern shore consists of the southern shore of the peninsula, which continues for 150 km up to the western tip of the peninsula at Cape Don. This is a more crenulate bedrock-controlled shore, with 20 small sandy beaches, but dominated by mangrove-lined, bedrock-backed shore, the mangroves sheltered by fringing coral reefs.

7.3.1 Sediments and Coastal Processes

Sediments within the gulf shore are derived from the six rivers that flow into the southern and eastern gulf shore supplying terrigenous material, from the gulf which supplies marine mud and from in situ biogenetic production including the dense mangrove forests.

Tide decrease into the gulf from 6.0 m at Darwin to 4.4 m at Cape Hotham and 2.9 m at Cape Don. Waves are entirely generated by winds blowing across the gulf waters (maximum fetch ~100 km) and remain low to very low seas, particularly at the shore where they are attenuated by the shallow nearshore gradients and wide intertidal flats.

Table 7.6 Western Northern Territory PC01.02 beach types and states

BS	BS	No.	%	Length (km)	%	Mean (km)	σ (km)
10	B + RSF	3	8.8	2.6	4.3	0.87	0.23
11	B + SF	6	17.6	5.0	8.4	0.84	0.91
12	B + TSF	3	8.8	3	5.0	1	0.26
13	B + TMF	19	55.9	46.6	77.8	2.46	2.88
14	R + RF	3	8.8	2.7	4.5	0.9	0.6
		34	100	60	100	1.76	

7.3.2 Beaches

The shoreline is dominated by intertidal mangroves grading into wide tidal sand and mud flats. The low waves and high tides result in entirely TD beaches, which occupy just 10% of the shore, with B + TMF dominating (78%) (Table 7.6), the flats averaging 0.4 km in width. The higher energy B + RSF (4.3%) and B + SF (8.4%) occur along the southern shore of the Coburg Peninsula which has a series of more exposed headland bound beaches which receives wave generated by the trades across the northern part of the gulf. The ridged sand flats are up to 700 m wide contain up to 7 ridges.

7.3.3 Barrier Systems

The gulf shoreline has just 15 barriers which occupy 51 km (8%) of the coast, the low proportion owing to the generally very low to zero wave energy and dominance of mud flats and mangroves. The barriers are low (mean height = 3 m) and range on average from 90 to 400 m in width, usually consisting of a series of cheniers, beach ridges and recurved spits near tidal creeks. They have a total volume of 145 M m^3, deposited at a unit volume of 2859 m^3 m^{-1}. The sediments are carbonate-rich with most carbonate probably derived from winnowing of the wide tidal flats. Both the rivers and the gulf deliver considerable fine terrigenous and marine material to build the deltaic plains and tidal flats.

7.3.4 Sediment Transport

Movement of sediment around the gulf shoreline is dominated by tidal currents and the seasonal river flow within the river and creek systems. The rivers deliver terrestrial sediment to the coast during the summer wet season, while tidal flows deliver marine mud from the gulf and redistribute the sediment onto the tidal flats. In situ carbonate production across the tidal and subtidal is winnowed by waves and moved shorewards to contribute to the few beaches and low barriers, while mangrove debris dominate the tidal flat facies.

7.3.5 SC:NT01.02.01 Gunn Point–Cape Hotham

SC:NT01.02.01 contains Adam Bay into which flows the meandering Adelaide River where it has deposited a 25 km long funnel-shaped delta bordered by mangrove-fringed tidal flats. The eastern side of the delta contains three meandering mangrove-lined creeks and their extensive mangrove-covered tidal flats that have tied Cape Hotham to the mainland. The bay is 30 km wide at its entrance and has 67 km of shoreline, with most fringed by mangroves. There are only six beaches occupying just 8.6 km (13%) of the shore, all located on the outer peninsulas, particularly the eastern Cape Hotham. In addition to the tide delivering mud to the bay and tidal flats, northwest waves are moving sand down the eastern size of the bay forming a 4 km long spit that trends southwest to the river mouth.

7.3.6 SC:NT01.02.02 Cape Hotham–Point Stuart

Chambers Bay (**SC:NT01.02.02**) is a 88 km long curving north-facing bay, essentially filled with mud from the Mary and other rivers, the Mary entering on its eastern shore. The bay does have five beaches all located along the eastern side of Cape Hotham, with the longest (NT-161) extending for 10 km from the base of the cape out along the muddy shore as a chenier. Mangrove-lined mud flats occupy the rest of the bay to the boundary at Point Stuart. Tidal flats and wetlands extend more than 10 km inland and include much of the Mary River National Park. Woodroffe and Mulrennan (1993) investigated the Mary River coastal plain and found that a 6–9 m deep valley was flooded by the rising sea level between 7 and 6 ka. This was followed by the 'big swamp' phase when saline mud was deposited and widespread mangroves occurred. The coast then built out at a decreasing rate reaching close to the present shoreline about 2 ka. Beginning about 4 ka freshwater wetlands replaced the mangroves and became very extensive by about 2 ka. Kingston et al. (1991) found that over the last 70 years, there has been rapid tidal channel expansion and saltwater intrusion up to 30 km into the freshwater wetlands covering an area of 17,000 ha.

7.3.7 SC:NT01.02.03: Point Stuart–Point Farewell

SC:NT01.02.03 extends for 182 km along the southern and southeastern corner of the gulf and contains the Finke Bay and the Wildman and the three Alligator rivers. The small Wildman River flows into the centre of the curving 30 km wide mangrove-lined Finke Bay. The East, South and West Alligator rivers flow into a 40 km long section of the southeast corner of the gulf, delivering fine material to their deltas and the gulf. Each river has well developed 5–10 km wide TD funnel-shaped deltas, with extensive mangrove-fringed salt flats, all located in Kakadu National Park. There are just five beaches in this PC, one on Point Stuart and four along the 10 m high bedrock Cape Farwell which separates the Wildman and West Alligator rivers. The Point Stuart cheniers were investigated by Clarke et al. (1979). Their results were combined in a study by Lee and Clements (1987) who also investigated the series of cheniers at Shoal Bay (NT 152) and the South Alligator River. They found the Shoal Bay and Alligator river cheniers were deposited between 3 and 0.5 ka, while the Point Stuart cheniers (Fig. 7.9a) date back to 5.5 ka, though Lees (1992) found the outer chenier dated 1.3 ka and concluded that it has been built during storm events coupled with delta switching of the Mary River. The delay in chenier development can be attributed to the fact the extensive underlying mud flats have to develop and accrete to a high tide elevation before the supratidal cheniers can be deposited.

A major study of the Mary and South Alligator rivers was undertaken by Woodroffe et al. (1984, 1985, 1986, 1989, 1993) and Woodroffe and Thom (1988). They found the estuaries went through three similar phases of infill. A transgressive phase (8–6.8 ka) accompanying the marine intrusion into the flooding valleys; the 'big swamp' phase (6.5–5.3 ka) when mangrove forests dominated extensive intertidal flats; and alluvial floodplain development since 5.3 ka, when the plains aggraded above high tide level causing salt marsh and salt flats to replace the intertidal mangroves. They also found that the gulf has been a major source of clay, silt and fine sand for coastal plains. The ecological impact of this transition was investigated by Clark and Guppy (1988).

7.3.8 SC:NT01.02.04 Point Farewell–Waragil Point

SC:NT01.02.04 occupies the low 178 km long eastern shore of the gulf, together with the southern shores of the elevated Coburg Peninsula. The eastern gulf shores are dominated by a series of 1–3 km wide funnel-shape mangrove-lined tidal inlets (Murgenella, Salt Water, Minimini and Iwalg creeks) and their extensive salt flats.

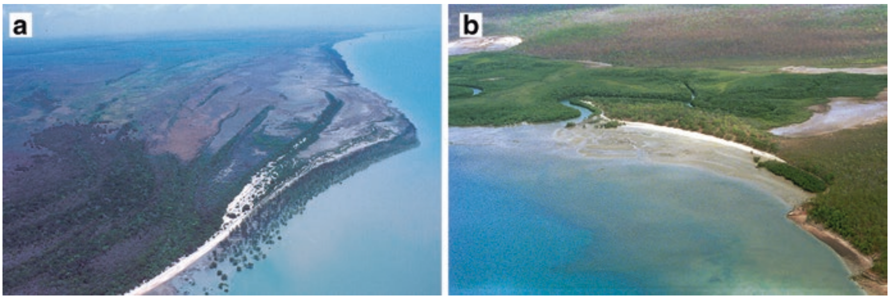

Fig. 7.9 (**a**) Point Stuart (NT 162) with its cheniers splaying to the west; and (**b**) small beach near Warigili Point (NT 178) bordered by a tidal creek and mangroves and fronted by 0.4 km wide sand flats grading into outer fringing coral reef. (Photos: AD Short)

They are separated by low mangrove-lined peninsulas, with just three beaches on the eastern shores. The longest Aralaij (NT 167) is receiving sediment from the East Alligator river and is part of a 20 km long series of north-trending barrier spits that continue to the mouth of Murgenella Creek. There is also a 5 km long series of mangrove-lined south-trending spits on the northern side of the mouth, indicating the creek is a sediment sink. The other eastern beaches are located on more exposed sections of bedrock including Endyalgout Island (NT 169). The northern shore of this PC trends west along the base of the low Coburg Peninsula. The shore is a mix of mangroves, low bluff and TD beaches (NT 170-8) (Fig. 7.9b), with the beaches increasing in energy from east to west. The highest energy beaches face southeast across the gulf and with a fetch of more than 50 km receive winter trade wind waves. They are the western most beaches and consist of B+ RSF containing up to 10 sand ridges.

7.3.9 SC:NT01.02.05 Waragil Point–Cape Don

PC:NT01.02.05 occupies the southern shore of the western tip of the peninsula extending for 88 km from Waragil Point to Cape Don the western tip of the peninsula. It is an irregular southwest-facing shore containing a mix of mangrove-filled bays, mangrove-line irregular bluffs fronted by fringing coral reefs and just five sandy beaches (NT 179-183) which occupy just 4 km (4.5%) of the shore, primarily in the most exposed southern points. Two Hills Bay beach (NT 182) is the highest energy in the region and backed by a foredune, the two hills rising to 162 and 143 m behind the bay, the highest hills on the peninsula and the highest coastal hinterland in the NT.

7.4 Regional Overview

The western NT region (NT01) extends for 1354 km from Pearce Point to Cape Don. In between is a mix of shorelines orientated west into the Timor Sea and north into the enclosed Van Diemen Gulf. Most of the west coast is a low drowned coastal plain, with numerous shallow inlets and bays now occupying the former valleys, the inlets infilling with fine sediments sheltered by regressive barriers and spits on the west coast. The region is feed by eight small- to moderate-sized river and scores of smaller creeks and streams, most of which are delivering sediment to the coast, together with sediment from sections of eroding laterite bluffs. In the gulf the sea-level rise flooded a low gradient coast plain with mangroves and mud flats now dominating most of shoreline, with the few beaches either backed by bluffs or forming cheniers on more exposed mud flats. Woodroffe et al. (1993) based on their studies of the Mary and South Alligator rivers found that in the gulf, the ‘major source for the clay, silt and fine sands which have infilled the estuary and coastal plain has been from seaward'. They also found that the 'Mary has been blocked entirely, and its former estuarine palaeochannels have been infilled with tide-transported sediment'. The low south and east gulf shores contrast with the higher relief Coburg Peninsula, though mangroves still dominated the sedimentary and bedrock shoreline.

The relatively few beaches are backed by low regressive barriers located primarily along the western shore (NT01.01), which are low in volume and an order of magnitude less than the Australian average. Apart from the coastal plain and higher peninsula, this is a low-lying coast dominated by tidal flats and mangroves and low barrier systems. Rising sea level will have major impacts on all the low gradient shore. Chappell and Woodroffe (1994) found that the freshwater ecosystems of the estuarine plains and backwater swamps of northern Australia will be endangered as sea-level rises, as illustrated by the current saline intrusion into the lower reaches of the Mary River, a process which commenced in the 1940s (Kingston et al. (1991). Chappel and Woodroffe also propose that the rise will lead to channel widening, which in turn will increase sediment delivered to the estuarine plains, partly offsetting the inundation. Likewise, Woodroffe (1994) found that the broad coastal plains of Van Diemen Gulf depend on a balance between sedimentation and sea-level change and that with rising sea level the present freshwater swamps may revert to saline conditions. The western NT coastal plains, estuaries and deltas will therefore experience major changes as sea-level rises, salt water intrudes inundating the plains causing ecosystem to switch from fresh to marine allowing mangroves to expand onto the existing extensive salt and supratidal flats.

References

Chappell J (1993) Contrasting Holocene sedimentary geologies of lower Daly River, northern Australia, and lower Sepik-Ramu, Papua New Guinea. Sediment Geol 83:339–358

Chappell J, Woodroffe CD (1994) Macrotidal estuaries. In: Carter RWG, Woodroffe CD (eds) Coastal evolution: late quaternary shoreline morphodynamics. Cambridge University Press, Cambridge, pp 187–218

Clark RL, Guppy JC (1988) A transition from mangrove forest to freshwater wetland in the monsoon tropics of Australia. J Biogeogr 1(5):665–684

Clarke MF, Wasson RJ, Williams MAJ (1979) Point Stuart cheniers and Holocene sea levels in northern Australia. Search 10:90–93

Heron ML, Prytz A (1999) Tidal analysis of ocean surface currents in the Northern Territory using HF radar. In: 14th Australasian conference on coastal and ocean engineering, Perth, 8 p

Knighton AD, Mills K, Woodroffe CD (1991) Tidal-creek extension and saltwater intrusion in northern Australia. Geology 19:831–834

Lees BG (1992) Geomorphological evidence for late Holocene climatic change in northern Australia. Aust Geogr 23:1–8

Lees BG, Clements A (1987) Climatic implications of chenier dates in Northern Australia. Radiocarbon 29:311–137

Nott J (1996) Late Pleistocene and Holocene sea-level highstands in northern Australia. J Coast Res 12:907–910

Nott J (2003) The urban geology of Darwin. Quat Int 103:83–90

Semeniuk V (1985) Mangrove environments of Port Darwin, Northern Territory: the physical framework and habitats. J R Soc West Aust 67:81–97
Short AD (2006a) Australian beach systems – nature and distribution. J Coast Res 22:11–27
Short AD (2006b) Beaches of the Northern Australia coast: the Kimberley, Northern Territory and Cape York. Sydney University Press, Sydney, 463 p
Winn KO, Saynor NJ, Eliot MJ, Eliot I (2006) Saltwater intrusion and morphological change at the mouth of the East Alligator river, Northern Territory. J Coast Res 22:137–149
Woodroffe CD (1994) Response of tide-dominated mangrove shorelines in northern Australia to anticipated sea level rise. Earth Surf Process Landf 20:65–85
Woodroffe CD, Mulrennan ME (1993) Geomorphology of the lower Mary River plains, Northern Territory. Australian National University North Australia Research Unit & Conservation Commission Northern Territory, Darwin, 152 p
Woodroffe CD, Thom BG (1988) Shell middens in the context of estuarine development, South Alligator River, Northern Territory. Archaeol Ocean 23:95–103
Woodroffe CD, Chappell J, Thom BG, Wallensky E (1984) Geomorphology of the South Alligator tidal river and plains, Northern Territory. In: Bardsley D, Woodroffe CD (eds) Coasts and tidal Wetlands of the Australian monsoon region. Northern Australian Research Unit, Darwin
Woodroffe CD, Thom BG, Chappell J (1985) Development of widespread mangrove swamps in mid-Holocene times in northern Australia. Nature 317:711–713
Woodroffe CD, Chappell J, Thom BG, Wallensky E (1986) Geomorphological dynamics and evolution of the South Alligator tidal river and plains, Northern Territory. Northern Australian Research Unit, Darwin, 190 p
Woodroffe CD, Chappell J, Thom BG, Wallensky E (1989) Depositional model of a macrotidal estuary and floodplain, South Alligator River, northern Australia. Sedimentology 36:737–756
Woodroffe CD, Mulrennan ME, Chappell J (1993) Estuarine infill and coastal progradation, southern Van Diemen Gulf, Northern Territory. Sediment Geol 83:257–275

Chapter 8
North Arnhem Land Region

Abstract The north Arnhem Land coast extends for 1872 km along the northern coast of the Northern Territory. The coast is largely undeveloped and most is aboriginal land. It faces generally north with the southeast trades blowing off to alongshore. This is a tropical monsoonal region with a distinct wet and dry season, the wet delivering river floods which bring terrigenous sediment to the coast; however coastal sediments remain roughly 50:50 quartz and carbonate. Tides are meso to macro and waves generally low seas except on more exposed easterly facing shores. The beaches are predominately tide-dominated with tide-modified in more exposed locations, while mangroves dominate the more sheltered shores. Barrier systems are limited and mainly low regressive beach-foredune ridges, with limited dune transgression on some east-facing sections. This chapter describes the processes operating along the coast and its beach, barriers and sediment transport, with the framework of primary and secondary sediment compartments.

Keywords Arnhem Land · Meso-tidal · Macro-tidal · Trade wind · Beaches · Barriers · Sediment transport · Sediment Compartments

8.1 Introduction

The northern Arnhem Land coast extends for 1872 km from Cape Don to Cape Arnhem on the northeastern tip of the NT and encompasses essentially the entire northern coast of the NT, which faces north into the Arafura Sea (Fig. 8.1). While the coast trends generally east-west, there are about 15 bedrock-controlled bays of variable size, separated by a mix of points, elongate peninsulas and islands, which results in an overall crenulation ratio of 3.1. In addition, there are several large island chains, the longest the Elcho-Wessel islands extending in a linear northeast trend for 210 km and more than 160 upland and tidal creeks and several small- to moderate-sized rivers which drain to the coast with most supplying terrigenous sediment. Beaches and sandy shore occupy 833 km (44%) of the shore, the remainder a mix of red laterite bluffs along the exposed portions, some sandstone points and extensive mangrove-fringed tidal flats in the more sheltered bays, particularly

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Fig. 8.1 The north Arnhem Land region extends from Cape Don to Cape Arnhem and includes three PCs:NT02.02-04. (Source: Google Earth)

Junction, Castlereagh, Buckingham and Arnhem bays and around the entrances to the many tidal creeks and estuaries. As a consequence, this is a generally low, to at best moderate, wave energy, meso-tidal coast that is highly variable in its orientation, degree of sheltering and shoreline type. It is divided into three PCs and seven SCs (Table 8.1) which are discussed below.

The geology of the Arnhem Land coast is presented in Sect. 2.3.2 and Fig. 2.1 and consists from west to east of the Monkey Shoals Basin, the Pine Creek Oregon, the Arafura Basin and the small Arnhem Inlier. The rocks range from sedimentary (sandstone, siltstone, mudstone and conglomerates) on the Coburg Peninsula to metasedimetary along much of the eastern coast including Cape Arnhem. However, all the surfaces have been planated down to a low coastal plain which in turn has been deeply laterised. Red laterite bluffs ranging from 5 to 35 m in height are commonly exposed along the coast, usually fronted by laterite flats and reefs. The entire coast is relatively low with the tilted sandstone of the NT's highest headland, Cape Wilberforce, rising to just 40 m. The only major development in this region is the town of Nhulunbuy (population 4000) on the Gove Peninsula, site of a large bauxite mine. The Coburg Peninsula is occupied by Gurig National Park and surrounded by Coburg Marine Park. It houses a small settlement at Port Smith and a tourist resort at Seven Spirits Bay. Most of the region, including all the islands, are part of the Arnhem Land Aboriginal Land Trust, with four aboriginal coastal communities at Maningrida (2100), Milingimbi (1000), Ramingining (800) and Yirrkala (700) together with a number of small outstations. There are also aboriginal communities on Crocker (300), South Goulburn (300), Elcho (2000) and Wessel islands, the latter made up of 35 islands with a total population of over 2000. In all Galloway (2003) found there are 148 islands along the NT coast with an area > 1 km^2.

Table 8.1 The north Arnhem Land region (NT02), PCs and SCs

Comp.[a]	Boundaries	Beach ID[b]	No. beaches	km [c]	Total km
NT02.01.01	W Bathurst-Melville Is[d]	–	–	–	–
NT02.01.02	N Bathurst-Melville Is	–	–	–	–
NT02.01.03	E Bathurst-Melville Is	–	–	–	–
PC:NT02.01					
NT02.02.01	C Don-C Crocker	NT 184–410	227	1859–2243	384
	Crocker Is (W)	CIs 45–139	95	61–136	75
NT02.02.02	Crocker Is (E)	CIs 1–44	44	0–61	61
	C Crocker-Laterite Pt	NT 411–506	96	2243–2373	130
PC:NT02.02			*462*		*649*
NT02.03.01	Laterite Pt-Hall Pt	NT 507–578	72	2373–2528	155
NT02.03.02	Hall Pt-C Stewart	NT 579–656	78	2528–2734	206
NT02.03.03	C Stewart-Woolen R	NT 657–676	20	2734–2809	75
PC:NT02.03			*170*		*436*
NT02.04.01	Woolen R-Rimbija Is	NT 677–776	100	2809–3114	305
NT02.04.02	Rimbija Is-C Arnhem	NT 777–1053	277	3114–3731	617
PC:NT02.04			*377*		*922*
NT02	**W NT and N Arnhem Land**	**Total**	**1009**		**2007**

[a]NCCARF compartment number
[b]ABSAMP beach ID
[c]Distance from WA/NT border
[d]Not included

8.1.1 Rivers and Deltas

A series of 160 creeks and small- to moderate-sized rivers reach the coast, an average of one every 10 km. Most are either small upland creeks where the coastal plain forms the coast or small- to medium-sized tidal creeks, with several small- to moderate-sized rivers, from west to east; these are the King, Goomadeer, Liverpool, Blyth, Glyde and Woolen. The rivers and creeks all have TD mouths and their TD estuary-delta plains are dominated by a mix of mangroves and supratidal salt flats depending on the stage of infilling.

8.1.2 Sediments and Processes

Coastal sediments along the Arnhem Land beaches are primarily moderately-well to moderately sorted carbonate-rich (~50%) medium sand. The coarsest material is deposited in the high tide swash zone with a slight fining in the nearshore (to 4 m depth), and slightly finer and better-sorted sand in the low foredunes (Table 8.2). There is considerable longshore variation in grain size and carbonate along the

Table 8.2 North Arnhem Land (NT02) beach sediment characteristics

N Arnhem Land	Dune	HT swash	LT swash	1–4 m depth
n	30	60	35	31
Mean size (mm)	0.36	0.46	0.44	0.39
σ (mm)	0.19	0.35	0.34	0.28
sorting	0.53	0.74	0.88	0.89
σ (sorting)	0.15	0.26	0.2	0.28
% Carbonate	42	48	57	47
σ (%)	31	31	27	29

coast. Mean swash sand size ranges from 0.1 to 2 mm and percent carbonate from 0% to 100%, while dune sand while slightly finer has similar ranges, with no discernable trends in sediment character (Fig. 8.2a, b) indicative of variable local sources and limited longshore transport.

As the coast faces north, the southeast trades blow generally offshore or at best alongshore on northeast-facing sections of some of the bays, and the easternmost Gove Peninsula coast. For most of the coast ocean waves range from low to very low, dropping to zero in some of the bays, with much of the coast both sheltered from the trades winds with additional sheltering within the large number sheltered bays and in lee of islands. Only the summer northwesterlies deliver wave energy to much of the north-facing coast. The modal breaker wave height for the NT coast is 0.3 m, with 75% of the beaches receiving waves of 0.5 m or less and only 22% receiving waves between 0.6 to 1 m and 3% exceeding 1 m (Table 2.4). The highest energy sections extend south of Cape De Courcy and on parts of the eastern Gove Peninsula where breaking waves can average 1 m. Tides range between 4.4 m at Cape Hotham, decreasing to 2.0 m at Cape Don and 2.4 at Cape Crocker, then rising to 4.8 m at Yabooma before dropping to 2.9 m at Gove Harbour (Table 5.3).

8.1.3 Beaches

The north Arnhem Land beaches are a product of a general low energy breaker wave climate, meso to macro-tides, variable sediments (fine to coarse and low to high carbonate), the tropical climate, and locally the prevalence of laterite and in places coral reefs. The 870 beaches have an average orientation of 163°; however the large standard deviation (123°) (Table 8.3) and range indicates that the beaches while located on a generally north-facing coast face a wide range of directions, reflecting the influence and control of the local geology. Likewise, the high tide beaches themselves range in width from 1–20 m with a mean of just 6.3 m, again attesting to the low level of wave energy. The sand flats that front 549 of the beaches average 385 m in width. The typical northern Arnhem Land beach is usually a sheltered beach of variable orientation, with a narrow (<10 m) moderately steep (5°) high tide beach fronted by 400 m wide intertidal sand flats. Beaches fronted by rock (laterite)

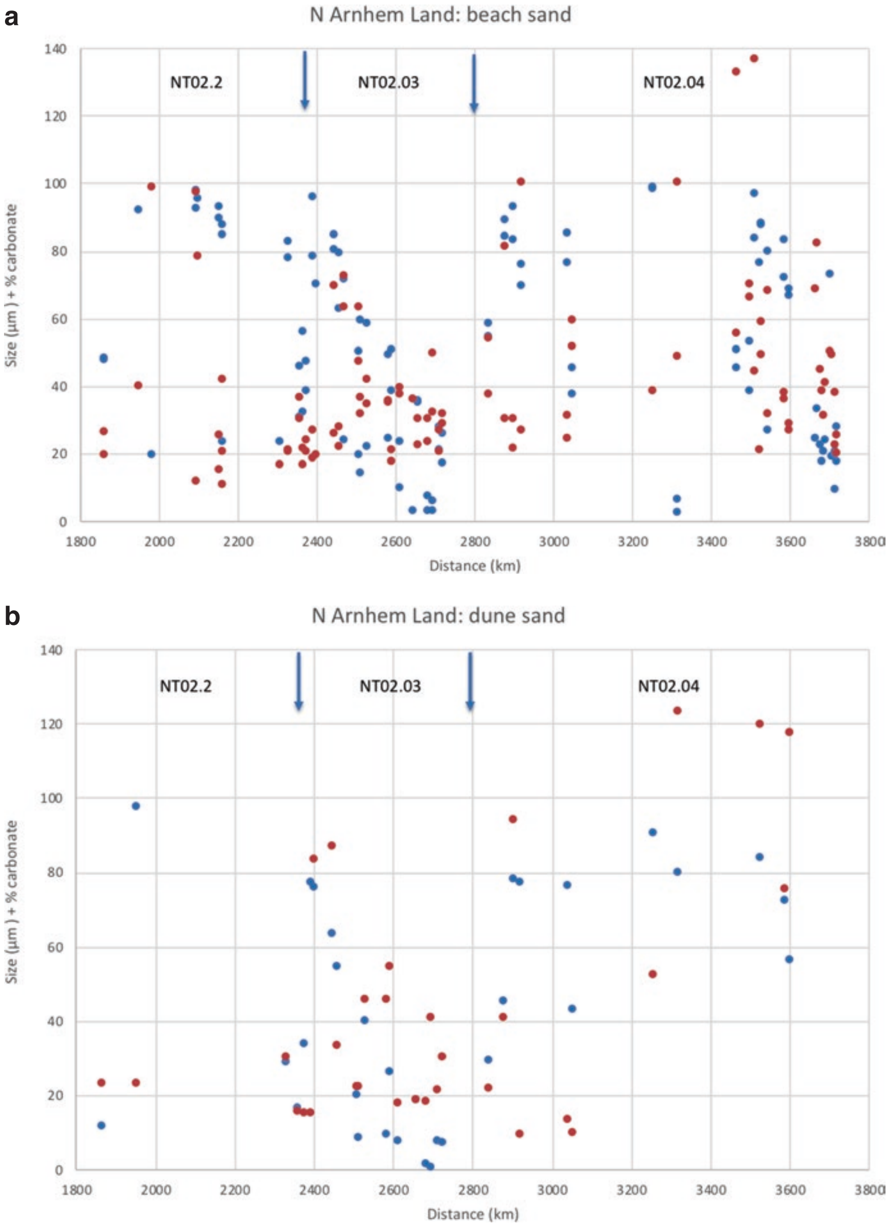

Fig. 8.2 (**a**) Longshore variation in (**a**) swash; and (**b**) dune sand size (µm, red) and % carbonate (blue). PC boundaries indicated by arrows. Distance is from WA/NT border

Table 8.3 Some characteristics of the north Arnhem Land (NT02) beaches[a]

	n	Mean	σ	Min	Max
Orientation (deg)	870	163	123	1	359
Embaymentisation	870	0.77	0.23	0.1	1.0
Gradient (deg)	870	5.1	1.3	0.5	10
Beach width (m)	870	6.3	3.9	1	20
Sand ridges (m)	42	5.7	2.9	2	14
Sand flats (m)	549	385	375	50	4000
Rock/coral flats (m)	344	305	441	50	4000

[a]Source: Short (2006)

Table 8.4 North Arnhem Land (NT02) beach types and states

BS	BS	No.	%	Length (km)	%	Mean (km)	σ (km)
7	R + LTT	80	9.2	128.7	15.5	1.6	2.2
8	R + LTR	35	4.0	49.7	6.0	1.4	2
10	B + RSR	38	4.4	86.3	10.4	2.3	2.9
11	B + SF	309	35.5	315.2	37.8	1	1.1
12	B + TSF	80	9.2	57.8	6.9	0.7	0.8
13	B + TMF	61	7.0	34.9	4.2	0.6	0.7
14	R + RF	233	26.8	125.4	15.1	0.5	0.7
15	R + CF	33	3.8	34.9	4.2	1.1	1.4
		869	100	832.9	100	0.96	1.37

flats (R + RF) are also common (15%) with the rock flats averaging 300 m in width and indication of the influence of laterite at the coast (Nott 1994).

The beaches are primarily TD (59% by length) and TM (21.5%) the remainder fronted by rock flats (15%) and 33 with fringing coral reefs (4%) (Table 8.4). As noted above the TD beaches have intertidal sand flats average 385 m in width, while the rock and coral flats average 305 m in width. The higher energy B + RSF average 580 m in width and have on average 7.2 ridges, ranging from 2 to 14 with an average spacing ~80 m, the Australian average. Short (2006) describes each of the beaches in detail, while the beaches of the three PCs and seven SCs are discussed below.

8.1.4 Barriers

There are a total of 211 barrier systems along the north Arnhem Land coast spread amongst the three mainland PCs (Table 8.5). They have a total length of 572 km occupying 30% of the coast and are predominately low energy regressive chenier-beach ridge to low foredune ridge/s. Some near river mouths have undergone substantial progradation with the largest at the mouth of the Blyth River prograding

Table 8.5 North Arnhem Land: regional and PC barrier dimensions

PC	NT02.01[a]	NT02.02	NT02.03	NT02.04	NT02 N Arnhem
Number		79	50	82	211
Total length (km)		190	199	183	572
Mean width (m)		160–450	170–550	110–310	–
Mean height (m)		4.2	3.5	3.8	–
Area (ha)		4955	12,480	4183	21,618
Unstable (ha)		211	799	374	1384
Total volume (M m^3)		232	430	169	831
Unit volume ($m^3\ m^{-1}$)		1218	2158	942	1452

[a]NT02.01 (Bathurst and Melville islands) is not included

5 km and capped by 40 ridges. The barriers range from 110–450 m in width, with a mean height between 3.5 and 4.2 m. Only south of Du Courcy Head and out towards the exposed Cape Arnhem is there some minor dune transgression, with unstable dunes making up only 6% of the barrier area. The compartment has a total barrier volume of 831 M m^3, with a unit volume between 942 and 2158 $m^3\ m^{-1}$, the low volumes typical of the low energy sections of the northern Australian coast.

8.2 PC:NT02.02 The Northern Coburg Peninsula

PC:NT02.02 extends for 514 km from Cape Don, the western tip of Coburg Peninsula to Angulari Creek in Aurari Bay and contains two SCs (NT02.02.01 and 02) (Fig. 8.3). The peninsula itself has five north-south-trending bays up to 30 km long, separated by protruding peninsulas resulting in a highly irregular shoreline, followed by 40 km long Croker Island which is separated from the mainland by 2.5 km wide Bowen Strait. East of the island are the larger Mountnorris and Aurari bays separated by De Courcy Head. The shoreline has an overall crenulation ration of 3.5 and is a mix of laterite bluffs, small sandy beaches and their sand flats, with mangroves-lined shores located generally at creek mouths towards the base of the bays.

8.2.1 *Rivers and Creeks*

More than 60 small- to medium-sized upland and tidal creeks, but no rivers, flow into this PC. The creeks have small catchments and deliver limited terrigenous sediment to the coast, particularly in the bays. A number have developed small deltas, some elevated to salt flats. All the bay creeks have mangroves lining their mouths, while those entering the more open Aurari Bay drain across regressive barrier ridges.

Fig. 8.3 SCs:NT02.0201–02. The northern Coburg Peninsula extends from Cape Don to Laterite Point near the base of Aurari Bay. (Source: Google Earth)

Table 8.6 Sediment characteristics of north Arnhem Land region (PCs 02.02-02.04)

PC	NT02.02	NT02.03	NT02.04
Dune: n	5	16	9
Size (mm)	0.26	0.29	0.26
σ (mm)	0.09	0.08	0.09
Sorting	0.53	0.53	0.53
σ (sorting)	0.24	0.14	0.24
% Carbonate	48	29	64
σ (%)	40	26	21
Swash: n	18	34	43
Size (mm)	0.33	0.37	0.26
σ (mm)	0.23	0.29	0.09
Sorting	0.77	0.82	0.53
σ (sorting)	0.27	0.4	0.24
% Carbonate	63	39	55
σ (%)	29	27	30

8.2.2 Sediments and Processes

Beach sediments are moderately sorted, medium sand with 63% carbonate, fining in the dunes to fine-medium sand with 48% carbonate (Table 8.6). It is expected that sediment for the beaches and barrier came initially from offshore terrigenous and biogenic source, as indicated by the ~50% carbonate material, with the rivers and 30 creeks only supplying sediment to the open coast once their deltas have formed.

Coastal processes are constrained by the highly indented nature of the northern peninsula coast, with wave energy grading from low to moderate on the outer sections of the peninsulas to very low to zero deeper into the bays. Significant trade wind and waves only arrive on the eastern shore of Mountnorris Bay and particularly south of De Courcy Head in Aurari Bay. Spring tide ranges from 2.9 m at Cape Don to 2.4 m at Cape Croker.

8.2.3 Beaches

The northern Coburg Peninsula has 323 beaches that occupy 277 km (72%) of the shore, a relatively high proportion, particularly in the NT, mainly owing to the near continuous beaches east of Croker Island in Mountnorris and Aurari bays. The beaches have an average length of 0.85 km and consist of a mix of TD beaches particularly those sheltered in the seven major bays of the peninsula and higher energy TM located on the exposed tips of the peninsulas and on the east-facing shore extending for 50 km south of De Courcy Head. The sheltered TD beaches are dominated by B + SF (57%) with 12% having tidal mud flats (Table 8.7). There are 31 TM beaches (9%) including 35 R + LTR a product of the high waves (~1 m) along the exposed east-facing shore south of De Courcy Head. There are a total of 80 beach rips along this section (NT 466–511), with a spacing ranging between 150 and 200 m. In addition, there are 56 topographic rips against the numerous laterite reefs and points. There are also 65 beaches (20%) fronted by (laterite) rock flats reflecting the prevalence of the laterite bluffs and reefs along this PC.

8.2.4 Barriers

The northern peninsula has 79 barriers which occupy 200 km (38%) of the shore, the remainder dominated by laterite bluffs on exposed sections, while mangroves line the sheltered bay shores on the northern peninsula. The barriers have an average

Table 8.7 North Arnhem Land PC:NT02.02 beach types and states

BS	BS	No.	%	Length (km)	%	Mean (km)	σ (km)
7	R + LTT	12	3.7	7.2	2.6	0.6	0.6
8	R + LTR	19	5.9	18.8	6.8	1	1.4
10	B + RSR	12	3.7	20.6	7.4	1.7	1.2
11	B + SF	134	41.5	156.6	56.6	1.2	1.2
12	B + TSF	1	0.3	1.0	0.4	1	–
13	B + TMF	60	18.6	34.4	12.4	0.6	0.7
14	R + RF	65	20.1	23.3	8.4	0.4	0.4
15	R + CF	20	6.2	15.0	5.4	0.7	0.7
		323	100	276.9	100	0.8	

length of 2.5 km and range in average width from 160 to 450 m. They are predominately low regressive beach-foredune ridge barriers, as well as some cheniers in more sheltered locations. Transgressive dunes back the exposed coast south of De Courcy Head, with all the unstable barriers located along this section. The barriers have a total volume of 231 M m^3 and a unit volume of 1218 m^3 m^{-1} (Table 8.5).

Woodroffe et al. (1992) investigated three sites along the northern peninsula coast. Around Cape Don they found three types of inactive sand deposits with no modern equivalent, including an inner barrier rising 2 m above HWM that dated ~9.3 ka, sand ridges 3–4 m above HWM dating ~15 ka and aeolian deposits extending a few hundred metres inland dating ~10.7 ka. They believe these all represent sand deposited when sea level was lower and reworked onshore by waves and strong southerly wind during the PMT between 15 and 9.3 ka. In Port Essington they found table reef encrusted with three phases of ferricrete dating 131 ka, 47 ka and 24 ka, indicating the platform must have formed during the last interglacial ~120 ka. Finally, just east of Port Smith, they dated a 2 km wide series of three barrier complexes and found the inner carbonate-rich and indurated barrier dated 6.7 ka, the middle barrier at 1.9 ka and the outer quartz-rich at 1.5 ka. The result indicates the barrier commenced around 7–6 ka, with the outer most recent phase of accumulation occurring in the past 2 ka. They also concluded that sea level was 0–1 m above present on the Coburg Peninsula 6 ka, in general agreement with Nott (1996) who found sea level was at +2.5 m in the Darwin region between 2 and 3.4 ka.

These results indicate that much of this coast may have experienced similar evolutionary sequence, that is, they contain remnants of last interglacial deposits, PMT deposits as well as regressive Holocene deposits.

8.2.5 SCs:NT02.02.01-02

SC:NT02.02.01 extends along the irregular northern shore of the Coburg Peninsula for 384 km (excluding Crocker Island) (Fig. 8.3). It has 227 beaches averaging 0.83 km in length and occupying 189 km (83%) of the coast, all located on the outer sections of the peninsulas. The sheltered nature of the beaches in indicated by the dominance of B + SF (65% by length and all TD beaches 78%) mainly located in the bays. On the more exposed, outer tips of the peninsulas are the higher energy R + LTT (4%), R + RF (8%) and R + CF (8%). The SC also contains 58 barriers which occupy 138 km (36%) of the shore, with an average length of 2.4 km. They are primarily located towards the tips of the peninsulas in the numerous small embayments which have provided accommodation space for the mix of terrigenous and carbonate sands. Given the location of these barriers, remote from creek and rivers, an offshore source is most likely. Most of the barriers consist of a few low beach-foredune ridges. The largest on Wanaraij Point (NT 241–2) is 2 km wide and contains over 30 ridges (Fig. 8.4b). Other larger barriers occur at Araru Point (Fig. 8.4a), Trepang Bay (10 ridges), and Danger Point (10). As discussed above the

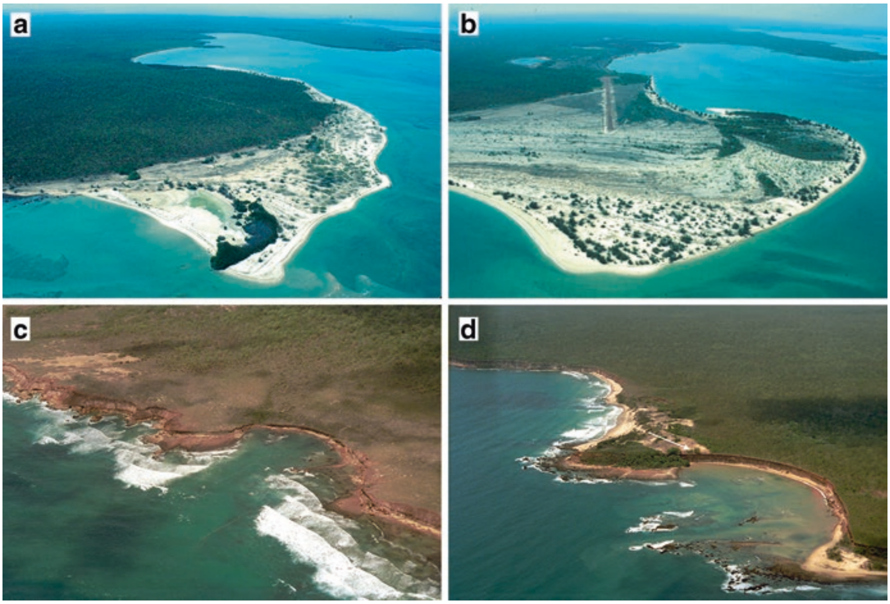

Fig. 8.4 PC:NT02.02 beaches: (**a**) the Araru strand plain at the tip of a peninsula has accumulated sand moving easterly around the point and into the bay (NT 200–201); (**b**) Wanaraij Point on the next peninsula has sand transport to the west then south building a 1.3 km wide regressive barrier (NT 241–242); (**c**) a small deeply embayed beach on the exposed coast just south of De Courcy Head (NT 465); and (**d**) two beaches one sheltered by reefs the other exposed with rips, with minor northerly headland overpassing across the central headland (arrow), located a few kilometer south of De Courcy Head (NT 468–469). (Photos: AD Short)

2 km wide Smith Point triple barrier was investigated by Woodroffe et al. (1992). Most of the barriers appear to be self-contained sediment sinks, with a few moving sand a limited distance southwards into the bays, as indicated by the spits extending south of Araru and 4 km long Wanaraij point (Fig. 8.4a, b).

SC:NT02.02.02 has 96 km of generally more exposed sandy shoreline in Mountnorris and Aurari bays with 96 beaches occupying 88 km (92%) of the shore. The higher energy is reflected in the greater proportion of higher energy beaches particularly along the Du Courcy coast with R + LTR occupying 19 km (22%), R + LTT 4 km and R + RF 8 km. The TD beaches consist of B + RSF (21 km particularly in Mountnorris Bay) and B + TSF and TMF, 35 km and 4 km, respectively, particularly in the more sheltered Malay Bay. The beaches are backed by 21 barriers that occupy 52 km (54%) of the shore with an average length of 2.5 km. The barriers can be divided into two sections. Those in the more sheltered north-facing Mountnorris Bay all consist of a few beach-chenier ridges and some recurved spits, all with TD beaches, including a 10 km long section of ridged sand flats in the southwest section of the bay. The next section between De Courcy Head and Angulari Creek faces northeast, exposing it obliquely to the southeast winds and waves. This relatively straight 50 km long section of coast has 50 higher energy TM beaches with half fronted by laterite rock flats (Fig. 8.4c, d), while the sandy beaches are either R + LTR or R + LTT. There are 18 beaches with rips having a total of 80 rip channels with an average spacing between 150 and 200 m. The higher wave energy is also accompanied by exposure to the easterly winds that have deposited blufftop dunes, orientated 330º, that extend a few hundred metres inland, usually as multiple blowouts. The dunes increase in size northwards where there are a few larger parabolics, the longest extending 2 km inland. This is one of the higher energy sections of the north Arnhem Land coast. The transgressive dunes that extend south of De Courcy Head were dated by Lees et al. (1990) who found they consist of a basal Pleistocene unit (81 ka), overlain by four Holocene sequences. The first sequence accompanied the PMT (8.6 ka), followed by sequences at 2.8 ka, 1.9 ka and 0.2 ka, indicating episodic dune emplacement during the Holocene with the most recent transgression still ongoing with 50% of the dunes presently active.

8.2.6 PC Overview

The northern Coburg Peninsula consists of the highly indented generally sheltered northern peninsula coast with narrow bays and peninsulas and to the east the more open, sandy and exposed Mountnorris and Aurari bays shoreline. While lower energy TD beaches dominate overall (77%), the remainder are more exposed higher energy TM and R + RF/CF, leading to a spectrum of beach types and states. This spectrum is also reflected in the barriers which range from chenier to beach ridge to foredune ridges with, minor to moderate dune transgression in lee of the more exposed TM beaches. Overall this PC has low vulnerability owing to the elevated nature of most of the Coburg peninsulas and coastal plain to the east. Sea-level rise will inundate the many small creek mouths and their associated deltas/tidal flats, with coastal ‘squeeze’ occurring as it rises against the backing higher relief hinterland.

8.3 PC:NT02.03 Central-North Arnhem Land

PC:NT02.03 extends along the central section of north Arnhem Land between Angulari Creek and the Woolen River, a distance of 436 km and contains three SCs NT02.03.01-03 (Fig. 8.5). The coast consists of a series of northeast-trending points and islands separating a series of embayments, including the larger Junction, Boucaut and Castlereagh bays, with the latter two up to 60 km wide, into which flow six small rivers and about 35 smaller creeks. The resulting shoreline varies within each bay depending on orientation and exposure.

Fig. 8.5 SCs:NT02.03.01-03. Laterite Point to Woolen River consist of a series of open north-facing bays. (Source: Google Earth)

8.3.1 Rivers and Creeks

Seven small rivers draining the 400–500 m high Arnhem Plateau in the south and 200–300 m high Parsons-Mitchell ranges in the east flow into this PC. From the west they are the King (1110 km^2) Goomadeer (2156 km^2), Liverpool (8626 km^2), Blyth (7657 km^2), Glyde (10,234 km^2), Woolen (1325 km^2) and Buckingham (1345 km^2). They are described in more detail in the following sections.

8.3.2 Sediments and Processes

Beach sediments are typically moderately sorted medium sand averaging 40% carbonate, fining slightly into the dunes with an average of 30% carbonate (Table 8.6). There is however considerable longshore variation in both size (σ = 0.1 mm) and percent carbonate (σ = 26%) as illustrated in Fig. 8.2. Waves remain low along the coast with the winter trades blowing offshore and only delivering significant energy (~1 m) to some of the headlands and their easterly shores. The main source of waves appears to be the summer northwesterlies, which blow directly onto the north-facing beaches and bays delivering waves up to 1 m. Tide increase eastwards from 2.4 m at Cape Crocker to 4.8 km at Yabooma Island in Castlereagh Bay.

8.3.3 Beaches

The beaches are predominately TD (59%) but do contain 12 longer more exposed R + LTT beaches (21%) all located towards the most exposed northeastern part of the points with some backed by transgressive dune fields (Fig. 8.6c, d). As the bay shores become more sheltered and/or face north and west, the mix of TD beaches (predominately B + RSR and B + SF) grade into a low energy mangrove-lined shoreline. Laterite reefs continue to outcrop along the coast with 49 beaches fronted by rock flats (29%; Fig. 8.6b) and 12 with fringing reefs (Table 8.8). There is evidence of localized longshore sand transport in the form of migrating sand spits moving sand southwards into the bays, with rates expected to be very low (~100's m^3 $year^{-1}$). Based on the size of the spits extending south in Anuru Bay (Fig. 8.6a), it would at this location be on the order of 200 m^3 $year^{-1}$. However, sediment transport is expected to be contained within each of the SCs and within the bays and smaller embayments (TCs), with no evidence of exchange between the bays and the SCs.

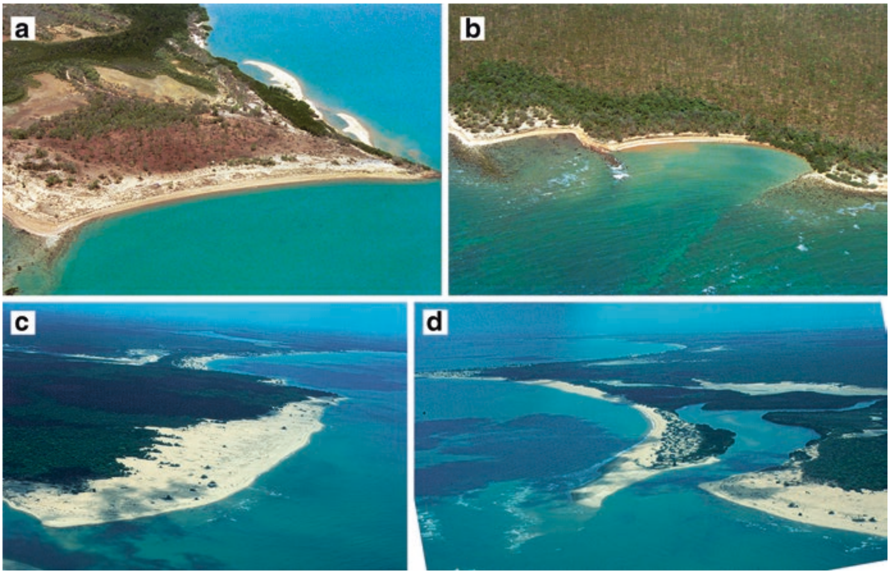

Fig. 8.6 PC:NT02.03 beaches. (**a**) Anuru Bay showing sand moving southwards via spits into the bay (NT 525-526); (**b**) beach NT 548 embayed by laterite reefs; (**c**) the beach at Relief Point is backed by up to 400 m of dune transgression (NT 574); and (**d**) mangrove-lined inlet and sand spit at Relief Point (NT 575). (Photos: AD Short)

Table 8.8 North Arnhem Land PC:NT02.03 beach types and states

BS	BS	No.	%	Length (km)	%	Mean (km)	σ (km)
7	R + LTT	12	7.1	51.3	20.8	4.3	3.8
8	R + LTR	1	0.6	0.1	–	0.1	–
10	B + RSR	17	10.0	56.6	23.0	3.3	4.0
11	B + SF	47	27.6	63.0	25.6	1.3	1.3
12	B + TSF	28	16.5	23.2	9.4	0.8	1.2
13	B + TMF	4	2.4	2.3	0.9	0.6	0.6
14	R + RF	49	28.8	31.1	12.6	0.6	0.7
15	R + CF	12	7.1	18.9	7.7	1.6	2.1
		170	100	246.5	100		

8.3.4 Barriers

This PC has 50 barriers that occupy 200 km (46%) of the shore. The barriers average 4 km in length with most consisting of a few chenier-beach-foredune ridges, which average between 170 and 550 m in width, the largest being the 30 km^2 Goomadeer River deltaic chenier plain. There are two areas of minor to moderate dune transgression up to a few hundred metres inland (Fig. 8.6c), located on the exposed northern shore of the Cuthbert-Hall Point peninsula and along some of the northeast-facing section of Boucaut Bay. The barriers have a total volume of 430 M m^3 and a unit volume of 2158 $m^3\ m^{-1}$.

8.3.5 SCs:NT02.03.01-03

SC:NT02.03.01 is 155 km long and located between Laterite and Hall points. It is a generally north-facing compartment containing a series of smaller bays (Aurari, Anuru, Waminari, Wangularni, Arrla, and Madarrgaidj), each separated by low northeast-trending peninsulas, together with North and South Goulburn islands extending north of Ross Point. This is a generally more open and exposed shoreline, with 72 beaches occupying 114 km (74%) of the shore, the more exposed beaches dominating and occupying about half the sandy shore. There are five R + LTT (totalling 32 km, 21%), including 15 km long beach (NT 572) extending the east of Guion Point and extensive generally exposed rock-reef flats with 26 R + RF (20 km, 13%) and 11 R + CF (18 km, 12%). TD beaches are restricted to the more sheltered smaller bays with 5 B + RSF (11 km, 7%) and 22 B + SF (31 km, 20%).

Beginning in the west Aurari Bay is a gently curving 35 km wide northeast-facing bay, with a 15 km long near continuous regressive barrier occupying its southern shore and containing about 10 ridges, the outer ridges experiencing some instability. The barrier is feed by two small tidal creeks; however beach sediments are predominately carbonate (average 63%, range 35–95%), the amount of carbonate increasing east between White and Ross points where coral reefs fringe the shore. Anuru Bay is a more sheltered 5 km wide northeast-facing bay with a predominately mangrove-lined shore and coral reefs also fringing the eastern Barclay Point. Waminari and Wangularni bays are two small adjoining bays, located within a 12 km wide bay between Barclay and Turner points. Both have east-facing regressive barriers at their base containing about ten ridges with adjacent mangrove-lined tidal creeks. Sediments contain between 60% and 85% carbonate in Wangularni Bay. The bedrock-controlled King River mouth and Arrla Bay occupy the next embayment. The lower reaches of the river flow for 20 km through a 1–3 km wide northeast aligned, bedrock-controlled valley, into a very sheltered bay. It has a typical TD funnel-shaped mouth lined by dense mangrove-covered tidal flats along its channel. The extensive mangroves indicate the river is in the second ‘big swamp’ phase of evolution. Surrounding beach sediments range from 10% to 80% carbonate (mean = 52%), indicating that marine, rather than fluvial, sediments are dominating the sedimentation in the bay. Ten-kilometre-wide Madarrgaidj Bay is bounded by Cuthbert and Hall points, with a near continuous beach running from Relief Point (Fig. 8.6c) for 18 km to Hall Point, with coral reefs fringing all three points, and sediment averaging 35% carbonate.

SC:NT02.03.02 is a 206 km long compartment located between Hall Point and Cape Stewart consisting of the two larger U-shaped Junction and more open Boucaut bays, which are separated by the Liverpool River, with a more open crenulation ratio of 2.3. The shoreline contains 78 beaches occupying 125 km (61%) of the shore and range from moderately exposed TM to sheltered TD. There are seven R + LTT beaches (15 km, 14%) each located on the tip of the points (Hall, West and Skirmish), which they tend to share with 14 R + RF (7 km, 3%), with 14 B + RSF all located along Boucaut Bay where they occupy 47 km (23%) of the shore. In the more sheltered bays, including Junction, are 24 B + SF occupying 36 km (17%) and 19 B + TSF occupying another 20 km (10%).

Three rivers have built deltas at the coast. In the west the Goomadeer River flows into 8 km wide east-facing Junction Bay where the low waves have reworked its sediment to form a 1.5 km wide outer chenier plain containing about six cheniers, fronted by 1.5 km wide mud flats. These are backed by an older/raised (Pleistocene?) chenier plain that extends west for another 1.5 km (Fig. 8.7). In the centre the Liverpool flows into the base of a sheltered 3 km wide bedrock-controlled valley, the river depositing a typical TD funnel-shaped mangrove-lined estuary. The Blyth enters the coast on the eastern side of Boucaut Bay where its sediments have been reworked by waves to form a 5 km wide series of regressive spits and beach ridges primarily to the eastern side of its tide-dominated 3 km wide funnel-shaped TD mouth, with sand flats extending 2 km into the bay.

SC:NT02.03.03 occupies the western side of the 40 km wide Castlereagh Bay (Fig. 8.5) and has 75 km of generally very low energy shore. While much of the bay faces northeast, it has a predominately TD shoreline, sheltered by Yabooma and Milingimbi islands in the west and Banyan and Howard islands in the east. The shoreline is dominated by mangrove-lined tidal flats, with 20 beaches occupying just 11 km (15%) of the shore. Most are located on the exposed east-facing shore of

Fig. 8.7 Junction Bay and the Goomadeer River delta which is flanked by an inner and outer chenier plain with tidal flats averaging about 1 km in width. (Source: Google Earth)

Cape Stewart (ten R + RF occupying 8 km), with the remaining ten B + TSF (3 km) scattered in amongst the mangroves. The Glyde River enters the base of the bay (Fig. 8.8). It has a funnel-shaped entrance bordered by 4 km wide tidal flats that extends 30 km to the west, all fringed by mangroves, with the sinuous river channel and flood plain extending more than 20 km inland.

8.3.6 PC Overview

PC:NT02.03 consists of a series of generally north-facing bays ranging in width from 5 to 40 km, with each acting as a sink for in situ carbonate sediments, shelf-derived sand and fluvially delivered mud where rivers are present. SC02.03.01 has a series of closed bays, each acting as a sink for primarily in situ carbonate sediments, together with shelf-derived terrigenous sands, while the King River is infilling its valley but yet to supply substantial bedload to the bay. SC2.03.02 has received substantial sediment from the Goomadeer, Liverpool and Blyth rivers each of which have built muddy deltas at their mouths, with the Liverpool contains within its bedrock valley. SC02.03.03 is a largely sheltered low energy embayment, dominated by

Fig. 8.8 Castlereagh Bay is a very low energy mangrove and salt flat fringed bay into which flow the Glyde and Woolen rivers. The Milingimbi community is located on Milingimbi Island. (Source: Google Earth)

mangroves and mud flats including the muddy delta that extends west of the Glyde River mouth. The mix of elevated lateritic coastal plain, low sandy beaches and barriers and extensive low gradient tidal sand and mud flats will produce a range of responses to sea-level rise with the tidal flats and their tide-dependent ecosystems most vulnerable to inundation.

8.4 PC:NT02.04 Northeast Arnhem Land

PC:NT02.04 includes the northeastern section of Arnhem Land between the Woolen River and Cape Arnhem and has two SCs NT02.04.0-02 (Fig. 8.9). This is a highly irregular coast with a shoreline distance of 922 km and a crenulation ratio of 4.8, owing to a series of northeast-trending peninsulas, three enclosing the large mangrove-lined Buckingham and Arnhem bays, together with the Elcho and Wessel island chains extending for up to 200 km to the northeast. As a consequence, there is considerable longshore variation in shoreline type, orientation and degree of exposure. Within the very sheltered Buckingham and Arnhem bays, beaches occupy just 16% of the 340 km of shoreline, most located on the outer headland and peninsulas, with most of the inner shore fringed by wide mangrove-lined mud and salt

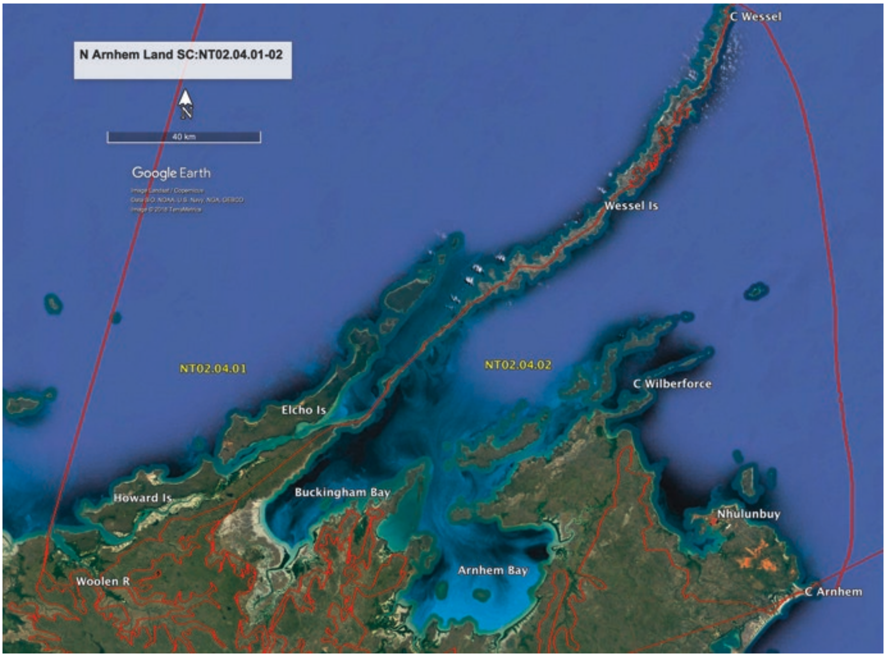

Fig. 8.9 SCs:NT02.04.01-02. Woolen River to Cape Arnhem. (Source: Google Earth)

flats, which in Buckingham Bay extend up to 20 km inland. This compartment also has some of the most exposed sections of the NT coast on the east-facing headlands, peninsulas and island chains. Cape Wilberforce located at the tip of a narrow 15 km long peninsula is the highest point on the NT coast at 40 m (Fig. 8.10d).

8.4.1 Rivers and Creeks

This PC is bordered by the northern slopes of the Mitchell Range and the Fredrick Hills, with about 20 small streams and nine small rivers reaching the coast. The Woolen flows into Castlereagh Bay along a bedrock-controlled northwest-trending valley, wide enough for the river to deposit a 2 km wide mangrove-lined funnel-shaped lower mouth. The Buckingham flows into the sheltered southern reaches of Buckingham Bay, with a 3.5 km wide mangrove-lined, funnel-shaped mouth and a few cheniers on its northern coastal plain. Five small rivers flow into the circular almost landlocked 35 km wide Arnhem Bay, all located along a 60 km long section of the southern and eastern shore. These are the Habgood (784 km^2), Baralminar (303 km^2), Goromuru (1026 km^2), Cato (836 km^2) and Peter John (493 km^2). Most of the bay is lined with mangroves and mud flats, and each of the rivers has funnel-shaped mangrove-lined mouths. The final two rivers, the Giddy (300 km^2) and the

Fig. 8.10 PC:NT02.04 beaches and coast. (**a**) Tombolo at Worrmi Point (NT 704-705); (**b**) two pockets of sand (NT 776–777) at the tip of the Napier Peninsula, which is composed of jointed Proterozoic sandstone; (**c**); deeply embayed beach NT 843 has three sand ridges filling much of the bay; (**d**) the sloping sandstone of 40 m high cape Wilberforce; (**e**) Parfitt Point is a 2 km long recurved spit moving sand into Melville Bay (NT 979-980); and (**f**); beach NT 1019 at the Rainbow Cliffs is sheltered by fringing rock flats that extend 0.4 km offshore. (Photos: AD Short)

Latram (133 km^2), flow into the small 12 km wide Melville Bay. Both have dense mangrove-covered deltaic plains and funnel-shaped mouths.

8.4.2 Sediments and Processes

As indicated in Fig. 8.2, sediment size and texture continue to vary considerable alongshore, indicative of the localized sources of sand and very limited, if any, longshore sand transport. Beach sand are finer (mean = 0.26 mm) and moderately well sorted, with an average of 55% carbonate, while the dune-overwash flats sand are similar in size and sorting with 64% carbonate (Table 8.6).

8.4.3 Beaches

There are 377 beaches averaging 0.8 km in length and occupying 310 km (34%) of the PC. Most of the shore is dominated by mangrove-lined mud flats, particularly in Buckingham and Arnhem bays, and the smaller indented bays along the shore of Nalwarung Straits and Melville Bay. Exposed bluffs and cliffs occur along the more exposed peninsula shores, with many small beaches wedged in between the bluffs. TD beaches dominate occupying 137 km (44% of the sandy shore), with the majority B + SF (31%) followed by B + TSF (10%), with the flats averaging 300 m in width (σ = 275 m) (Table 8.9). On the exposed north-facing section of Howard and Elcho islands and the east-facing parts of the Gove Peninsula are a range of higher energy TM R + LTT and LTR, which occupy 100 km (33%). The predominance of laterite bluffs also along these exposed sections contributes to the 120 beaches fronted by laterite flats (R + RF), which occupy 23% of the shore, with the intertidal rock flats averaging 120 m in width (σ = 90 m) (Fig. 8.10f).

Beside the mainland beaches, there are many beaches on the major islands (Table 8.10) as well as the 148 smaller islands that lie right along the northern NT-Arnhem Land coast (Galloway 2003). These islands are not discussed in this book.

8.4.4 Barriers

Eighty-two barriers occupy 183 km (20%) of the coast. They have an average length of 2.2 km and range in mean width from 110–310 m, with an average height of 3.8 m. Most of the barriers consist of one to a few beach-foredune ridges, with those near creek mouths terminating in recurved spits. Twelve of the more exposed

Table 8.9 North Arnhem Land PC:NT02.04 beach types and states

BS	BS	No.	%	Length (km)	%	Mean (km)	σ (km)
6	R	1	0.3	0.3	0.1	0.3	–
7	R + LTT	55	14.6	70.0	22.6	1.3	1.4
8	R + LTR	15	4.0	30.	10.0	2.1	2.4
10	B + RSF	9	2.4	9.1	2.9	1.0	1.0
11	B + SF	128	34.0	95.6	30.9	0.7	0.9
12	B_TSF	46	12.2	31.5	10.2	0.7	0.5
13	B + TMF	2	0.5	0.3	0.1	0.2	–
14	R + RF	120	31.8	71.2	23.0	0.6	0.8
15	R + CF	1	0.3	0.9	0.3	0.9	–
		377	100	309.84	100		

Table 8.10 Western Northern Territory and north Arnhem Land major islands and their beaches

Island	No. beaches	Coast length (km)
Bathurst	96	252
Melville	116	532
Crocker	145	131
North Goulburn	34	37
South Goulburn	55	48
Mallison	11	17
Total	457	1017

barriers have experienced minor dune transgression, the most extensive extending only a few hundred metres inland. Most of the beaches and barriers are embayed with no evidence of headland bypassing. There is however considerable evidence of longshore sand transport in the elongate spits usually moving southwards or laterally into the bays and their tidal creeks (Figs. 8.10e and 8.11). The barriers have a total volume of 169 M m^3 and a unit volume of 942 m^3 m^{-1}, the smallest in the region.

8.4.5 SCs:NT02.04.01-2

SC:NT02.04.01 has 305 km of shoreline which commences at the base of Castlereagh Bay where the Woolen River has deposited it bedrock-controlled funnel-shaped TD mangrove-lined deltas (Fig. 8.8). Extending east of the river mouth is the 40 km long Hutchinson Strait, which separates Howard Island from the mainland. The channel is largely filled with supratidal salt flats separated by a narrow meandering mangrove-fringed tidal stream, that links Castlereagh Bay with Cadell Strait, which in turn separates Elcho Island from the Napier Peninsula, the 50 km long peninsula part of the mainland. Most of the eastern bay shore is made up of the bedrock Howard and Elcho islands, which between them have 104 generally small embayed beaches, separated by laterite and sandstone bluffs, with sediment predominately carbonate and reaching in places 98% (mean = 64%, σ = 24%). The beaches total 125 km in length (41% of the shore) and are a mix of TM and TD and RF reflecting the variation in exposure and extensive laterite flats. There are 18 TM beaches totalling 18 km in length including 8 more exposed R + LTR all located in exposed east-facing locations. There are 35 TD beaches, including B + SF (29 beaches, 25 km), B + RSF (8, 8 km) and B + TSF (4, 5 km). However, the dominate beach type is the R + RF, with 39 occupying 47 km (15%) of the shore.

SC:NT02.04.02 is the longest SC on the north Arnhem Land coast, with 617 km of shoreline. However, it is also the most indented with a crenulation ratio of 5.1, largely owing to the combination of long narrow bedrock peninsulas (Napier, Flinders, Cape Wilberforce (Fig. 8.10d), Gove) and the two large almost landlocked Buckingham and Arnhem bays. While the east-facing side of the peninsulas are well

Fig. 8.11 The small Bakirra community is located on a point separating two bays. The western bay has an inner (Pleistocene or stranded Holocene?) barrier separated by a 1.8 km wide mangrove swamp from the south-tending recurved spits of the outer barrier, while the southern bay connects to a mangroves-lined tidal creek, with an irregular west-trending recurved spits across the entrance, with tidal shoals dominating both entrances and the ebb-tide delta extending 1.5 km seaward. Sand has moved longshore into the bay (arrows), with tidal flows dominating the inlet

exposed, receiving wave generated in the Gulf of Carpentaria, the bays are extremely sheltered providing a marked contrast in coastal settings, both of which are infilling with mud from the rivers.

There are a total of 277 beaches occupying 185 km (30%) of the shore, the remainder a mix of bedrock on the peninsulas with exposed east-facing shores and mangrove-lined mud flats in the bay. There are 15 TM beaches occupying 54 km (9%) of shore, including 10 higher energy R + LTR primarily along the eastern Gove Peninsula, together with 26 R + RF occupying 69 km (11%) in amongst the laterite bluffs, including the Gove Peninsula's Rainbow Cliffs (Fig. 8.10f). The peninsula beaches tend to be embayed, increasing in length moving down into Melville Bay, and backed by limited dune transgression. TD beaches however dominate with 98 TD beach occupying 153 km (25%) of the shore, primarily in the bays and sheltered shores.

The only obvious longshore sand transport is occurring within some bays like Birkirra (Fig. 8.11) and on both sides of Melville Bay-Gove Harbour. On the western entrance is 6 km of south-trending spits extending south of Parfitt Point (Fig. 8.10e). On the eastern Gove Peninsula side, beginning at Town Beach (NT 1015), sand is moving up and around Cape Wirawarol, then along the 13 km long northern coast, with probably headland bypassing of the three points, and then down the 2 km long Dundas Point (NT 1004, now highly developed with port facilities) on its eastern entrance. Rates on both sides are expected to be low on the order of perhaps 1000's m^3 $year^{-1}$. From Town Beach southeast to Yirrkala is a series of curving beaches (NT 1013–1025) backed by densely vegetated granite slopes rising to 73 m at Mount Dundas, and fronted by fringing coral reefs. South of Yirrkala down to Cape Arnhem, the coast tends more southerly exposing it to the trades. On exposed sections the trades have deposited Pleistocene dunes that have been lithified to calcarenite bluffs up to 20 m high. In between are a few small exposed embayed beaches (Little Bondi, Turtle and Macassan NT 1041–45), and two larger sheltered bays (Rocky and Dalywoi) which have filled with up to 20 regressive beach to foredune ridges. This section has lower carbonate content (mean = 25%, σ = 15%) perhaps owing to the contribution of the Archaean granite that forms the northern and southern shores of the peninsula, with the weathered Cretaceous bauxite in between.

8.4.6 PC Overview

PC:NT02.04 has a highly variable shoreline ranging from the long-exposed north-east-trending bedrock-controlled peninsulas and long linear islands, together with the eastern Melville Bay-Gove Peninsula sector, to the two large sheltered largely mud and mangrove-filled Buckingham and Arnhem bays. The Woolen River flows into Castlereagh Bay, the Buckingham into Buckingham bay and several small rivers into Arnhem Bay. The rivers are depositing largely muddy TD deltas at their mouths. Both the larger bays and many small embayed beaches and barrier have acted as TC sediment sinks with very limited longshore transport apart from that moving down into Melville Bay and around Cape Wirawarol, both terminating in the Melville Bay TC.

8.5 Regional Overview

The north Arnhem Land coast is a generally low energy, north-facing shore containing a series of larger bays, within which are numerous smaller embayments. Eight small rivers and more than 160 streams and creeks drain into the bays and embayments, with each of the rivers and many of the creeks having well-developed TD funnel-shaped mouths, some bordered by chenier plains. Beaches occupy 41% of the coast and barriers 29%, with most of the coast a mix of the beaches, mangrove-lined tidal flats, low laterite bluffs and some sandstone cliffs. The beaches reflect the low wave energy and meso-macro-tides and are predominately TD (59% by length), followed by TM (22%) and those fronted by rocks and coral flats (19%). Likewise, most of the barriers consist of a few low beach-foredune ridges. They are predominately stable (94%), with only a few area of minor dune transgression on the eastern Gove Peninsula. Barrier volumes and volume per metre are both relatively small (Table 8.5). There is no evidence of inter PC or SC sediment transport, with most transport associated with movement into the bays and creek mouths, resulting in numerous TCs, slowly filling with nearshore and in situ carbonate sediments.

This region has a range of exposure to sea-level rise ranging from elevated elongate peninsulas and islands to extensive coastal and estuarine plains as at the river mouths and in the eastern bays (Woodroffe 1995). The higher bedrock and laterite bluffs will experience a reactivation in their erosion, slow as it is. The predominately low beaches will experience increased overwashing and can be expected to slowly retreat through rollover where space is available or, in the case of the R + RF, possibly be eroded. The greatest impact and most vulnerable areas are the extensive low gradient tidal flats associated with the rivers, creeks and sheltered bay shores. These will be gradually inundated and unlikely to keep up with sea-level rise, leading to an extension in habitat area from mangroves at the expense of the supratidal salt flats.

References

Galloway RW (2003) Northern territory. In: Bird ECF (ed) The world's coasts: online Australia. Kluwer online

Lees BG, Lu Y, Head J (1990) Reconnaissance thermoluminescence dating of northern Australian coastal dune systems. Quat Res 34:169–185

Nott J (1994) The influence of deep weathering on coastal landscape and landform development in the monsoonal tropics of northern Australia. J Geol 102:509–522

Nott J (1996) Late Pleistocene and Holocene sea-level highstands in northern Australia. J Coast Res 12:907–9105

Short AD (2006) Beaches of the Northern Australia coast: the Kimberley, Northern Territory and Cape York. Sydney University Press, Sydney, 463 p

Woodroffe CD (1995) Response of tide-dominated mangrove shorelines in northern Australia to anticipated sea-level rise. Earth Surf Process Landf 20:65–85

Woodroffe CD, Bryant EA, Price DM, Short SA (1992) Quaternary inheritance of coastal landforms, Coburg Peninsula, Northern Territory. Aust Geogr 23:101–115

Chapter 9
Gulf of Carpentaria Division

Abstract The Gulf of Carpentaria is a 300,000 km^2 U-shaped semi-enclosed shallow sea exposed to a tropical monsoonal climate and occasional tropical cyclones and feed by a series of seasonal rivers around its perimeter. The coast is part of the McArthur and larger Carpentaria basins and generally low-lying with low gradient nearshore, especially along the southern coast. Tides are meso, and waves are fetch-limited and generally low, but increase in height to the west where they maintain moderate energy wave-dominated and tide-modified beaches. Mangroves and wide tidal flats dominate the sheltered southern coast, while barriers range from long regressive beach-foredune ridges along the western Cape York Peninsula coast to some large transgressive dune systems on the trade wind exposed Groote Eylandt and eastern Arnhem Land coast. This chapter describes the geology, climate and coastal processes around the gulf coast.

Keywords Gulf of Carpentaria · Geology · Coastal processes · Coastal ecosystems · Beaches · Barriers · Sediment transport · Sediment compartments

9.1 Introduction

The Gulf of Carpentaria (in this chapter called the 'Gulf') is a large shallow semi-enclosed sea located between the NT Arnhem Land and the Cape York Peninsula (the 'Peninsula') and is the world's largest tropical epicontinental sea (Reeves et al. 2008). The U-shaped gulf has a 540 km wide entrance between Cape Arnhem and Van Spoult Head and extends for 380 km along its western shore south of Cape Arnhem and for 750 m south of Van Spoult Head, with a 640 km long southern base. It covers an area of around 300,000 km^2 and for the most part is between 40 and 60 m deep (Fig. 9.1). This chapter and Chaps. 10, 11 and 12 examine the entire Gulf shoreline.

The Gulf coast is for the most part remote, difficult and in places impossible to access by vehicle. The only coastal towns on the Gulf are Numbulwar (population 670), Borroloola (45 km inland, 950), Burketown (35 km inland, 200), Karumba (550), Kowanyama (25 km inland, 1000), Pormpuraaw (600), Aurukun (1300), the

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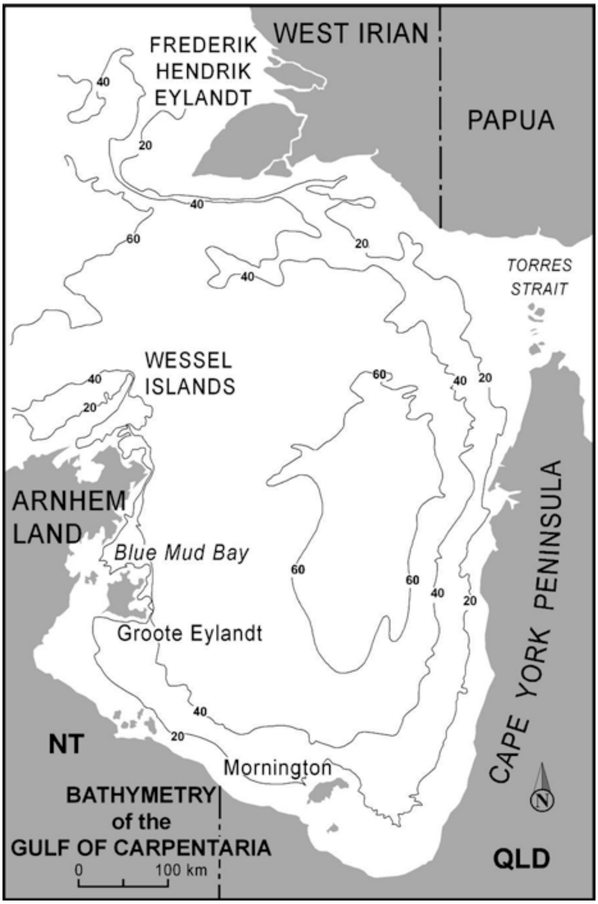

Fig. 9.1 The Gulf of Carpentaria and its bathymetry

large Weipa (3350) and Bamaga (800), together with several smaller aboriginal communities and outstations, particularly along the east Arnhem Land coast, and a scattering of professional fishing camps in some of the rivers. Three of the larger islands Bickerton, Groote Eylandt and Mornington have populations of 200, 1500 and 1000, respectively. This would bring the entire coastal and island population of the Gulf to about 12,000, the majority of which is aboriginal and islander. Vehicle access to the coast is very limited, essentially to the above towns, most of which are cut off by flooding during the summer wet season.

The Gulf division contains 3 regions (Fig. 9.2), 6 PCs and 14 SCs (Table 9.1), only 11 of which are considered in this discussion. The east Arnhem Land region (NT03) extends for 828 km from Cape Arnhem south to Warrakunta Point in the southwestern corner of the Gulf and contains two PCs (NT03.01 and 03.02). The southern Gulf region (NT04 and QLD01) straddles the NT-QLD border and extends

Fig. 9.2 Gulf of Carpentaria division three regions: east Arnhem Land, southern Gulf and western Cape York peninsula. (Source: Google Earth)

southeast for 854 km to Karumba at the mouth of the Norman River and contains two PCs (NT04.01 and QLD 01.01). The western Cape York Peninsula region occupies the eastern shore of the Gulf, also the western shore of Cape York Peninsula, and extends north from Karumba for 1015 km to Van Spoult Point, near the tip of the Peninsula, and contains two PCs (QLD02.01 and 02.02). The entire division has a shoreline length of 2697 km.

9.2 Geology and Geomorphology

The Gulf is basically made up of two large basins (Mcarthur and Carpentaria) bordered at the northern tips by two small inliers (Fig. 2.1; Table 9.2). The small *Arnhem Inlier* extends along the eastern Arnhem Land coast from Melville Bay-Gove to Cape Shield. It consists of Proterozoic sediments, which have been folded and metamorphosed during the Barramundi Orogen (1860–1800 Ma). This inlier occupies the Gulf coast between Cape Arnhem and Cape Shield, a shoreline distance of 330 km. Bedrock of Bradshaw granite, Caledon granite and Mayoola granite

Table 9.1 Gulf of Carpentaria division, regions and PCs which are located in both the NT and QLD

Region/comp. No.[a]	Boundaries	Beach ID[b]	No. beaches	km[c,d]	Total km
NT03[e]	East Arnhem Land				
NT03.01	C Arnhem-C Barrow	NT 1054-1395	342	3731–4403	672
NT03.03	Cape Barrow-Warrakunta Pt	NT 1397-1437	41	4403–4559	156
NT03	Region sub-total		383		828
NT04 + QLD01	South Gulf of Carpentaria				
PC04.01	Warrakunta Pt-Calvert R	NT 1438-1482	45	4559–4988	429
QLD01.01	Calvert R (NT)-Karumba (Qld)	NT 1483-1488	6	4988–5029	41
		QLD 1-9	29	0–384	384
NT04 + QLD01	Region sub-total		80		809
QLD02	Western Cape York Peninsula		0		
QLD02.01	Karumba-S Mitchell R	QLD 30-56	27	384–667	283
QLD02.02	S Mitchell R-Van Spoult Pt	QLD 57-177	121	677–1399	732
QLD02	Region sub-total	QLD 30-177	148	384–1399	1015
	Division Total		611		2697

[a]NCCARF compartment number
[b]ABSAMP beach ID
[c]Distance from WA-NT border
[d]Distance from NT-QLD border
[e]Bickerton Is and Groote Eylandt not included

Table 9.2 Major geological provinces of the Gulf of Carpentaria, their geology and generalised coastal morphology

No.	Region	Age (Ma[a])	Coast location	Geology	Coastal morphology
8	**Arnhem Inlier**	1860–1800	Melville Bay-Gove to Cape Shield	Deeply weathered (laterised) meta-sedimentary rocks	Low bedrock/laterite bluffs, laterite reefs, tidal flats, beaches
9	McArthur Basin	1800–1400	Blue Mud Bay-Robinson R; Groote Eylandt	Deeply weathered (laterised) sedimentary rocks	Low bedrock/laterite bluffs, laterite reefs, tidal flats, beaches
10	Carpentaria Basin	180–100	South and east Gulf of Carpentaria	Quaternary continental and coastal sediments, some laterised bluffs	Tidal creeks and flats, cheniers, beach ridges, some bluffs

Orogens in **bold**. Listed from west to east. See Fig. 2.1 for locations
[a]Ma = million years

form numerous generally low headlands (<20 m), points and islets along the coast and form the boundaries of many of the 247 beaches along this section.

The *McArthur Basin* is an intracratonic platform basin covering 180,000 km^2 and consisting of largely unmetamorphosed sedimentary rocks which were deposited 1800–1400 Ma and overlie rocks of the Pine Creek Orogen. The rocks include sandstone, shale, carbonate and interbedded volcanic and intrusive igneous deposits, which reach up to 8000 m in thickness. It occupies the coast between Blue Mud Bay and the McArthur-Robinson rivers region and includes Groote Eylandt. It extends down the coast south of Cape Shield to the southwest corner of the Gulf at Port Roper and then along the southern NT coast as far as the McArthur River, a total shoreline distance of 730 km. This is a predominately sedimentary shoreline with few headlands. The geology, when it outcrops, is a mix of the above sedimentary rocks, with several of the headlands weathered to Tertiary laterite. The shoreline is a mix of beaches (50%), a few low (<10 m) rocky and laterite points and river mouths and mangroves.

The QLD side of the Gulf is part of the larger Carpentaria Basin, which at its northern tip is the Cape York inlier. The *Carpentaria Basin* occupies the entire eastern half of the Gulf. It is a 560,000m^2 north-south-trending intracratonic basin formed by gentle downwarping that covers most of the Gulf (Figs. 2.1 and 9.1), with 80% located in Queensland waters. At the coast it occupies a section of NT coast between the northern McArthur Basin centred on Arnhem Bay and the English Companys Islands in the north and Blue Mud Bay in the south. It then extends from just inside the NT border to include most of the low-lying southern and all the eastern coast of the Gulf of Carpentaria. The basin was formed in the middle Jurassic (180 Ma) and contains Mesozoic (180–100 Ma) clastic sandstone, siltstone and conglomerate sediments up to 1800 m thick. The geology is only manifest in the offshore islands (Sir Edward Pellew and Wellesley groups), with no exposures along the shore apart from the deeply weather laterite that occupies much of the eastern shore north of Worbody Point (QLD-79) (Fig. 5.2). The bulk of the coast, especially south of Worbody Point is sedimentary, with river and creek mouths, including extensive areas of mangroves in the southern Gulf. The Gulf division terminates at the sandy Van Spoult Head, 12 km east of which are the first rocks of the Cape York Inlier.

9.2.1 Lake Carpentaria

The Gulf has a maximum depth of 70 m, and during the glacial low sea levels (~120 m depth) it dries and becomes cut off from the Arafura Sea and Coral Sea via Torres Strait. However, a depression in the centre (Fig. 9.1) is supplied by the rivers and remains full of water and is known as Lake Carpentaria. Studies by Torgerson et al. (1983, 1988) and Chivas et al. (2001) show that the lake had an area of ~180,000 km^2 and depth of ~15 m. Vibrocore records reveal sea level/lake level changes particularly between 80 and 40 ka, with fresh-brackish water between 35 and 12 ka. Reeves et al. (2008) found that at low sea levels, the exposed Gulf was a grassland traversed by meandering rivers flowing to the lake, with a connection from the perched lake to the Arafura Sea. Full marine conditions returned by 10.5 ka when connected to the Arafura Sea in the west (sill depth 53 m), followed by a connection via Torres Strait (sill depth 12 m) to the Coral Sea about 8 ka, the Gulf reaching present sea level about 6.5 ka (Woodroffe and Chappell 1993).

9.2.2 Laterite

As discussed in Chap. 5, much of the coastal plain has been laterised, and there are extensive outcrops of laterite along the eastern Arnhem Land and the northwestern shore of the Cape York Peninsula (Fig. 5.2), with the laterite mined for bauxite in both locations (Gove and Weipa). The laterite is exposed as low (<20 m) bright red bluffs some fronted by beaches and as low points usually fronted by laterite reefs. All of the points north of Worbody Point are either laterite or sandy forelands. As the bluffs erode, they leave laterite flats and reefs which have profound impact on coastal processes and landforms (Nott 1994).

9.3 Climate

The Gulf has a tropical monsoonal climate (Aw, Fig. 1.8) with maximum rainfall in the north decreasing into the southern Gulf. As discussed in Sect. 2.3, the climate is divided into a hot wet monsoonal summer season between December and March when the northwest monsoons, drawn in by the ITCZ/Cloncurry heat low, deliver heavy rains and occasional tropical cyclones to the region and a warm dry winter period dominated by the sub-tropical high-pressure systems which brings drier southeast trade winds. The highest rainfall occurs along the northern half of Cape York Peninsula (Horn Island 1820 mm; Weipa 1790 mm) and the northeastern area of east Arnhem Land (Nhulunbuy 1330 mm). It decreases southwards with the lowest rainfall in the southeast corner of the Gulf at Karumba (900 m). Mean daily temperature averages around 30 °C in summer and mid-20s°C in winter.

9.4 Coastal Processes

As discussed in Sect. 2.4, seven factors control the coastal processes across northern Australia, including the Gulf, namely, the generally shallow bathymetry (<60 m) and in places the inshore islands; the monsoonal climate with seasonal reversals in wind and wave direction; the generally low to moderate wave energy; the micro- to meso-tide regime; the usually very low gradient nearshore and intertidal zone; the Gulf circulation and seasonal changes in water levels; and the rich tropical biota, particularly seagrass (13 species), coral reefs and mangroves (19 species). In addition, 280 creeks and rivers drain into the Gulf, delivering during the summer wet season freshwater and nutrients and sediments ranging from mud through sand.

9.4.1 Waves

The Gulf's wave climate is driven by the seasonal winds, with the moderate winter trade winds producing waves up to 1–2 m along the east Arnhem Land coast, while the lighter summer northwesterlies produce low seas along the Peninsula coast, and occasional tropical cyclones delivering short periods of higher and longer seas in their vicinity. Overall waves are short (2–5 s) and low (<1 m) along the coast, with waves in the NT averaging just 0.3 m, though reaching up to 1.5 m along the east Arnhem Land coast and averaging 0.4 m along the western Peninsula coast (Table 2.4). Tides range from 2 to 4 m, resulting in predominately TM to TD beaches as is discussed in Sect. 9.5.5. The shallow Gulf seabed and low nearshore gradients particularly along the southern and eastern Gulf shore further attenuates and lower waves at the shore.

The Queensland Government has recorded wave data at Karumba and Weipa (data.qld.gov.au). Two waverider buoys were located at Karumba, an inner buoy located 15 km northwest of the Norman River mouth from 01.8.94 to 31.9.95 and an outer located 70 km northwest between 04.08.94 and 20.01.95. The Weipa buoy was located in Albatross Bay 15 km west of Weipa from 22.12.78 to 12.01.09. The results of these data are discussed in the following sections but in general confirm the above estimates of breaker height and period.

Tropical cyclones form in the Gulf and tend to trend south crossing the southern Gulf coast (Fig. 1.6). The cyclones deliver strong winds, high waves, storm surges and heavy rain all leading to coastal inundation and flooding, with a predicted storm surge potential of between 2 and 3 m (Fig. 1.14). Harris and Heap (2009) found evidence of cyclone deposited talus in lee of reefs in the southern Gulf, which they inferred showed evidence of net along coast cyclone-driven sediment transport.

9.4.2 Tides

The Gulf has a tidal system with an amphidromic point located just west of Torres Strait, as well as some tidal components arriving from the Coral Sea via Torres Strait. The tide ranges from 2 to 4 m, while the time of arrival is highly variable as indicated in Fig. 2.2 and Table 9.3. Because of the constriction caused by Torres Strait, very strong easterly tidal currents flow through the Strait. In addition, the southern Gulf occasionally has what are known as 'dodge' tides, when only one low and high will occur each day. Finally, the Gulf has wind and pressure-induced seasonal change in sea level discussed below.

Table 9.3 Tidal characteristics of the Gulf of Carpentaria coast

Location	Mean spring high tide (m)	Mean spring low tide (m)	Mean spring tide range (m)	Relative time WST of arrival
Northern Territory (East Arnhem Land)				(EST)
Cape Grey	1.8	0.4	1.4	−0033
Rose River	2.4	0.2	2.2	−0134
Centre Island	2.9	0.6	2.3	−0031
Queensland (Western Cape York Peninsula)				
Karumba	3.8	0.3	3.5	
Staaten River	4.1	1.2	3.1	−0128
Nassau River	2.4	0.6	1.8	
Archer River	2.3	0.6	1.7	+0015
Weipa	2.9	0.7	2.2	
Cullen Point	3.5	0.8	2.7	−0102
Vrilya Point	3.6	0.7	2.5	−0104
Thursday Island	3.0	0.6	2.4	

9.4.3 Water Circulation and Sediments

The water circulation in the Gulf is driven by a slow clockwise Gulf-wide gyre in the surface waters with a return flow in the bottom waters (Forbes and Church 1983; Wolanski 1993). The wind and atmospheric pressure generates seasonal sea-level fluctuations of up to 0.75 m in the southern region of the Gulf with the salt flats only tidally inundated in summer when the higher water levels and estuarine outwelling occur. Large-scale coastal outwelling, driven by river discharge, occurs during the summer wet season. The nutrient-enriched coastal-trapped water occurs all along the Gulf coast, with little mixing between estuarine and offshore waters. Somers and Long (1994) found that the central Gulf water is stratified with a bottom temperature of 25 °C and surface 30 °C, while waters in the north are well-mixed due to tidal mixing through Torres Strait, with uniform 35–36 °C water temperature. The waters are also better stratified in summer but become well-mixed with the passage of tropical cyclones. They also reported that sediments >20 m depth are predominately sandy in the southeast and muddy in the northwest, with muddy sediments in the coastal zone (<20 m) in sheltered embayments or adjacent to rivers.

Jones (1987) mapped the modern sedimentation in the Gulf and found it is confined primarily to the marginal areas in water depths of <50 m. The distribution within this zone is irregular being controlled by proximity to sediment sources and exposure to wave and tidal activity. In the western Gulf, he found that fine-grained fluvial sediment from Limmen Bight is being transported northwards by waves and tidal currents and deposited in Blue Mud Bay, leading to high rates of deposition in the bay. Wave action prevents deposition of fine-grained sediment in the Bight in areas shallower than 25 m, with the inshore zone consisting of relic fluvial and marine sediments and terrigenous mud being deposited in deeper waters. In the eastern Gulf, the rivers have lobes of fluvial sand grading into prodelta mud with relict sand and mud in deeper water.

9.4.4 Rivers

The McArthur and Carpentaria basins act as major catchments for the summer wet season with 280 creeks and rivers flowing into the Gulf, including 23 small to moderate-sized river. All the rivers have infilled their shallow estuaries and built both river and tide-dominated deltas at the coast and are delivering suspended and bedload sediment to the coastal system. The largest are the Roper in the southwest corner, the Flinders on the south coast and the Mitchell on the east coast. The rivers will be discussed in more detail in Chaps. 10, 11, and 12.

9.5 Coastal Ecosystems

The Gulf coastal ecosystems are similar to those of the Kimberley-Territory division (see Sect. 5.5). The tropical climate and warm waters support rich marine ecosystems including tropical seagrasses, coral reefs, mangroves and dune vegetation. There are 13 species of seagrass in the Gulf with the largest meadows found along the east Arnhem Land coast down to Limmen Bight, along the southern coast down to the Wellesley Islands, with smaller communities on the Peninsula coast between Archer Bay and Port Musgrave. Poiner et al. (1987) mapped the Gulf's seagrass communities and found they have a total are of 906 km^2 and fringed 670 km of the coastline, with 74% of the communities fringing the open coast where they have depth-zoned species. Coral reefs are found in the southern and western Gulf, particularly around the islands, with extensive shallow reefs also occurring in the nearshore of the southwestern Gulf. Harris et al. (2008) found a submerged early Holocene reef system along the former shoreline at depths from 27 to 30 m. The reef was unable to keep up with sea-level rise and became extinct by 7 ka.

Mangroves occur around most of the Gulf shore, particularly in the Arnhem Land bays, along most of the southern and southeastern coast, and on the Peninsula north from Weipa, as well as in all creek and rivers. There are 20 species of mangroves along the eastern Gulf shore, rising to 33 species along the western shore (Table 2.10; Short and Woodroffe, 2009). The Gulf has 2440 km^2 of mangroves, which represents 21% of Australia's mangroves (Table 2.9). Asbridge et al. (2016) found that mangroves are expanding both seaward and landward along parts of the southern Gulf. They attributed the changes to increased rainfall and associated flooding and sea-level rise.

9.6 Beach Systems

The Gulf coast has 612 beach systems which occupy 58% of the coast, the remainder either mangrove-lined tidal flats, laterite bluffs or creek and river mouths. The east Arnhem Land coast has the shortest beaches (mean = 1.24 km) owing to the numerous bluffs and reefs and its generally higher crenulation ratio (1:2.7). The low-energy southern Gulf has a straighter coast with a crenulation ratio of 1:1.3 and has fewer but longer beaches (mean = 4.2 km), which occupy just 39% of the coast, the remainder predominately mangrove-lined tidal flats and river mouths. The higher energy western Peninsula is also straighter (1:1.3) with the longest beaches (mean = 5 km; and the longest beach in northern Australia at 50 km), which occupy 73% of the coast, the highest regional percentage in northern Australia (Table 9.4). The beaches are a mix of WD on the most exposed Arnhem Land and Peninsula beaches, TM and TD, as will be discussed in the following three chapters (10, 11, and 12). Descriptions of all the Gulf beaches are also provided by Short (2006).

9.7 Barrier Systems

Most of the beaches are backed by barrier systems which occupy 1439 km (53%) of the coast. As Table 9.5 indicates, the barriers are spread around the Gulf shore and occupy 41% of the east Arnhem Land coast, 50% of the southern Gulf coast and 66% of the western Peninsula coast. The Arnhem Land barriers tend to be short (mean = 3.4 km), averaging 8 m high owing to the northern transgressive dunes and range on average up to 1.5 km wide. They are also the most unstable with 10% bare sand. The southern Gulf barriers tend to be longer (14.3 km), lower, wider (up to 4 km) and more stable (2% unstable). The western Peninsula has the most extensive barriers which are also reasonably long (8.1 km), low, up to 8 km wide and very stable (<1% unstable). Each of the regions has a similar per metre barrier volume on the order of 10,000 $m^3\ m^{-1}$ and order of magnitude greater than the low-energy Kimberley and remaining NT coast (Appendix 34.2). The barrier systems range from active transgressive dunes along the exposed east Arnhem Land coast, to low

Table 9.4 Beach characteristics of the Gulf of Carpentaria division and its three regions

	Regions:			Division:
	East Arnhem	Southern Gulf	Western Cape York	Gulf of Carpentaria
Coast length (km)	828	854	1015	2697
No. beaches	384	80	148	612
Length beaches (km)	476	336	745	1557
% beaches	57	39	73	58
Mean length (km)	1.24	4.2	5.0	2.5
σ (km)	1.61	3.4	7.2	–
Max length (km)	11.6	20.2	50	50

Table 9.5 Gulf of Carpentaria regional and division barrier dimensions

Region/division	E Arnhem Land	S Gulf	W Cape York Pen.	Gulf division
No.	101	30	46	177
Total length (km)	343	428	668	1439
Mean width (m)	240–1570	200–4070	800–7670	–
Mean height (m)	7.8	4.2	5.4	–
Area (ha)	24,506	88,265	188,705	301,476
Unstable (ha)	2582	2100	1188	5870
Total volume (M m^3)	3878	4500	9675	18,053
Unit volume (m^3/m^{-1})	11,295	10,523	14,052	12,545

regressive chenier plains along parts of the southern Gulf, to extensive regressive beach-foredune ridge plains along the western Peninsula. The barriers systems in each region are discussed in more detail in regional Chaps. 10, 11, and 12.

9.8 Summary

The Gulf of Carpentaria is a 300,000 km^2 roughly U-shaped shallow gulf, with three shores – the east-facing more irregular eastern Arnhem Land coast; the very low-energy southwest-trending, low gradient sediment-rich southern shore; and the relatively straight western coast of Cape York Peninsula. The Gulf is exposed to winter trades and summer monsoons and occasional tropical cyclones. The summer wet floods the rivers which deliver sediment to most of the southwest, southern and western shore. The trades blow across the Gulf delivering the highest waves to the exposed section of the Arnhem Land and Groote Eylandt where the waves and wind have built substantial transgressive dune systems. The very low gradient southwest and southern coast has 12 river systems and numerous tidal creeks and is predominately sand and mud flats with mangroves on sections of the open coast. The Peninsula coast is a lee coast; however occasional bursts of higher tropical cyclone waves are sufficient to develop WD rhythmic beach topography. Tides are meso, and beaches range from TM on exposed sections to TD where sheltered and in particularly along the southern coast. Sediment is generally moving northwards up the Arnhem Land coast interrupted by several bays. On the Peninsula coast 14 rivers deliver sediment to the coast and its deltas with sediment generally moving northwards.

DERM (2011) predicts a sea-level rise along the QLD coast of between 0.26 and 0.79 m by 2100, combined with an increase in rainfall associated with tropical cyclones. In the Gulf region, this will exacerbate flooding, storm surge potential and extreme water levels, all of which will have considerable impact of the low-lying, low gradient southern shores and all tidal systems.

References

Asbridge E, Lucas R, Ticehurst C, Bunting P (2016) Mangrove response to environmental change in Australia's Gulf of Carpentaria. Ecol Evol 6(11):3523–3539

Chivas AD, and others (2001) Sea-level and environmental changes since the last interglacial in the Gulf of Carpentaria, Australia: an overview. Quat Int 83–85:19–46

DERM (2011) Queensland coastal processes and climate change. Queensland Climate Change Centre of Excellence. Department of Environment and Resource Management, Brisbane, 49 p

Forbes AMG, Church JA (1983) Circulation in the Gulf of Carpentaria. II. Residual currents and mean sea level. Mar Freshw Res 34:56

Harris PT, Heap AD (2009) Cyclone-induced net sediment transport pathway on the continental shelf of tropical Australia inferred from reef talus deposits. Cont Shelf Res 29:2011–2019

Harris PT, Heap AD, Marshall JF, McCulloch M (2008) A new coral reef province in the Gulf of Carpentaria, Australia: colonisation, growth and submergence during the early Holocene. Mar Geol 251:85–97

Jones MR (1987) Surficial sediments of the western Gulf of Carpentaria. Aust J Mar Freshw Res 38:151–167

Nott J (1994) The influence of deep weathering on coastal landscape and landform development in the monsoonal tropics of northern Australia. J Geol 102:509–522

Poiner IR, Staples DJ, Kenyon R (1987) Seagrass communities of the Gulf of Carpentaria, Australia. Aust J Mar Freshw Res 38:121–131

Reeves JM, Chivas AR, García A, Holt S, Couapel MJJ, Jones BG, Cendón DI, Fink D (2008) The sedimentary record of palaeoenvironments and sea-level change in the Gulf of Carpentaria, Australia, through the last glacial cycle. Quat Int 183:3–22

Short AD (2006) Beaches of the Northern Australia coast: the Kimberley, Northern Territory and Cape York. Sydney Univ Press, Sydney, 463 p

Short AD, Woodroffe CD (2009) The coast of Australia. Cambridge University Press, Melbourne, 288 p

Somers I, Long B (1994) The sediments and hydrology of the Gulf of Carpentaria. Aust J Mar Freshw Res 45:283–292

Torgersen T, Hutchinson MF, Searle DE, Nix HA (1983) General bathymetry of the Gulf of Carpentaria and the quaternary physiography of Lake Carpentaria. Paleogeogr Palaeoclimatol Palaeoecol 41:207–225

Torgersen T, Luly J, De Deckker P, Jones MR, Searle DE, Chivas AR, Ullman WJ (1988) Late Quaternary environments of the Carpentaria Basin. Paleogeogr Palaeoclimatol Palaeoecol 67:245–261

Wolanski E (1993) Water circulation in the Gulf of Carpentaria. J Mar Syst 4:401–420

Woodroffe CD, Chappell J (1993) Holocene emergence and evolution of the McArthur River delta, southwestern Gulf of Carpentaria, Australia. Sediment Geol 83:303–317

Chapter 10
East Arnhem Land Region

Abstract The East Arnhem Land coast is the highest energy section of both the Northern Territory coast and the Gulf of Carpentaria. It faces east into the Gulf exposing it to the trade winds and waves. This is a remote coast with little settlement and includes Groote Eylandt and a number of smaller islands. The climate is tropical monsoonal dominated by the trades with occasional summer tropical cyclones which can form in the Gulf. A few small- to moderate-sized rivers drain to the coast delivering terrigenous sediment which are transported northwards by the waves and flooding tides, while carbonate material comprises ~20% of the beach material. The coast is a mix of low bedrock points and wave-dominated and tide-modified beaches, the former occurring along the exposed higher energy northern section of the coast where both Pleistocene and Holocene transgressive dunes blanket the hinterland. Elsewhere the beaches are tide-dominated with extensive tidal flats and more subdued barriers, with mangroves occupying the shores of the several bays including the large Blue Mud Bay. This chapter examines the coastal processes, beaches, barriers and sediment transport within a framework of sediment compartments.

Keywords Arnhem Land · Meso-tides · Transgressive dunes · Beaches · Barriers · Sediment transport · Sediment compartments

10.1 Introduction

The coast of the East Arnhem Land region extends for 828 km from the protruding Cape Arnhem, the easternmost point of the NT mainland, south to the low Warrakunta Point, essentially the southernmost bedrock point on the eastern NT mainland. It includes the large Blue Mud Bay and a series of several smaller bays, while offshore it includes Bickerton, Winchelsea and Groote islands, together with a number of smaller islands (Fig. 10.1). The coast faces east exposing it to the trade wind and waves, with some of the highest energy WD beaches in northern Australia located along the most exposed sections south of Cape Arnhem and on eastern Groote Eylandt. The islands and bays provide considerable variation in shoreline exposure and orientation resulting in a range of WD, TM and TD beaches, as well

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https://doi.org/10.1007/978-3-030-14294-0_10

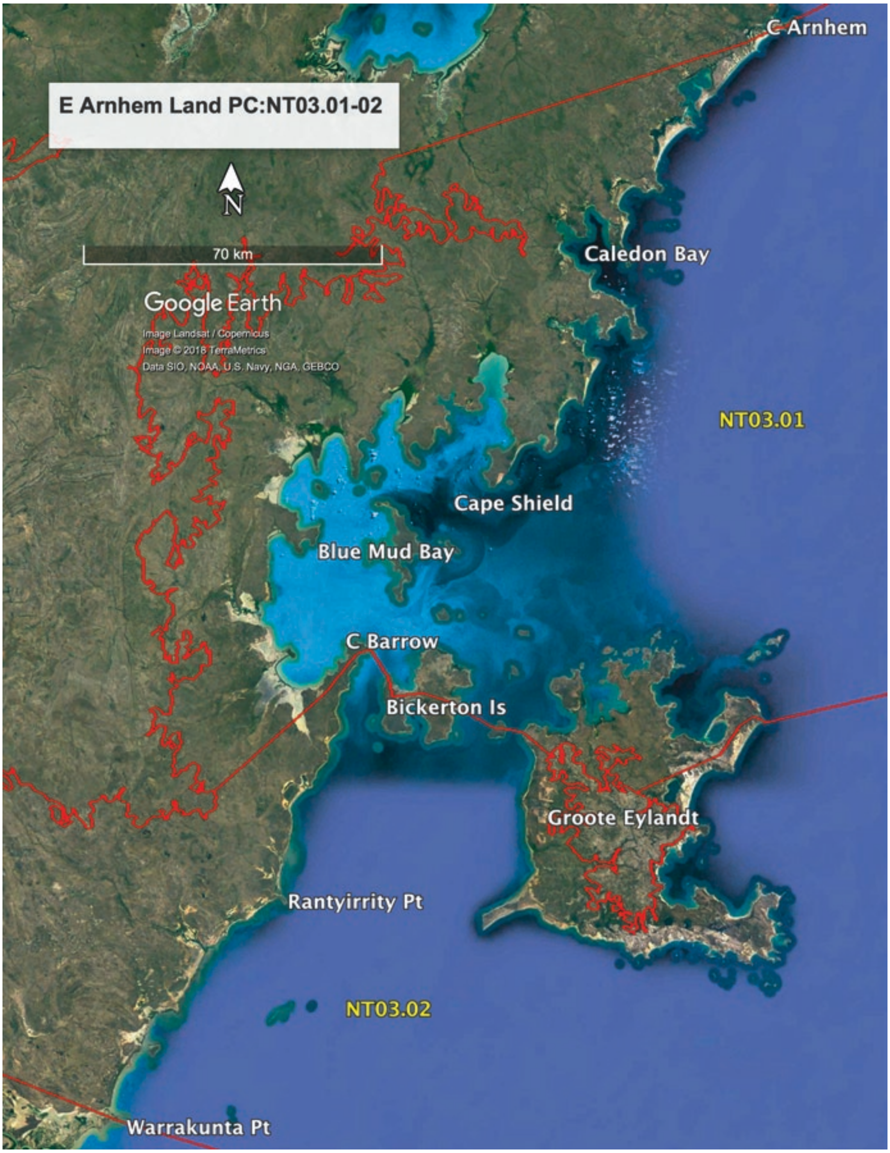

Fig. 10.1 The East Arnhem Land region NT03 and its two PCs:NT03.01-02 extends from Cape Arnhem to Warrakunta Point and include Groote Eylandt. (Source: Google Earth)

as extensive intertidal rock flats. It contains two PCs:NT03.01–02 and seven SCs (Table 10.1). Only the four mainland SCs are discussed in any detail below.

All the East Arnhem Land coasts including all the islands are part of Arnhem Land Aboriginal Land and are sparsely populated, with Numbulwar (700) together with several small outstations the only mainland communities. Bickerton Island has

Table 10.1 East Arnhem Land region and compartments

Region/Comp. No.[a]	Boundaries	Beach ID[b]	No. beaches	km[c, d]	Total km
NT03	**East Arnhem Land**				
NT03.01.01	C Arnhem-Wanyanmera Pt	NT 1054-1110	57	3731–3832	101
NT03.01.02	Wanyanmera Pt-C Shield	NT 1111-1300	190	3832–4063	231
NT03.01.03	C Shield-C Barrow	NT 1301-1395	95	4063-4403	340
NT03.01.04	N Bickerton and N Groote Eylandt[d]	–	–	–	–
PC:NT03.01	*PC sub-total*		*342*		*672*
NT03.02.01	E Groote Eylandt[d]	–	–	–	–
NT03.02.02	S Groote Eylandt[d]	–	–	–	–
NT03.02.03	Cape Barrow-Warrakunta Pt	NT 1397-1437	41	4403–4559	156
PC:NT03.02	*PC and region sub-total*		*383*		*828*

[a]NCCARF compartment number
[b]ABSAMP beach ID
[c]Distance from WA/NT border
[d]Bickerton Is and Groote Eylandt not included

the small community of Milyakburra (180), while on the larger Groote Eylandt is Alyangula (1200), the bauxite mining town of Angurugu (700) and small community of Umbakumba.

10.1.1 Rivers and Streams

The region has more than 50 small usually upland streams and creeks reaching the coast, together with three small rivers, draining the Parsons Range. The Koolatong (2845 km^2) and Walker (2232 km^2) rivers rise in the low Parsons and Mitchell ranges and flow east for about 50 km into Blue Mud Bay, with mangrove-lined tidal flats at their mouths, while the larger Rose River (3572 km^2) drains the southern Parsons Range and reaches the coast at Numbulwar, the only town on the coast.

10.1.2 Sediments and Coastal Processes

The beaches and subtidal (1–4 m depth) sediments are composed of moderately well-sorted, medium sand, averaging 40–50% carbonate (Table 10.2). The sand fines slightly into the dunes where it is well-sorted with an average of 26% carbonate. There is however considerable longshore variation in the sediment characteristics,

Table 10.2 Sediment characteristics of East Arnhem Land beach and dune sand

East Arnhem 03.01 and 02	Dune	Swash-surf	1–4 m depth
n	15	29	15
Mean size (mm)	0.23	0.3	0.29
σ (mm)	0.08	0.24	0.15
Sorting	0.42	0.65	0.78
σ (sorting)	0.1	0.35	0.45
% carbonate	26.0	51.3	42.2
σ (%)	21.8	26.3	19

with size ranging from fine to very coarse and carbonate from zero to 95% (Fig. 10.2), indicating there is limited longshore transport and numerous small TC particularly along the embayed sections. The high carbonate contents may be related in part to the extensive seagrass meadows (440 km^2) that extend along the East Arnhem Land coast, particularly between Cape Barrow and the Rose River (Poiner et al. 1987).

The open coast faces directly into the southeast trades resulting in the highest energy WD beaches in the NT with waves averaging up to 1.5 m and reaching 3 m during strong wind conditions. Tides range from 1.8 m at Cape Grey to 2.4 m at Rose River (Table 9.3) maintaining WD conditions along the most exposed beaches, while within the bays, waves decrease to zero and TD conditions prevail. There are 384 beaches, which occupy 57.5% of the coast, with an average length of 1.24 km. They predominately face southeast (mean = 144°) and are slightly embayed (0.83), with a narrow (~10 m wide) moderately steep (5.2°) high tide beach, usually fronted by sand flats averaging 328 m or rock flats averaging 314 m (Table 10.3). The B+RSF average 7.9 ridges very close to the Australian average of 7.2. Short (2006) provides a detailed description of all the region's beaches.

10.2 PC:NT03.01: Cape Arnhem-Cape Barrow

The northern PC (NT03.01) contains a higher energy WD southeast-facing section of coast between Cape Arnhem and Point Alexander, together with the sheltered Caledon and Trial bays, and then the large crenulate and sheltered Blue Mud Bay (Fig. 10.1). It has a total shoreline distance of 672 km, with a crenulation ratio of 4.2 owing to the extensive bay shorelines. Offshore it includes the indented northern shores of Bickerton Island and the large Groote Eylandt, which includes the small Winchelsea Island. It contains three mainland SCs (NT03.01.01-03), which are discussed below.

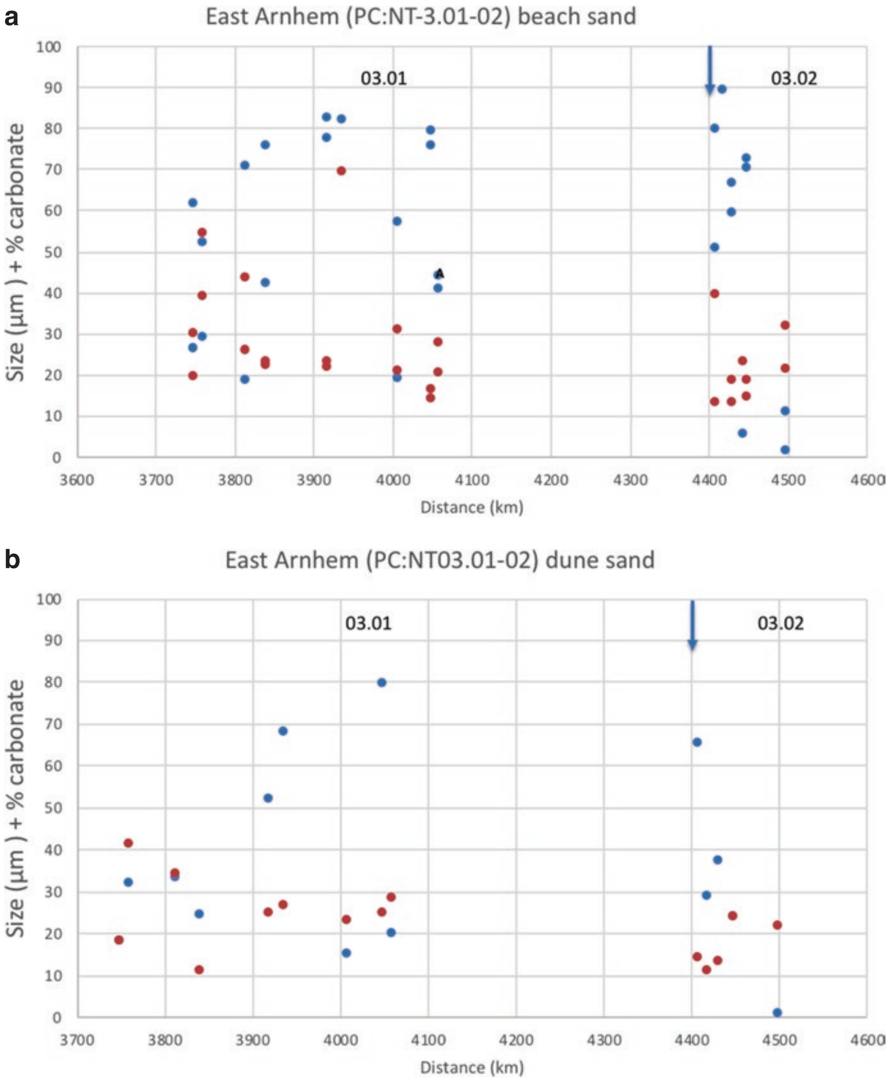

Fig. 10.2 (**a**) Beach and (**b**) dune sand characteristics of PCs:NT03.01-02 showing longshore variation in sediment size (red, µm) and percent carbonate (blue). Arrow indicates PC boundary. Distance from WA/NT border

10.2.1 Beaches and Sediments

The compartment has 343 mainland beaches, which are a mix of WD, TM and TD (Table 10.4). The WD beaches occur along the exposed southeast-facing coast south of Cape Arnhem where the tide range is ~2 m and waves average up to 1.5 m. They are also associated with longer, less embayed beaches which are more exposed to the

Table 10.3 East Arnhem Land beach characteristics (PCs:NT03.01-03.02)

	n	Mean	σ	Aust. mean[a]	Min	Max
Beach length (km)	(476 km)	1.24	1.61	–	.03	11.6
Orientation (deg)	383	144	85		1	355
Embaymentisation	383	0.83	0.17		0.1	1.0
Gradient (deg)	383	5.2	1.0	–	2	9
Beach width (m)	383	9.8	5.0	–	5	30
Sand ridges (m)	10	7.9	4.0	7.2	3	14
Sand flats (m)	144	328	272	485	50	2000
Rock/coral flats (m)	138	314	366	495	50	3000

[a]Source: Short (2006)

Table 10.4 East Arnhem Land: PC:NT03.01 beach types and states

BS	BS	No.	%	Length (km)	%	Mean (km)	σ (km)
4	TBR	14	4.1	45.4	12.1	3.2	3.8
5	LTT	27	7.9	47.1	12.6	1.7	2.2
6	R	60	17.5	35.9	9.6	0.6	1.4
7	R+LTT	7	2.0	1.3	0.3	0.2	0.1
8	R+LTR	7	2.0	6.5	1.7	0.3	1.2
11	B+SF	90	26.2	101.1	27.0	1.1	1.0
12	B+TSF	15	4.4	13	3.5	0.9	0.9
13	B+TMF	17	5.0	20.6	5.5	1.2	1.4
14	R+RF	106	30.9	103.5	27.6	1.00	1.1
		343	100.0	374.3	100	1.1	–

southeast waves, with TBR beaches averaging 3.2 km in length (σ = 3.8 km). Along this section the beaches are WD R (9.6% by length), LTT (12.6%) and the highest energy TBR (12.1%). TM beaches occupy 2%, while the 36% are TD and 27.6% fronted by rock/laterite flats, the latter also tending to be located in more exposed locations (Table 10.4; Fig. 10.3d). The relatively high wave energy on the exposed section coasts is also indicated by the presence of 312 beach rips with an average spacing of 140 m (σ = 27 m), together with 34 topographic rips. The beach sand while variable is predominately fine to medium, while carbonate ranges from 20% to 83% (Fig. 10.2a).

10.2.2 Barriers

Cape Arnhem marks the northwest tip of the Gulf where the coast turns and trends south-southwest to the southwest corner of the Gulf. In the northern section between the Cape and Cape Shield is the most exposed part of the NT coast and the highest energy section of the Gulf shore. The open beaches here are exposed to the full force of the trade winds, which arrive predominately from the east and particularly the southeast (Fig. 10.4) and their accompanying waves. The waves maintain higher

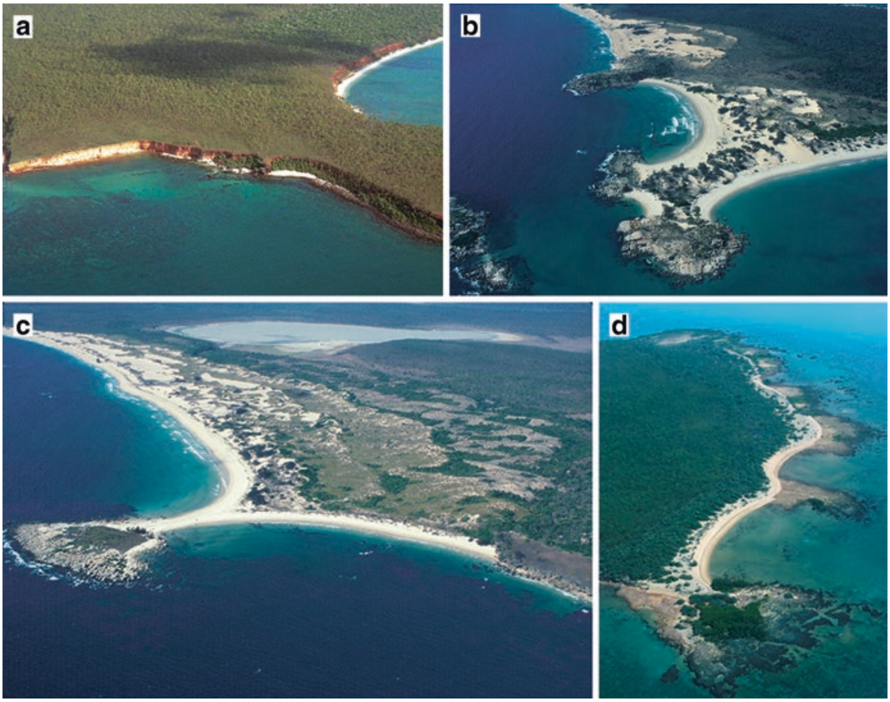

Fig. 10.3 PC:NT03.01 beaches: (**a**) Fifteen metre high laterite bluffs at Middle Point (NT 1153); (**b**) a series of WD embayed beaches and backing transgressive dunes at Du Pre Point (NT 1200-2); (**c**) multiple episodes of dune transgression in Wardarlea Bay with rips dominating the southern beach (NT 1277-8); and (**d**) beaches bordered and fronted by rock flats in Grindall Bay (NT 1377). (Photos: AD Short)

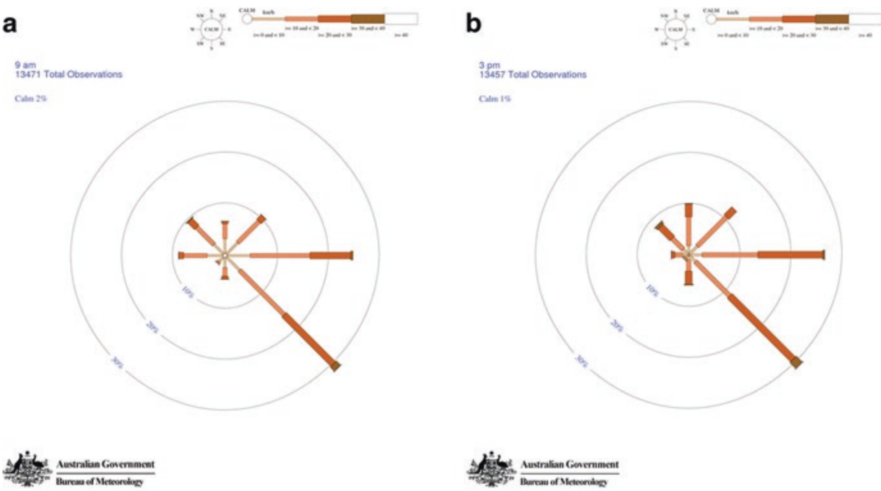

Fig. 10.4 Wind roses for Gove (**a**) 0900; (**b**) 1500. Note the predominance of strong east and southeast winds. (Reproduced with permission of Bureau of Meteorology, © 2018 Commonwealth of Australia)

Table 10.5 East Arnhem Land PC and regional barrier dimensions

PC	NT03.01	NT03.02	E Arnhem
No.	84	17	101
Total length (km)	244	99	343
Mean width (m)	240–760	370–1570	–
Mean height (m)	7.7	8	–
Area (ha)	16766	7740	24506
Unstable (ha)	2022	560	2582
Total volume (M m^3)	2645	804	3449
Unit volume (m^3/m^{-1})	10,824	8116	10,055

energy rip-dominated TBR beaches, most backed by transgressive dune systems. The dunes consist of parabolic to longwalled parabolics, extending up to 4 km inland. The dune system on Cape Arnhem was dated by Lees et al. (1990, 1995) who found there had been several episodes of transgressive dune development, with the earliest dating 19 ka, when they suggested the sand was sourced from the exposed seabed. This was followed by episodes associated with the PMT at 9.5–6.8 ka and then during the sea-level stillstand at ~5 ka, ~3.5 ka, ~2.1 ka and the last 1 ka and still active.

There are 84 mainland barriers along this PC and with a total length of 244 km occupying 36% of the shore. They range in average width from 240 to 760 m and have a mean height of 7.7 m (Table 10.5). The largest Cape Arnhem dunes however extend 4 km inland and reach a maximum height of 85 m. The dunes are presently active with 12% consisting of unstable bare sand. The barriers have a total volume of 3449 M m^3, with a unit barrier volume of 10,055 m^3 m^{-1}, the largest in the NT.

On Groote Eylandt, 170 km south of Cape Arnhem, Shulmeister and Lees (1992) and Shulmeister et al. (1993) dated the transgressive dune sequences that have transgressed up to 10 km inland at Scott Point on the northeastern tip of the island. They found two deeply weathered (red) Pleistocene basal units dating ~130 ka, overlain by four (yellow) Holocene units dating between 5.7–4.1 ka, 2.9–0.8 ka and 0.5–0.2 ka. Shulmeister and Head (1993) also found the dunes transgressed the several kilometres across the point and deposited sand in the backing Little Lagoon between 3 and 2 ka. This sand has been reworked by waves and transported to the southwest developing the 7 km long Qantas Spit that now encloses Little Lagoon bay (Fig. 10.5).

10.2.3 Sediment Transport

Much of this PC faces squarely into the prevailing southeast trades, resulting in primarily onshore transport from the shelf to the beaches, dunes and into the bays. Transport in the three mainland SCs is discussed below.

Fig. 10.5 Red Pleistocene dunes in the foreground have overpassed (left to right) 10 km wide Scott Point (Groote Eylandt 81–85) to supply sand to the lee shore that waves have then transported south to build 7 km long Qantas Spit. (Photo: AD Short)

10.2.4 SC:NT03.01.01 Cape Arnhem-Wanyanmera Point

SC:NT03.01.01 extends for 101 km between Cape Arnhem and Wanyanmera Point as a generally straight southeast-facing coast, largely contained within three exposed curving embayments. In the centre is Port Bradshaw a 50 km^2 drowned valley estuary with Gwapilina-Binanangoi points and Wanyanmera Point bordering its 1.5 km wide entrance (Fig. 10.6). The exposed beaches occupy over half the coast and are a mix of WD (60%) and TM (14%), with 180 rips dominating most of the WD and TM beaches. They were backed by massive transgressive dunes extending up to 4 km inland as multiple, imbricated parabolic to longwalled parabolic dunes. The dunes have been a major sink for marine sands (~40% carbonate), with a total volume of 1994 M m^3 and a unit volume for the open coast (excluding Port Bradshaw) of 15,686 m^3 m^{-1}. This high per metre volume is the same magnitude of many of the higher energy southern Australian barrier systems (Appendix 34.2). The high level of wave energy is also reflected in the limited seagrass communities along this coast, with Poiner et al. (1987) finding only 4.3 km^2 or 0.5% of the Gulf's seagrass located between Cape Arnhem and Cape Shield.

The sheltered Port Bradshaw estuary located in the middle of the SC contains 45 km of sheltered shoreline, the northern half lined by mangroves, while the more exposed southern half includes 14 TD beaches. The entrance and southern bay are

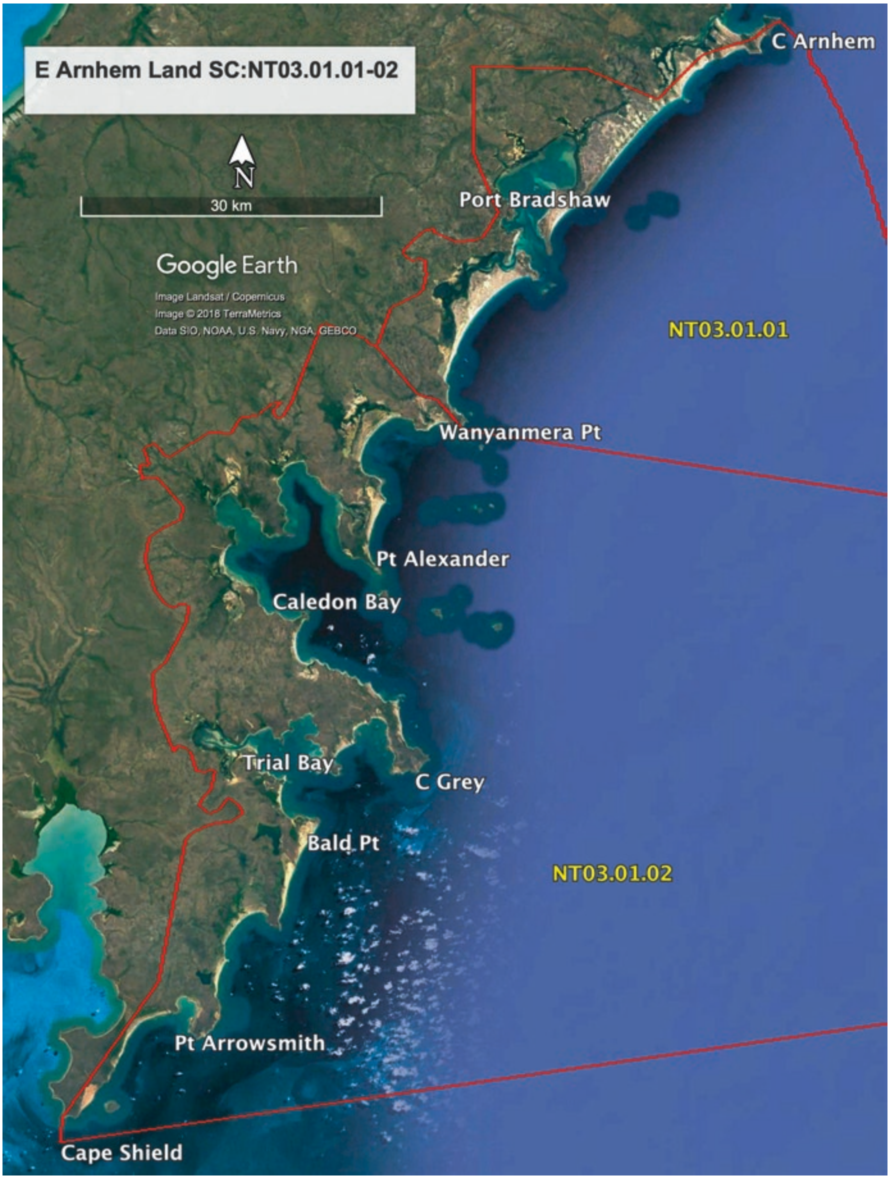

Fig. 10.6 SCs:NT03.01.01-02 is the most exposed of the east Arnhem Land coast. (Source: Google Earth)

aligned to the southeast enabling southeast waves to penetrate into the estuary, as well as the trades generating fetch-limited waves across the 8 km of fetch. The combination of flooding tides and the waves has deposited a sandy flood tide delta that extends 6 km into the estuary. Assuming the 12 km^2 delta is 3 m thick, this would represent 36 M m^3 of sand. Wonga Creek enters to the western side of the estuary where it is bordered by a 1 km wide regressive series of beach ridges which face due southeast towards the entrance. The ridges have been developed by a combination of fetch-limited waves generated within the estuary and possibly wave entering the entrance with the estuary acting as a major sink for marine and terrestrial sediments.

10.2.5 SC:NT03.01.02 Wanyanmera Point-Cape Shield

SC:NT03.01.02 is dominated by a series of protruding granite headland, points and peninsulas that have enclosed the larger Caledon, Wonga, Trial, Wardarlea and Marajella bays, together with a series of smaller bedrock-bordered embayments (Fig. 10.6). The irregular 231 km of coast has a crenulation ratio of 3. The coast is a mix of rocky shore, some exposed WD beaches (37%), including 130 beach rips occupying about 20 km of the coast, particularly south from Bald Point; sheltered TD beaches (37%) in the bays and 45 generally exposed beaches fronted by rock flats (26%). Sediment transport is predominately onshore onto the beaches, into the dunes and into the bays where several regressive barriers have developed. Then only longshore transport is sand moving into some of the bays.

Between Wanyanmera Point and Point Alexander are two 6 km long embayed beaches. The northern is more sheltered and is backed by a 2 km wide regressive barriers, while the more exposed outer beach is backed by episodes of dune transgression extending up to 6 km inland and in place overpassing the headland. Both embayments are sinks for marine sands (~50% carbonate). Point Alexander marks the northern boundary of the large Caledon Bay, with Du Pre Point-Cape Grey 12 km to the south the southern boundary while in between is 75 km of bay shore. The bay faces southeast exposing much of its shore to Gulf and local wind waves. There is sufficient wave energy to maintain 72 generally small (mean = 0.8 km) largely TD (B+SF) beaches which occupy 58 km (76%) of the bay shore. Marine sand is moving into the bay in the form of sand waves off Point Alexander and headland bypassing and some overpassing along the series of embayed WD beaches that extend into the bay for 20 km west of Du Pre Point.

To the south of Du Pre Point-Cape Grey are Wonga and Trial bays, located inside an 8.5 km wide entrance between Cape Grey and Bald Point. Wonga Bay faces due southeast and has three embayed beaches at its northern base each backed by dune transgression, the longest extending 1.5 km inland. Trial Bay is larger and more crenulate resulting in a mix of exposed outer to sheltered inner shorelines. The exposed outer beaches are backed by moderate dune transgression the longest extending 2 km inland, while the sheltered beaches include small regressive barriers and more stable TD beaches, together with sections of mangroves. Marine sands are moving into the bay and then into the regressive and transgressive barriers, with the final sink being a 4 km long tidal delta in the almost landlocked western arm of the bay.

The southern section of this SC between Bald Point and Cape Shield consists of a series of generally exposed embayed beaches backed by transgressive dunes, the largest extending 2 km inland, together with two regressive barriers sheltered in lee of Bagbiringula Point (2.8 km wide) and Point Arrowsmith (0.5 km wide). Sand transport in this section is predominately onshore into the dunes and barriers, with inactive headland overpassing and possible headland bypassing at Bald Point.

The barriers along this SC occupy 127 km (55%) of the shore and have a total volume of 1187 M m^3, a similar volume to its northern neighbouring SC; however the per metre volume, while reasonably high, is considerable less at 9335 m^3 m^{-1}.

10.2.6 SC:NT03.01.03 Blue Mud Bay

Blue Mud Bay (NT03.01.03) is a heavily indented bay, with an entrance width of 47 km and 340 km of shoreline and a crenulation ratio of 7.2. It is sheltered by the elongated Cape Shield and Cape Barrow, as well as the central 25 km long Woodah Island (Fig. 10.7). Its shoreline is a mix of protruding rocky points separating mud-filled bays and seabed, as indicated by its name. Of the 88 beaches in the bay, 85 are

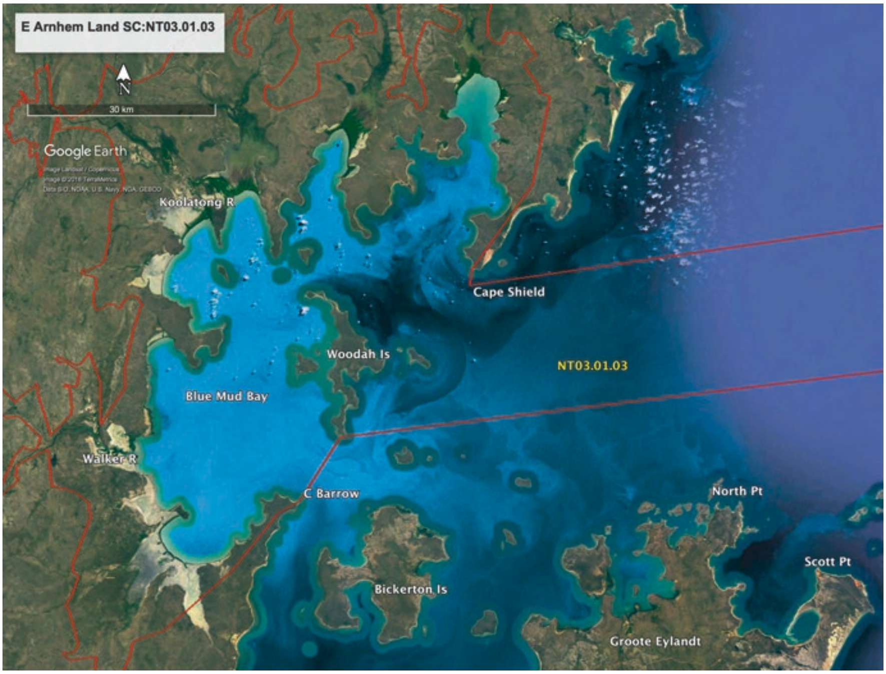

Fig. 10.7 SC:NT03.01.03 Blue Mud Bay

TD and 50 of these are B+TM, attesting to the muddy nature of much of the shore. The lowest energy bays have mangrove-fringed tidal flats and no beaches, including the tide-dominated mouths of the Koolatong and Walker rivers. The beaches occupy 133 km (40%) of the bay shore, the remainder a mix of mangrove-fringed mud flats and laterite bluffs, some also fringed by mangroves, together with 80 km^2 of seagrass meadows (Poiner et al. 1987)

The northern half of the bay has three south-facing U-shaped bays (Myaoola, Grindall and Jaima) each fed by a small river (Wonga, Durabudboi and Ludtanba). Each of the rivers disperse across the supratidal flats, containing dense mangrove forests up to 4 km wide and drained by a series of tidal creeks, with no clearly defined river mouths. The small Koolatong River enters a 6 km wide bay just west of Jaima Bay and has a clearly defined channel that meanders for 8 km across supratidal salt flats to reach the bay where the narrow river-creek mouth and flats are fringed by mangroves. The other four western bay embayments, including the mouth of the Walker River and the southern Bennett Bay, have also been infilled to the supratidal elevation. The small Walker River meanders for 7 km across the flats to reach the centre of its 5.5 km wide bay.

The entire Blue Mud Bay is a sink for marine sediment moving in through its wide entrance, as well as possibly around Cape Shield, and for the terrestrial sediments delivered by the numerous small rivers and creeks that flow into the bays and its embayments. Jones (1987) found that fine-grained fluvial sediment from the Limmen Bight (Roper, Towns and Limmen Bight rivers) is transported northwards by waves and tidal currents and deposited in the bay, leading to high rates of sedimentation. The northern bays, like Myaoola, are still at the second ‘big swamp’ phase of infilling, while the western and southern bays have aggraded to the third salt flat stage. While the bay is a large sediment sink, the low barriers have a total volume of just 37 M m^3 together with a low per metre volume of 539 $m^3\ m^{-1}$. The low volume reflects the low energy nature of much of the bay and the fact that much of the sediment is being deposited on the bay floor and consequently not considered in the volume estimates.

10.2.7 North Bickerton, Winchelsea and Groote Islands (NT03.01.04)

SC:NT03.01.04 includes the northern shores of Bickerton, Winchelsea and Groote islands which are a mix of rocky shore and generally sheltered north-facing beaches (Fig. 10.8). Bickerton has 27 beaches along its 50 km of northern shore, while Groote has 107 beaches along its northern shore, and Winchelsea has a total of 28 beaches and 34 km of shoreline. Fringing coral reefs protect parts of the northern Bickerton shore, with the reefs backed by mangrove-filled bays. On Groote the shoreline is heavily indented, including the all but attached Winchelsea Island, resulting in a generally low energy shoreline dominated by rocky points and small

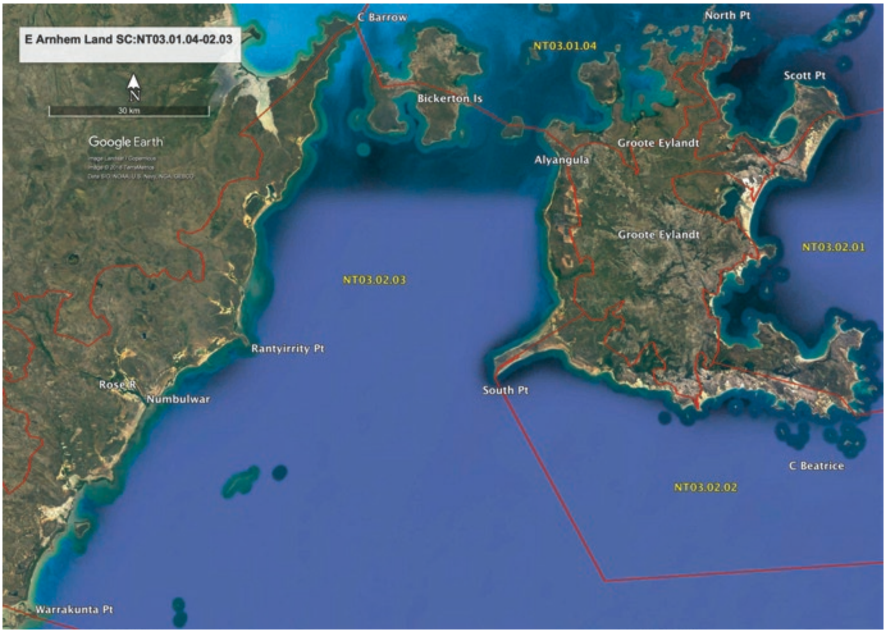

Fig. 10.8 PC:NT03.02 includes mainland between Cape Barrow and Warrakunta Point as well as the southern shores of Bickerton Island and Groote Eylandt. (Source: Google Earth)

embayed beaches, while mangroves line the more sheltered bay shores. The east-facing sections of North Point do contain higher energy beaches, some backed by both red Pleistocene and white Holocene transgressive dunes.

10.3 PC:NT03.02 Cape Barrow-Warrakunta Point

PC:NT03.02 trends south-southwest for 156 km along the mainland between Point Barrow and Warrakunta Point with only minor indentations, while offshore it includes the indented southern shores of Bickerton and Groote islands (Fig. 10.8). This section only considers the mainland shore which is a relatively straight (crenulation ratio 1.3) exposed, east-southeast-facing coast. It is however sheltered from the waves by Groote Eylandt in the north and its location in the southern gulf in the south. The island shores range from very exposed along the northeast and southern Groote coast to a sheltered leeward west coast. The generally more sheltered nature of this coast is indicated by the extensive seagrass communities, with 293 km^2 between Cape Barrow and the Rose River, as well as extensive meadows in lee of Bickerton Island and Groote Eylandt (Poiner et al. 1987).

Fig. 10.9 The mouth of the Rose River at Numbulwar (NT 1433) showing the inner transgressive (T), then regressive (R) barrier that extends for 8 km north of the river mouth. (Photo: AD Short)

10.3.1 Rivers and Streams

There are just 14 generally small streams and tidal creeks along the coast, with the Rose River the only major system (Fig. 10.8). The Rose River enters the centre of the compartment, adjacent to Numbulwar, and is supplying sand to the coast. The sand has been transported northwards developing a 7 km long, 3 km wide beach-foredune ridge plain on its northern side (Fig. 10.9). This barrier contains an inner section of now stable transgressive dunes which increase in area to the south where they extend 1.5 km inland and then a 1.5 km wide regressive plain containing 15 ridges, the outer ridges showing evidence of northerly longshore transport, while two outer active recurved spits trend south for up to 3.5 km, indicating a reversal and southerly transport. The terrestrial origin of this sand is indicated by the low proportion of carbonate in the beach and dune sands (mean = 6%, range 1–11%), the lowest in this region.

10.3.2 Sediments and Beaches

Mainland beach sediments range from fine to coarse sand and from 0% to 90% carbonate (Figs. 10.2 and 10.10a), indicating the local source for beach material, limited longshore transport and numerous TCs. This PC contains 41 mainland

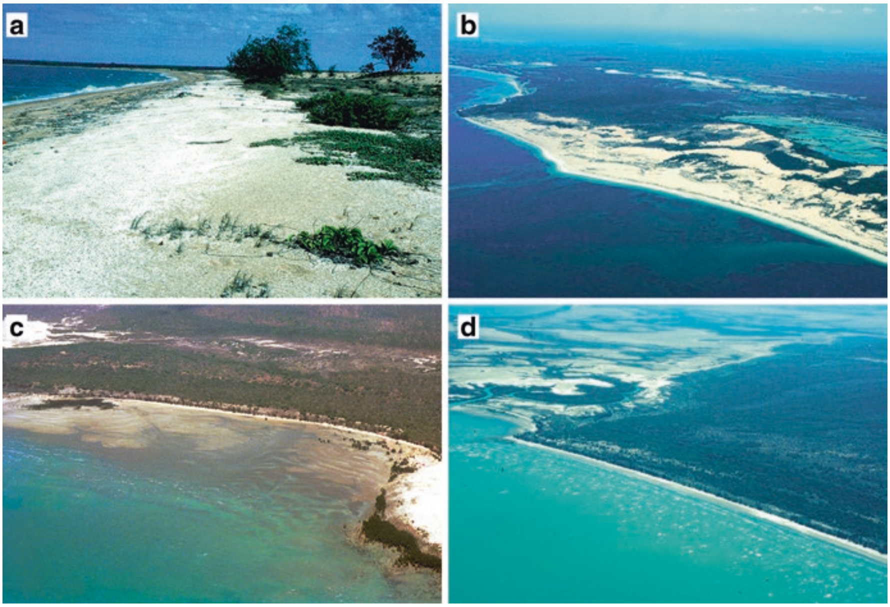

Fig. 10.10 (**a**) Reflective high tide beach backed by a shell-rich beach ridge at Dharni (NT 1405); (**b**) R+coral reef beach backed by active dune transgression at Minintirri (NT 1427); (**c**) beach and 16 ridged sand flats (low tide) north of Wiyakipa (NT 1434); and (**d**) tidal creek with ridged sand flats (high tide) at Wiyakipa beach (NT 1436). (Photos: AD Short)

beaches, which occupy 101 km (65%) of the coast. Most are embayments between rocky points and reefs, with an average length of 2.5 km and generally facing east into the trades. The waves averaging ~0.5 m and combine with the ~2.5 m tide range to maintain a low to moderate energy shoreline dominated by TM (10%) and TD (40%) beaches, though beaches fronted by rocky flats dominate at 49%, followed by B+RSF (34%) (Fig. 10.10c, d) (Table 10.6). The RSF have an average width of 820 m (σ = 480 m) and contain on average eight ridges (σ = 3.7). The rock flats average 740 m in width (σ = 600 m), and the SF and TSF 670 m (σ = 490 m), indicating all beaches, have a wide intertidal zone.

10.3.3 Barriers

There are 17 mainland barrier systems along this compartment that occupy 99 km (63%) of this predominately open and exposed coast. They range in type from small regressive foredune plains to transgressive dunes extending up to 5.5 km inland and reaching 30 m in height, with 10% of the barriers presently active. The barriers tend to be regressive along the sheltered northern coast, with some small to moderate dune transgression along the southern coast (Fig. 10.10b), with headland

Table 10.6 East Arnhem Land: PC:NT03.02 mainland beach types and states

BS	BS	No.	%	Length (km)	%	Mean (km)	σ (km)
6	R	1	2.4	0.6	0.6	0.6	–
9	UD	2	4.9	10.2	10.1	5.1	–
10	B+RSF	10	24.4	34.8	34.4	3.48	3.1
11	B+SF	1	2.4	0.4	0.4	0.4	–
12	B+TSF	3	7.3	5.8	5.7	1.93	1.5
14	R+RF	24	58.5	49.3	48.7	2.05	1.9
		41	100	101.1	100	2.5	

overpassing occurring at Arndani Creek. They also include a number of transgressive systems that were active in the mid-Holocene and are now stable and vegetated. The barriers have a total volume of 803 M m^3 and a unit volume of 8116 m^3 m^{-1}.

10.3.4 Groote and Bickerton islands

The exposed northeast and south coast of Groote Eylandt have extensive Pleistocene and Holocene dune transgression extending up to 10 km inland (discussed in Sect. 10.2.2), mixed with moderate to low energy sections, particularly in Dalumbu Bay. The southwest tip of the island is protruding a 12 km long, 2.5 km wide sand spit, crossed in part by transgressive dunes. The western side of the island is a lee shore and dominated by low energy beaches and tidal flats. The island has a total of 283 beaches along its 480 km of shoreline. They range from higher energy exposed multi-bar WD on the east coast, to TM to TD sand flats, particularly in the bays and on the west and north coast. Coral reefs fringe some of the southern beaches.

The H-shaped Bickerton Island lies in lee of Groote Eylandt and has a relatively sheltered 117 km long coast, with a mix of mangroves, particularly on the western and northern coast, bedrock and 54 low energy beaches.

10.4 Regional Overview

The east Arnhem Land region has a mainland coast of 828 km much of which faces east-southeast into the dominating trade winds and waves. Tides decrease southward to micro-meso and breaker waves range from >1 m in the north to ~0.5 m in the more sheltered south. The coast has a mix of exposed WD and TM and sheltered TD shores. The exposed wave- and rip-dominated beaches are backed by the largest transgressive dune systems in the NT, particularly in the north, though transgressive dunes occur in the full length of the region in exposed locations. Between the straight exposed sections are numerous bays, including the large Blue Mud Bay. Each of the bays has been a sink for marine and terrestrial sediments infilling their smaller embayments with inter and supratidal flats, regressive and some transgressive barriers. Wave energy decreases southwards into the southern Gulf with the northern PC03.01 containing 35% WD beaches, compared to <1% in the southern PC03.02. Offshore are series of islands ranging in size up to the larger Woodah, Bickerton and Groote Eylandt (2326 km^2).

There is evidence of northerly longshore transport, particularly north from the Rose River, which takes a range of forms including north-trending spits, creek mouth deflected to the north, probably northerly headland bypassing, particularly where the headlands are subdued, and some headland overpassing. Jones (1987) also concluded that fine material is being transported northwards from Limmen Bight. However, given the relative low energy nature section of the coast, transport rates are expected to be low, on the order of 1000's m^3 $year^{-1}$.

The coast is presently vulnerable to tropical cyclone storm surge, winds and flooding which will continue into the future and has low to moderate vulnerability to sea-level rise. Much of the coast is a low but elevated coastal plain which together with the elevated transgressive dunes have low vulnerability to inundation, though with 10% of the dunes presently unstable, they are susceptible to changing wind systems. The lower energy beaches are moderately exposed to recession and overwashing, while the low energy bay shores are the most susceptible as their tidal flats become increasingly inundated and tide-dependent ecosystems shift landward. Apart from the dunes on Cape Arnhem and Groote Eylandt, there have been no studies of the east Arnhem Land coast, and the coast continues to remain largely undeveloped and sparsely populated. In this state it will be left to adapt to the impact of climate changes through natural processes.

References

Jones MR (1987) Surficial sediments of the western Gulf of Carpentaria. Aust J Mar Freshw Res 38:151–167

Lees BG, Yanchou L, Head J (1990) Reconnaissance thermoluminescence dating of Northern Australian coastal dune systems. Quatern Res 34:169–185

Lees BG, Stanner J, Price DM, Yanchou L (1995) Thermoluminescence dating of podsols at Cape Arnhem, northern Australia. Mar Geol 129:63–75

Poiner IR, Staples DJ, Kenyon R (1987) Seagrass communities of the Gulf of Carpentaria, Australia. Aust J Mar Freshw Res 38:121–131

Short AD (2006) Beaches of the Northern Australia coast: the Kimberley, Northern Territory and Cape York. Sydney University Press, Sydney, 463 p

Shulmeister J, Head J (1993) Aspects of the emplacement, evolution and 14C chronology of ridges on a coastal spit, Groote Eylandt, Northern Australia. Mar Geol 111:159–169

Shulmeister J, Lees BG (1992) Morphology and chronostratigraphy of a coastal dunefield: Groote Eylandt, northern Australia. Geomorphology 5:521–534

Shulmeister J, Short SA, Price DM, Murray AS (1993) Pedogenic uranium/thorium and thermoluminescence chronologies and evolutionary history of a coastal dunefield, Groote Eylandt, northern Australia. Geomorphology 8:47–64

Chapter 11
Southern Gulf of Carpentaria Region

Abstract The southern Gulf of Carpentaria coast is a relatively straight coast trending southeast for 900 km and forming the southern shore of the large Gulf. It has a monsoonal climate with the trade winds generally flow off to alongshore. The coast occupies part of the Carpentaria Basin and has a low to very low gradient coastal zone, with supratidal flats extending in places tens of kilometre inland. A series of small- to moderate-sized rivers delivered terrigenous sediment to the coast and have built deltas and extensive tidal flats, though beach sediments remain 40% carbonate. Tides are meso and wave energy low decreasing to the south as the tide-dominated beaches are replaced by tidal flats and mangroves. Regressive Pleistocene and Holocene barrier islands back the high energy sections, the islands now stranded by a mid-Holocene fall in sea level. To the south the barrier grades into wide chenier-capped tidal flats, usually fringed by mangroves. This chapter examines the coastal processes, beaches, barriers and sediment transport and compartments.

Keywords Gulf of Carpentaria · Mangroves · Meso-tides · Beaches · Barriers · Sediment transport and compartments · Tidal flats

11.1 Introduction

The southern Gulf region trends southeast (115°) for 884 km from Warrakunta Pt to the Norman River mouth. It straddles the NT/QLD border and contains two PCs NT04.01 and QLD01.01 and four SCs (Fig. 11.1 and Table 11.1). It is a relatively straight shore with a crenulation ratio of 1.3. The shoreline is however cut by 60 drainage systems, including 11 small- to moderate-sized rivers. It is for the most part a low energy lee shore, with a very low gradient coastal plain, intertidal zone and nearshore, the latter further reducing wave energy. There are 30 barriers and 80 beaches spread along this depositional coast, with the barriers occupying 428 km (48%) of the coast and the beaches 347 km (39%), the discrepancy owing to the fact that some of the barrier shores are fronted by dense mangroves and tidal flats. The remainder of the shore is dominated by mangrove-lined tidal flats and creek and river mouths. The only mainland bedrock in the region is a small laterite outcrops at

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https://doi.org/10.1007/978-3-030-14294-0_11

Fig. 11.1 The southern Gulf of Carpentaria region contains PCs:NT04.01 and QLD01.01 and extends from Warrakunta Point in the NT to Karumba at the mouth of the Norman River in QLD. (Source: Google Earth)

Table 11.1 Southern Gulf of Carpentaria region, PCs and SCs, which includes both NT and QLD coastline

Region/comp. No.[a]	Boundaries	Beach ID[b]	No. beaches	km[c,d]	Total km
NT04.01	*Southern Gulf of Carpentaria*				
NT04.01.01	Warrakunta Pt-Rosie Ck	NT 1438-1452	15	4559-4721	162
NT04.01.02	Rosie Ck-Calvert R	NT 1452-1482	30	4721-4988	267
NT04.01	*sub-total*		*45*		*429*
QLD01.01.01	Calvert R (NT)-Bayley Pt (Qld)	NT 1483-1488	6	4988-5029	41
		QLD 1-16	16	0-126	126
QLD01.01.02	Bayley Pt-Karumba	QLD 17-29	13	126-384	258
QLD01.01	*sub-total*		*35*		*425*
	Region total		*80*		*854*

[a]NCCARF compartment number
[b]ABSAMP beach ID
[c]Distance from WA/NT border
[d]Distance from NT/QLD border

Rosie Creek and 2 km long Sharker Point at the mouth of the McArthur River. Bedrock islands include Maria Island in Limmen Bight, the Sir Edward Pellew Group off the McArthur River mouth and the Wellesley Islands in the east. The few Gulf towns and communities are all located tens of kilometres inland behind the tidal flats and above the storm surge level (Borroloola (45 km inland, population 950) and Burketown (35 km, 200)). Karumba (550) is located at the mouth of the Norman River and just inside the next region. There is only one public road to the coast at Bing Bong (near Borroloola) which has the only development on the coast, a loading dock and a nearby boat ramp. Most of the coast is backed by pastoral leases and is only accessible in a few places by 4WD in the dry season.

11.1.1 Rivers and Creeks

Sixty rivers and creeks drain the low undulating topography of the McArthur and Carpentaria basins that extend inland from the southern Gulf shores. The 11 largest rivers from the west are the large Roper (84,665 km^2), Towns (4755 km^2) and Limmen (22,855 km^2), which all flow into Limmen Bight, a 60 km long section of the southwest corner of the Gulf. Fine sediment from these rivers is being transported northwards by waves and tidal currents and deposited in Blue Mud Bay (Jones 1987). One hundred and twenty kilometres further east is the McArthur (21,139 km^2), followed by the Robinson (5766 km^2), Calvert (7536 km^2), Albert (20,941 km^2), Leichhardt (32,568 km^2), the large Flinders River (109,460 km^2) and the Norman (49,588 km^2), which forms the regional boundary. All flow across a 10's km wide low gradient coastal plain to reach the coast where most have well-developed TD funnel-shaped mouths, with predominately supratidal salt flats fringed by mangroves, indicating they have aggraded to the third stage of infilling and delta development.

11.1.2 Sediments and Coastal Processes

The limited beach sand data available for the southern Gulf coast (Table 11.2) indicates that sediments are lower in carbonate (mean = 38%, σ = 13%) with the sand moderately well-sorted medium to coarse sand. The Gulf represents a transition from the high-carbonate regions to the west (>50%) and the low-carbonate regions to the more humid east. East Arnhem Land beaches average 51% carbonate, the

Table 11.2 Sediment characteristics of southern Gulf of Carpentaria beach sand

S Gulf Carp NT04-QLD01	Swash
n	7
Mean size (mm)	0.55
σ (mm)	0.36
Sorting	0.61
σ (sorting)	0.48
% carbonate	38
σ (%)	13

southern Gulf 38% and the eastern Gulf 22%, which drops further 5–15% on the eastern Cape York Peninsula. The decrease reflects the increase in terrigenous supply of quartz sand, the decrease in fringing reefs owing to the higher terrigenous sediment and freshwater discharge and possibly a decrease in local carbonate production. However, seagrass meadows occupy much of the coastal zone between Limmen Bight and the Wellesley Islands with an area of 183 km^2, which represents 20% of the Gulf's seagrass communities (Poiner et al. 1987). While these may be producing carbonate detritus, wave energy may be insufficient for it to be transported shorewards.

Tides along the southern Gulf shore are meso (2.4–2.9 m spring range; Table 9.3), and waves are low (<0.5 m) and short (2–3 s) which combine to maintain an entirely TD shoreline. Wave data for Karumba, at the eastern regional boundary, is listed in Tables 11.3 and 11.4. The outer waverider buoy located 70 km offshore showed a gradual increase in wave height and period from August (0.22 m, 2.97 s) to January (0.84 m, 4.72 s). At the inshore buoy located 15 km offshore, wave height

Table 11.3 Karumba outer wave characteristics: August 1994 to January 1995

	H_{max}	H_s	T_z	T_p	Dir $_{TRUE}$	SST (ºC)
Aug	0.43	0.22	2.84	2.97	137.59	20.81
Sept	0.67	0.36	3.07	3.68	213.00	24.19
Oct	1.03	0.55	3.23	3.94	176.50	26.66
Nov	1.13	0.61	3.26	3.99	192.81	28.90
Dec	1.06	0.57	3.28	4.10	173.37	29.83
Jan	1.54	0.84	3.69	4.72	na	na

Based on data from https://data.qld.gov.au/dataset/coastal-data-system-historical-wave-data

Table 11.4 Karumba inshore monthly wave characteristics: August 1994 to July 1995

	H_s	H_{max}	T_z	T_p
Aug-94	0.31	0.57	2.37	2.63
Sep-94	0.40	0.73	2.69	3.20
Oct-94	0.53	0.95	2.97	3.68
Nov-94	0.53	0.95	3.00	3.73
Dec-94	0.53	0.94	3.03	3.91
Jan-95	0.70	1.21	3.56	4.93
Feb-95	0.49	0.87	3.25	4.58
Mar-95	0.53	0.92	3.37	5.08
Apr-95	0.29	0.53	2.45	2.81
May-95	0.34	0.63	2.49	2.80
Jun-95	0.32	0.58	2.56	2.98
Jul-95	0.29	0.54	2.40	2.69
Mean	0.45	0.80	2.87	3.63
σ	0.26	0.44	0.66	1.43

Based on data from https://data.qld.gov.au/dataset/coastal-data-system-historical-wave-data also peaks in January (0.7 m, 4.93 s) with lower wave during winter (~0.3 m, 2.7 s). The seasonal variation is a product of the seasonal wind reversal from offshore trades during winter to onshore northwesterlies during summer, plus the occasional tropical cyclone during later summer. While the inshore wave height averages 0.45 m (T = 3.6 s), it is still located 15 km offshore, meaning that the breaker wave height will be significantly less owing to the very low gradient nearshore and intertidal zone, with breaker wave height estimated to average < 0.3 m at Karumba beach. As the spring tide range is 3.8 m, the RTR is >12 and TD beaches prevail.

Tropical cyclone-driven storm surges are a major threat to the generally low gradient Gulf shores. Haigh et al. (2012) modelled 100-year extreme water levels along the southern Gulf shore predicting they would reach between 2 and 3 m (Fig. 1.14). However, modelling by Smith et al. (2013) predicted storm surges have the potential to reach 9 m in the Gulf and penetrate 30 km inland. The discrepancy in the results of these models will require further investigation.

11.1.3 Beaches

The beaches in this region are relatively long (mean = 4.2 km), with the longest reaching 20 km (Table 11.5). They are associated with the barrier islands that lie along the coast, most of which are backed by wide supratidal flats with tidal creeks forming most of the boundaries. Most beaches are relatively straight (embayment ratio = 0.97) and face straight into the Gulf (mean orientation 69°). They are entirely TD (100%) and usually have a narrow (~8 m) moderately sloping (mean = 4.4°) high tide beach, fronted by very wide sand flats averaging 1.1 km (σ = 0.8 km), the widest in Australia. The majority of the sand flats are ridged with an average of 8.8 ridges. Rock flats front eight of the beaches with an average width of 760 m. The beaches are composed of moderately well-sorted, carbonate-enriched fine sand (mean 38% carbonate) (Table 11.2). Short (2006) describes each of the beaches in the region.

Table 11.5 Southern Gulf of Carpentaria region: PC:NT04.01 and QLD01.01 beach characteristics

	n	Mean	σ	Aust. mean[a]	min	max
Length (km)	336 km	4.2	3.4	–	.15	20.2
Orientation (deg)	80	69	91	–	1	355
Embaymentisation	80	0.97	0.09	–	0.5	1.0
Gradient (deg)	80	4.4	0.8	–	3	5
Beach width (m)	80	8.4	2.3	–	5	10
Sand ridges (m)	53	8.8	4.6	7.2	2	20
Sand flats (m)	77	1097	907	485	50	5000
Rock flats (m)	8	763	814	495	100	2000

[a]Source: Short 2006

11.1.4 Barriers

The coast is a mix of low barriers with TD beaches, tidal creek and river mouths and tidal flats and mangroves, all backed by supratidal salt flats that widen to 50 km in to the east. The barriers are a prominent feature of the southern Gulf occupying half the coast. They are typically consist of an inner Pleistocene barrier and series of outer regressive Holocene barrier/s with salt flats occupying the interbarrier depression. The Holocene barriers average between 0.2 and 1 km in width and 8 km in length in the NT (NT04.01), increasing in size to the east where they average 2.5–4 km in width and 21 km in length in the QLD section (QLD01.01), with the longest reaching 55 km. They are consist of regressive beach and foredune ridges, with cheniers occurring east of Bayley Point and only occasional minor dune transgression on some of the outer foredune ridges. Owing to the mid-Holocene fall in relative sea level, the barrier islands tend to be backed by usually dry supratidal salt flats drained by the boundary tidal creeks. The flats are only inundated during the summer by the seasonally elevated sea level combined with river flooding. The barriers have a regional volume of 450 M m^3 and a per metre volume of 10,500 m^3 m^{-1} (Table 11.6). This relatively high per metre volume on such a low energy shore is a result of the abundance of sand supplied by the rivers and its lateral transport to the adjacent barrier systems, probably supplemented by shelf sand during the PMT.

Based on the orientation of the many spits along the coast and the deflection of the creeks and river mouths, longshore transport is generally to the northwest, driven by the winter southeast trades. Some of the recurved spits have migrated more than 10 km, deflecting the creek mouths and leaving a series of recurves in their wake. The transport is however continually interrupted by the creek and river mouths and in the centre by the McArthur River mouth and the Sir Edward Pellew Group. The terminal spit immediate east of this obstruction extends west for 30 km to the lee of Vanderlin Island. Rates of longshore sand transport are unknown but would be expected to be on the order of a few thousand metre cubed per year. The 30 km long spit has a volume of ~15 M m^3. Assuming it has been built since the fall in sea level 4 ka (Woodroffe and Chappell 1993), it would represent a westerly rate of transport on the order of ~4000 m^3 $year^{-1}$.

Table 11.6 Southern Gulf of Carpentaria: regional and PCs NT:04.01 and QLD:01.01 barrier dimensions

	NT04.01	QLD01.01	S Gulf
No.	16	14	30
Total length (km)	133.2	294.4	427.6
Mean width (m)	200–1000	2460–4070	–
Mean height (m)	3.3	5.08	87
Area (ha)	10,155	78,110	88,265
Unstable (ha)	540	1560	2100
Total volume (M m^3)	435	4065	4500
Unit volume (m^3m^{-1})	3263	13,808	10,523

11.2 PC:NT04.01 Warrakunta Point-Calvert River

PC:NT04.01extends along 429 km of coast between Warrakunta Point/Roper River mouth and the Calvert River mouth, located 40 km west of the NT-Qld border (Fig. 11.2), and contains two SCs (NT04.01.01-02). It is an entirely depositional shoreline apart from the two rocky outcrops at Rosie River (the SC boundary) (Fig. 11.3b) and Sharker Point, though the Sir Edward Pellew Group that lies off the McArthur River mouth is predominately bedrock. There are 45 beaches, which occupy 166 km (39%) of the shore. The beaches are entirely TD and predominately wide B + RSF (77% by length; Fig. 11.3d) and B + SF (16%), with B + TSF forming 6%. They average 3.7 km in length (Table 11.7); their extra length is associated with the longer barrier islands that form much of the shore. The beaches are part of 16 barriers that occupy 133 km (31%) of the coast the remainder mainly mangrove-lined tidal flats and 27 creek and river mouths (Fig. 11.3a, c) particularly in Limmen Bight and lee of the island group.

Woodroffe and Chappell (1993) and Jones et al. (2003) both investigated the McArthur River delta, the only geomorphological investigations in the region. Woodroffe and Chappell found the delta has two active and several abandoned distributaries, which built a broad 25 m wide deltaic plain. The entire plain has emerged 1–2 m in the past 4 ka, which contributed to rapid mid-Holocene delta progradation. They found delta differs from other northern Australia deltas,

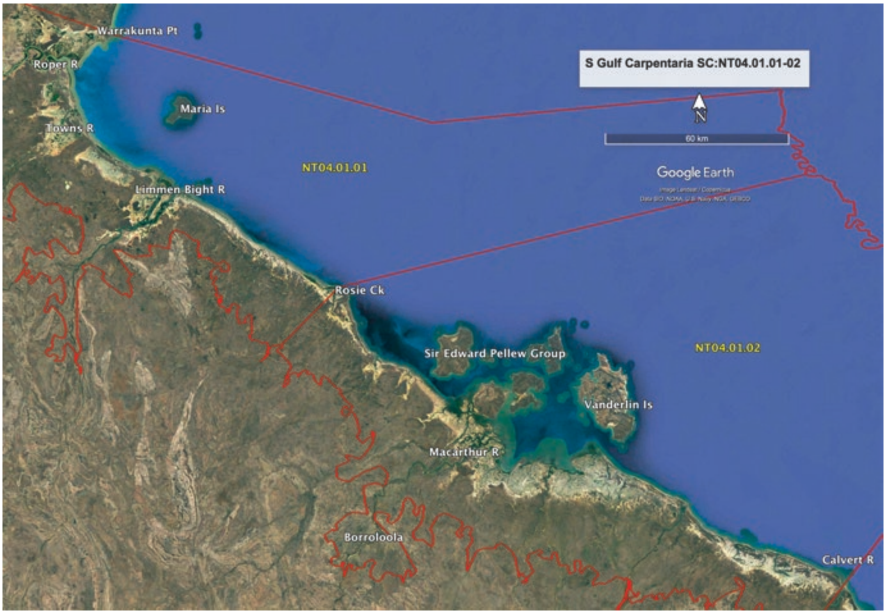

Fig. 11.2 SCs:NT04.01.01-02: the southwest Gulf of Carpentaria. (Source: Google Earth)

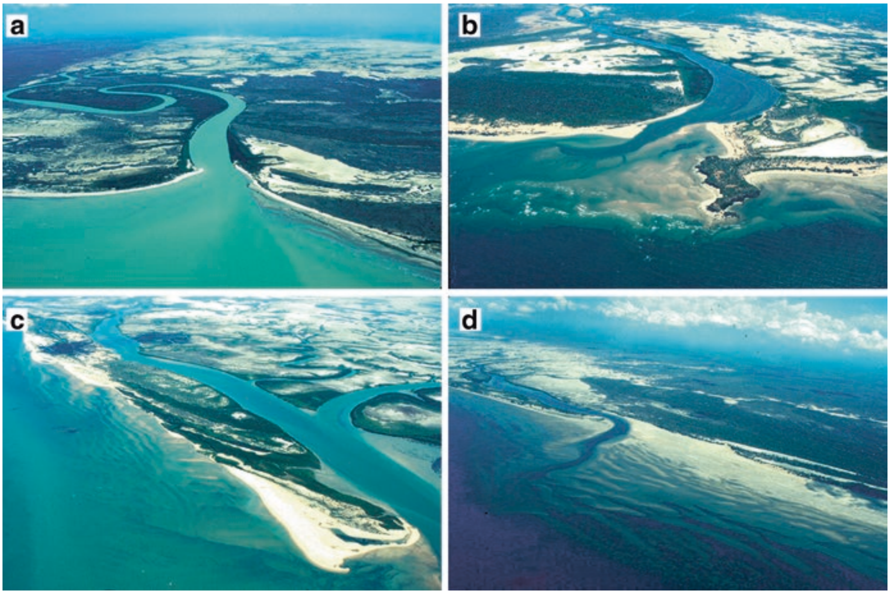

Fig. 11.3 PC:NT04.01 coast: (**a**) tide-dominated Towns River mouth with beaches NT 1441-2 to either side; (**b**) Rosie Creek enters the Gulf in lee of a low laterite point with beaches NT 1451-3 to either side; (**c**) Pelican Point (NT 1467) is part of a 12 km long northwest migrating sand spit that deflects the mouth of Fat Fellows Creek; and (**d**) ridged sand flats off the deflected mouth of Shark Creek (NT 1473). (Photos: AD Short)

Table 11.7 Southwest Gulf of Carpentaria (NT04.01) beach types and states

BS	BS	No.	%	Length (km)	%	Mean (km)	σ (km)
10	B + RSF	30	66.7	128.6	77.5	4.3	3.3
11	B + SF	8	17.8	27.1	16.3	2.6	2.4
12	B + TSF	3	6.7	7.2	4.3	2.4	1.1
14	R + RF	4	8.9	2.95	1.8	0.7	0.6
		45	100	165.9	100	3.7	

including other Gulf systems, in that it is river-dominated, a product in part of its sheltered location in lee of the Sir Edward Pellew Group of islands, with the distributaries controlling the broad deposition of the predominately sandy sediments on the upper deltaic plain, with saline mud flats occupying the lower plain. Jones et al. found that the lower deltaic plain has shelly sand overlain by muddy intertidal and supratidal deposits. They also found that sea level was slightly above present 6 ka, fell after 3 ka.

11.3 PC:QLD01.01 Calvert River to Norman River

PC:QLD01.01 occupies the eastern shore of the southern Gulf extending for 455 km from the Calvert River in the NT to the mouth of the Norman River in QLD (Fig. 11.4) and contains two SCs (QLD01.01.01-02). It also includes the Wellesley Islands which extend to within 10 km of the coast and include the large Mornington Island. The shoreline is relatively continuous but sinuous with a crenulation ratio of 1.3. As noted above, half of this coast consists of longer regressive barrier islands backed by the wide supratidal flats and bordered by deep mangrove-lined creeks, with the remainder occupied by mangrove-lined sand and mud flats, more than 30 tidal creeks and five moderate to larger rivers, including the Albert, Leichhardt, the large Flinders and the Norman. Beaches occupy 40% of this entirely sedimentary coast, the remainder mangrove-lined tidal flats and river and creek mouths. This is the lowest energy section of the Gulf coast, and with tides reaching 4 m, it is dominated entirely by TD beaches, tidal flats and drainage systems (Table 11.8).

11.3.1 SCs:QLD01.01.01-02

The QLD section contains two SCs which have quite contrasting shorelines. SC:QLD01.01.01 has a near continuous beach-barrier shoreline, with 22 beaches and barriers cut by numerous tidal creeks (Fig. 11.5a). Beaches average 6.3 km in

Fig. 11.4 SCs:QLD01.01.01-02 occupy the southernmost Gulf shore. (Source: Google Earth)

Table 11.8 Southern Gulf of Carpentaria (QLD01.01) beach types and states

BS	BS	No.	%	Length (km)	%	Mean (km)	σ (km)
10	B + RSF	19	52.8	112.5	62.2	5.9	4.1
11	B + SF	9	25.0	35	19.3	3.9	3.3
12	B + TSF	4	11.1	9.7	5.4	2.4	1.0
13	B + TMF	3	8.3	23.1	12.8	7.7	1.5
14	R + RF	1	2.8	0.6	0.3	0.6	–
		36	100	180.9	100		

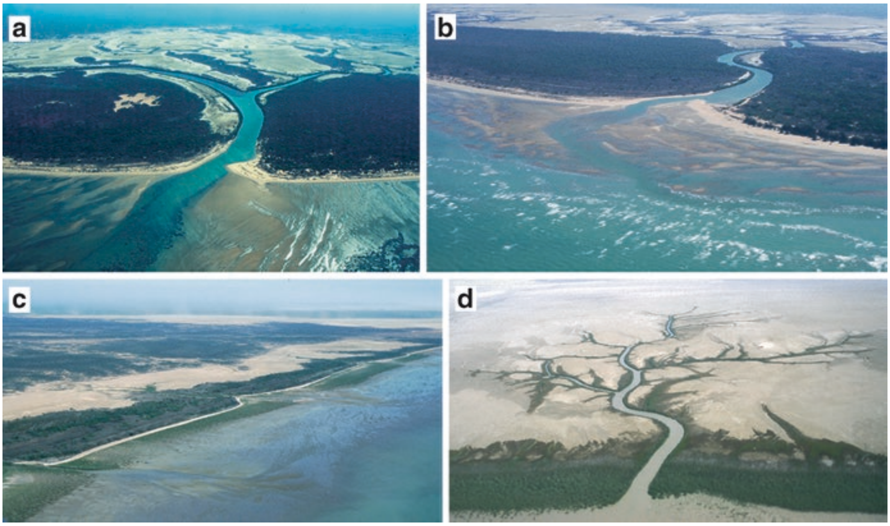

Fig. 11.5 PC:QLD01.01 coast: (**a**) Dingo Creek is bordered by 1 km wide barrier islands and drains extensive tidal flats with beaches NT 1485-6 to either side; (**b**) wave breaking at low tide at the mouth of Gum Creek (QLD 2-3) with 1.5 km wide barrier islands to either side; (**c**) low gradient coastal plain at James Creek with the barrier/beach fronted by mangroves then sand and mud flats (QLD 21); and (**d**) mangrove-lined shoreline and tidal creek draining the extensive tidal flats which extend 20 km inland (near QLD 27). (Photos: AD Short)

length and occupy 87% of the shore, the remainder the creek mouths and mangroves towards the east in lee of Mornington Island. The beaches are entirely TD and predominately B + RSF, with the flats averaging 1.04 km wide and containing on average 10 ridges. The presence of the ridges indicate wave energy is high enough to rework the wide sand flats and imprint the ridge form on the flats. In contrast SC:QLD01.01.02 has just 13 beaches averaging 2.8 km in length and occupying just 13.5% of the shore. The beaches are entirely TD and a mix of B + RSF and B + SF. The remainder of the coast consists of wide mangrove-lined mud flats together with creek and river mouths (Fig. 11.5b, c, d). The dominance of the tidal flats is a result of both the lower wave energy and the abundance of fine sediments supplied by the Nicholson, Albert, Leichhardt and Norman rivers and very low gradient shoreface.

The dominating characteristic of this section of the coast is its extremely low gradient, both in the nearshore and particularly across the supratidal salt flats, which can extend 50 km inland. Rhodes (1980, 1982) investigated the chenier plain along a 120 km long section of the coast between Burketown and Karumba and found it had prograded over 30 km into the Gulf. The flats consist of subtidal muds overlain with low tide muds, with cheniers forming on the flats during periods of reduced sedimentation, possibly associated with drier climate cycles. The 4–5 m high shelly cheniers are deposited by waves on top of the high tide mud flats and usually covered in a 2–3 m thick aeolian capping vegetated with *Casuarina* trees, reaching an average height of about 6 m AHD. The Karumba ridges prograded into the Gulf at rates between 1.6 and 4.8 m year^{-1}, assisted by a 1.5 m fall in sea level during past 5000 years, in agreement with Woodroffe and Chappell (1993) estimate for the western Gulf shore and general agreement with Jones et al. (2003).

11.4 Regional Overview

The southern Gulf region is the lowest energy region on the open Australian coast and is entirely TD, at testament to the very low breaker waves. The low wave energy is due to its location at the sheltered base of the Gulf, where the trade blows offshore, and when the summer monsoon flows onshore, the extremely low nearshore gradient reduces the waves to an average of 0.35 m in PC:NT04.01 and 0.25 m in PC:QLD01.01. The low gradient is due to its location on a very low gradient basin plain, coupled with the river-supplied fine sediments from the 11 rivers that flow to this region. This low energy sediment-rich region has near continuous beaches and barriers in PC:NT04.01 and SC:QLD01.01.01, which, as wave energy continues to drop, are replaced by mangrove-line mud flats in SC:QLD01.01.02. The entire shoreline and its river deltas have undergone considerable Holocene sedimentation, assisted by a 1.5 m late-Holocene fall in sea level, with most of the deltas reaching the third stages of infilling and dominated by supratidal salt flats, while in southeast Gulf, the shoreline has regressed in places by up to 30 km with the mud flats capped by shelly chenier ridges. There is however sufficient wave energy to maintain the ridged sand flats (69% of the beaches), the highest energy of the TD beaches, and to transport sand to the northwest at rates of a few thousand metre per year.

Storm surges are a major threat to this coast and are predicted to increase in intensity (Haigh et al. 2012, Smith et al. 2013; Fig. 1.14) making this a highly vulnerable coast. Rising sea level will also have dramatic impacts along this entire coast. The supratidal flats will become increasingly inundated leading to a resurgence in mangroves along the creeks and across the flats (Asbridge et al. 2016), as well as a landward shift in other tide-dependent ecosystems. The deepening nearshore will reduce wave attenuation leading to an increase in breaker wave height which should lead to increased rates of longshore sand transport. However, given the essentially undeveloped nature of this coast, it will be left to naturally adapt to these changes.

References

Asbridge E, Licas R, Ticehurst C, Bunting P (2016) Mangrove response to environmental change in the Gulf of Carpentaria. Ecol Evol 6(11):3523–3539

Haigh ID, Wijeratne EMS, MacPherson LR, Mason MS, Pattiaratchi CB, Crompton RP, George S (2012) Technical report: estimating present day extreme total water level exceedance probabilities around the Australian coastline. UWA Oceans Institute, University Western Australia, Perth, 89 p

Jones BG, Woodroffe CD, Martin GR (2003) Deltas in the Gulf of Carpentaria, Australia: forms, processes and products, vol 76. SEPM Special Publication, pp 21–43

Jones MR (1987) Surficial sediments of the western Gulf of Carpentaria. Aust J Mar Freshwater Res 38:151–167

Poiner IR, Staples DJ, Kenyon R (1987) Seagrass communities of the Gulf of Carpentaria, Australia. Aust J Mar Freshwater Res 38:121–131

Rhodes EG (1980) Modes of Holocene coastal progradation, Gulf of Carpentaria. Ph.D. thesis, Department of Biogeography and Geomorphology, ANU, Canberra

Rhodes EG (1982) Depositional model for a chenier plain, Gulf of Carpentaria, Australia. Sedimentology 29:201–222

Short AD (2006) Beaches of the Northern Australia coast: the Kimberley, Northern Territory and Cape York. Sydney University Press, Sydney, 463 p

Smith M, Harper B, Mason L, Schwartz R, Acworth C (2013) Gulf of Carpentaria storm tide and inundation study. In: 21st Australasian conference on coastal and ocean engineering, Institution of Engineers Australia, pp 691–696

Woodroffe CD, Chappell J (1993) Holocene emergence and evolution of the McArthur River delta, southwestern Gulf of Carpentaria, Australia. Sediment Geol 83:303–317

Chapter 12
Western Cape York Peninsula Region

Abstract The 1000 km long western coast of Cape York Peninsula faces into the Gulf of Carpentaria with several moderate-sized rivers draining the low Peninsula to deposit sandy deltas. The climate is tropical monsoonal with the trades predominately flowing offshore and only the summer monsoons and occasional tropical cyclone delivering higher energy conditions. The coast trends relatively straight to the north and grades from tidal flats, cheniers and mangroves in the low gradient low energy south to longer sandy beaches backed by regressive beach-foredune ridges, and elongate recurved spits at the river mouths, together with low laterite bluffs increasing in prominence to the north. Tides are meso, and the beaches are a mix of tide-modified and tide-dominated with sediment predominately quartz with ~20% carbonate. This chapter described the coastal processes, sediment, beaches, barriers and sediment transport and compartments.

Keywords Cape York Peninsula · Gulf of Carpentaria · Regressive barriers · Beach ridges · Mangroves · Beaches · Sediment transport · Sediment compartments.

12.1 Introduction

The western Cape York Peninsula region extends for 1015 km from Karumba, at the mouth of the Norman River in the southeast corner of the Gulf (17.5°S), north to Van Spoult Head, the northeastern boundary of the Gulf (10.9°S), located 50 km west of the tip of the Peninsula at Cape York (Fig. 12.1). This region forms the entire eastern side of the Gulf shore, as well as forming the western shore of the Peninsula. The southern half of the coast south of Worbody Point is entirely sedimentary, while to the north is a mix of sand and laterite bluffs together with more than 70 creeks and river mouths. This is a relatively straight coast trending north-northeast, with a crenulation ratio of 1.4. The region contains two PCs:QLD02.01-02 and three SCs (Fig. 12.1 and Table 12.1).

As discussed in Sect. 9.3, the Peninsula has a tropical monsoonal climate, with the southeast trades and drier conditions prevailing during winter and onshore

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Fig. 12.1 The 1000 km long western Cape York Peninsula region with PCs:QLD02.01–02. (Source: Google Earth)

humid northwest monsoonal winds during summer, with temperatures ranging from the mid-20s in winter to around 30 °C in summer. An average of one to two tropical cyclones forms in the Gulf each summer (Fig. 1.6a) bringing strong winds, storm seas, heavy rain and elevated water levels. Tides range from 3.8 to 2.3 m (Table 9.3), while seasonal water level fluctuations can raise the southern water level by as much as 0.75 m during summer.

Table 12.1 Western Cape York Peninsula PC and SCs

PC/SC No.[a]	Boundaries	Beach ID [b]	No. beaches	km[c]	Total km
QLD02	**Western Cape York Peninsula**				
QLD02.01.01	Karumba-S Mitchell R	QLD 30-56	27	384-667	283
QLD02.02.01	S Mitchell R-Worbody Pt	QLD 57-78	22	677-906	239
QLD02.02.02	Worbody Pt-Van Spoult Pt	QLD 79-177	99	906-1399	493
QLD02.02	*PC sub-total*		*121*		*732*
	Region sub-total		*148*		*1015*

[a]NCCARF compartment number
[b]ABSAMP beach ID
[c]Distance from NT/QLD border

12.1.1 Rivers

The high rainfall (800–2000 mm) particularly during the summer wet season and gently rising hinterland give rise to more than 70 creeks and rivers that reach the coast in this region, including 19 small- to moderate-sized rivers, the largest being (from south to north) the Gilbert (42,148 km^2), Staaten (25,772 km^2), Mitchell (65,278 km^2) and Archer (16,310 km^2). The rivers that flow directly to the coast have built extensive beach-foredune ridge plains at their mouths. The few rivers that flow into embayments such as the Archer, Mission and Ducie maintain well-developed TD deltas. Based on the orientation of the many creek and river mouth spits along the coast, longshore transport is limited south of the Gilbert River with both northerly and southerly deflections of the river and creek mouths. Further north it appears to be generally to the north, with some local reversals to the south, particularly on the south side of some of the river mouths. An estimate of the rates of northerly sand transport can be gauged from the volume of some of the north-trending spits and barriers. The barriers along the centre section between Christmas Creek and the Love River have volumes of 47 M, 115 M and 100 M m^3. Assuming the barriers have been deposited over the past 4000 years, this would provide rates of supply of between 12,000 and 29,000 m^3 year^{-1}. This is a relatively high rate for such a location and could be assisted by locally sourced river supply from the Mitchell, Holroyd and Love rivers.

Jones et al. (1993) investigated the evolution of the Gilbert River fan delta and found the 11,000 km^2 delta fan is up to 25 km wide and 8 m thick overlaying an irregular Pleistocene surface. Transport of pebbles and coarse sand is retarded by the tidal intrusion resulting in their being deposited in the river channels, with only the medium to fine sand and suspended material reaching the coast. The sand is only deposited at the coast during the summer wet season, with tidal flow restricting movement of coarser material as the river discharge decreases into winter. They found in the absence of bedrock control the river has a prograding coastal wedge of Holocene sediments extending for 125 km along the coast, with the subaerial portion prograding 15–20 km into the Gulf during the past 6.5 ka, depositing regressive beach-chenier ridges overlying delta-front and subtidal sands and prodelta mud.

Table 12.2 Weipa monthly average wave characteristics (1979–1981) (based on data from https://data.qld.gov.au/dataset/coastal-data-system-historical-wave-data)

Month	Hs (m)	Tp (s)
1	0.89	6.61
2	0.84	6.37
3	0.43	5.14
4	0.23	2.36
5	0.27	3.00
6	0.28	3.16
7	0.29	3.17
8	0.25	2.55
9	0.27	2.39
10	0.26	2.62
11	0.28	2.60
12	0.26	3.12
Mean	0.38	3.6

12.1.2 Coastal Processes

Spring tide range along the western Peninsula peaks in the southeast corner at Karumba (3.8 m) and Staaten River (4.1 m), decreasing along the central section to 2.4 m at Nassau River and 2.9 m at Weipa and then increasing northwards reaching 3.6 m at the northern boundary at Van Spoult Point (Table 9.3).

Wave data for Karumba on the southern Gulf is provided in Chap. 11 (Tables 11.3 and 11.4). For the western Peninsula, waves were recorded in Albatross Bay 10 km west of Weipa between 1979 and 2009. Table 12.2 lists the monthly mean H_s and $T_{p,}$ which shows a distinctly seasonal variation. Waves are highest and longest during summer (January–March) and low the remainder of the year. Most of the year, waves average ~0.3 m with a 3 s period. However, during late summer they increase to 0.9 m and 7 s. This increase is a product on the onshore northwesterlies, plus the occasional tropical cyclone. Periods of higher waves which can last a few days have been recorded during December and January, with H_s reaching 3 m and H_{max} 7 m with periods to 12 s. These occasional high waves have a dramatic impact on the beach morphodynamics as will be discussed in Sect. 12.5. The higher energy nature of this coast is also indicated by the very limited extent of seagrass meadows. Poiner et al. (1987) found only 19 km^2 of meadows between Archer Bay and Crab Island (Van Spoult Head) which represents just 2% of the Gulf's seagrass communities.

12.1.3 Sediments

Beach sediments along the coast are predominately moderately sorted, medium sand averaging 22% carbonate (Table 12.3). There is however considerable longshore variation in sediment texture, particularly in swash grain size

Table 12.3 Dune and beach sediment characteristics for the western Cape York Peninsula region (PCs:QLD02.01 and 02.02)

	Dune	Swash
n	18	63
Size (mm)	0.34	0.27
σ (mm)	0.19	0.13
Sorting	0.5	0.83
σ (sorting)	0.09	0.36
% carbonate	16.5	21.7
σ (%)	8.7	11.9

(0.15–0.6 mm) and percent carbonate (1–62%) (Fig. 12.2a). The dune sands while more uniform in size (0.3–0.4 mm) are slightly coarser and consist of well-sorted, medium sand averaging 16.5% carbonate (Fig. 12.2b). In some locations thick shell beds have been deposited leading to the local formation of beachrock and shellrock (Fig. 12.3).

12.1.4 Beaches

Beaches occupy 745 km (73%) of the coast, the highest proportion for any region in northern Australia. The 148 beaches have an average length of 5 km, well above the Australian average of 1.3 km. They tend to be straight (embayment ratio = 0.9) and face west (mean = 251°). Compared to the southern Gulf, they are higher energy resulting in a relatively wide high tide beaches (mean = 31 m), with a moderate slope (mean = 5.6°), and narrower tidal flats (mean = 347 m) resulting in fewer ridges (mean = 4.8) on the ridged sand flats (Table 12.4). See Short (2006b) for a full description of the region's beaches.

12.1.5 Barriers

Barriers occupy 689 km (66%) of the shore, the remainder consisting of mangrove-lined tidal flats in the south and 5–20 m high red laterite bluffs north of Worbody Point, together with the many creek and river mouths. The barriers consist of regressive beach-foredune ridge plains averaging between 3.7 and 7.8 km wide in the southern QLD02.01 and 0.8–1.8 km wide in the northern QLD02.02 (Table 12.5). They are also relatively long averaging 19 km in the south and 13 km in the north, with their average height increasing from 4.6 m in the south to 6.3 m in the north. Many of the beaches and barriers recurve into the river mouths, and on the lower gradient sections of the coast, there are inner Pleistocene and outer Holocene barriers (as described by Smart 1976), separated by supratidal salt flats. The barriers are stable with minimal dune transgression (1%) as the stronger trade winds blow offshore. They are however exposed to storm surges and overwashing and flooding of the adjacent rivers and supratidal flats.

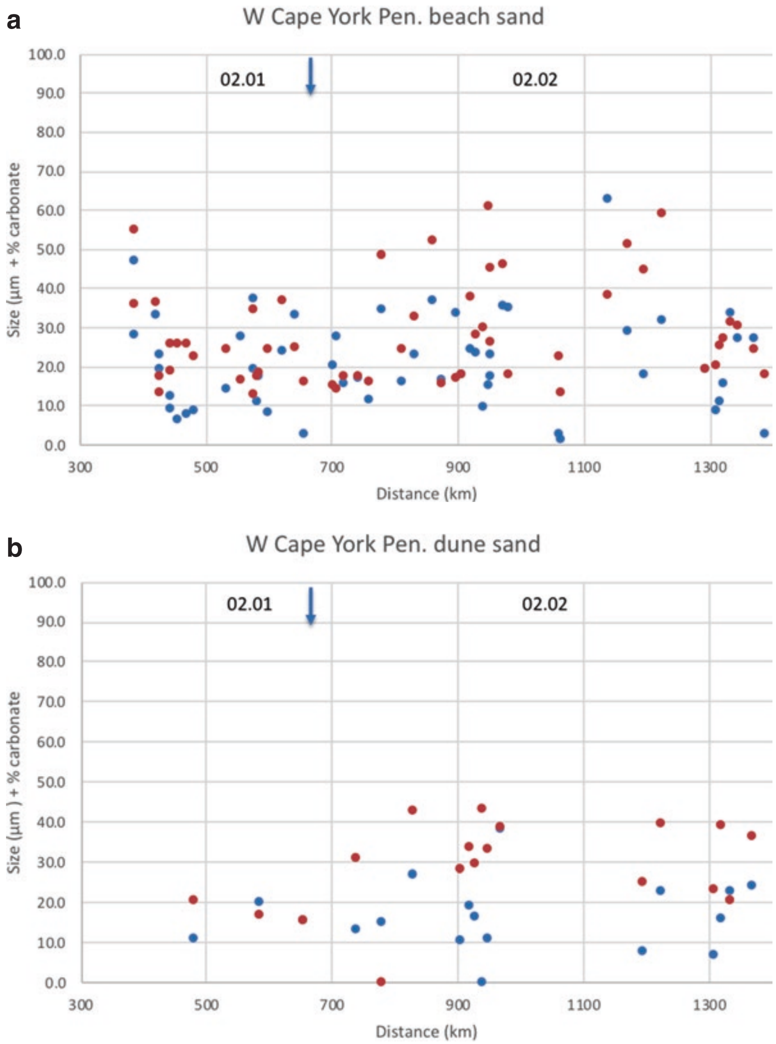

Fig. 12.2 Longshore variation in (**a**) beach; and (**b**) dune sand size (red, µm) and % carbonate (blue) in PCs QLD 02.01 and 02.02; distance from NT/QLD border; arrow indicated PC boundary

12.2 PC:QLD02.01 Karumba-South Mitchell River

The southern PC (QLD02.01) contains just one SC (QLD02.01.01), and both are combined in this discussion. The SC extends for 283 km between Karumba and the South Mitchell River (Fig. 12.4a), a relatively straight section of coast with a crenulation ratio of just 1.08. Waves average about 0.3 m, and the spring tide range

Fig. 12.3 A high concentration of shell-rich carbonate beach sediments has led to the formation shellrock, which occurs commonly along the western Peninsula coast, shown here at Hersey Creek (QLD 67). (Photo: AD Short)

Table 12.4 Beach characteristics for PCs:QLD02.01 and 02.02

	n	Mean	σ	Aust. mean[a]	Min	Max
Length (km)	745 km	5.0	7.2	–	0.05	50
Orientation (deg)	148	251	72	–	13	355
Embaymentisation	148	0.9	0.2	–	0.1	1.0
Gradient (deg)	148	5.6	1.0	–	3	12
Beach width (m)	148	31.0	14.3	–	10	50
Sand ridges (m)	22	4.8	4.0	7.2	2	20
Sand flats (m)	125	347	431	485	50	3000
Rock flats (m)	29	333	263	495	50	1000

[a]Source: Short (2006a)

is 4 m, producing an RTR of 13 and a transition from TD beaches in the south to a few TM beaches towards the northern end as wave height increases slightly. The 27 beaches average 7.5 km in length, with most bordered by tidal creeks or rivers. They occupy 202 km (71%) of this entirely sedimentary coast, the remainder occupied by mangrove-lined tidal flats and 24 creek and river mouths, including the Accident (1889 km^2), Smithburne (1003 km^2), Gilbert (42,148 km^2), Staaten (25,772 km^2) and Nassau (5797 km^2) rivers, all of which deliver terrigenous sediment to the coast during the summer wet.

Table 12.5 Western Cape York Peninsula: PC and regional barrier dimensions

Compartment/region	QLD02.01	QLD02.02	W Cape York
Number	10	36	46
Total length (km)	188	480.5	668.5
Mean width (m)	3770-7670	800-1830	800-7670
Mean height (m)	4.6	6.3	10.9
Area (ha)	88,000	100,705	188,705
Unstable (ha)	0	1188	1188
Total volume (M m^3)	4200	5475	9675
Unit volume (m^3 m^{-1})	22,340	11,394	14,052

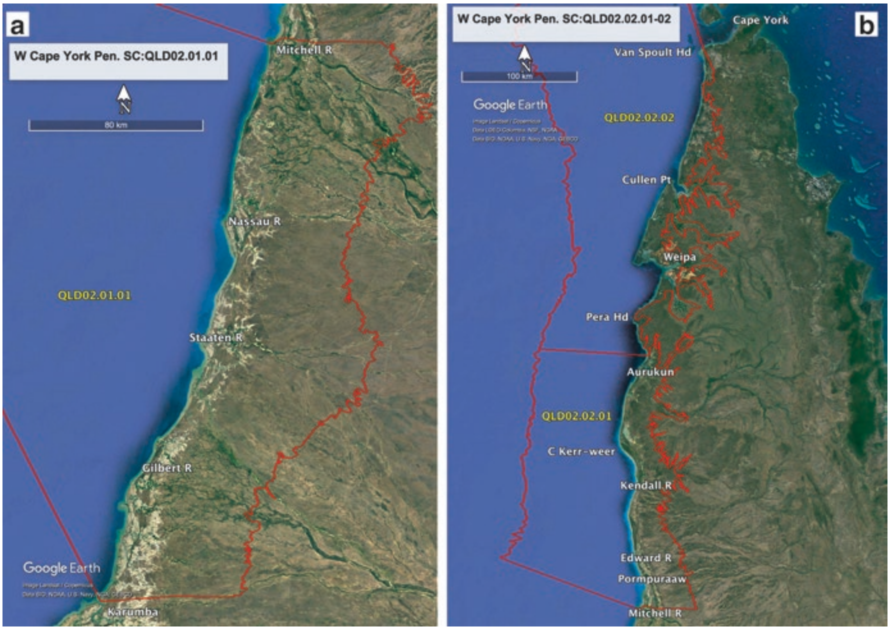

Fig. 12.4 (**a**) SC:QLD02.01.01 and (**b**) SCs:QLD02.02.01–02 extend the full length of the western coast of Cape York Peninsula. (Source: Google Earth)

In the south the TD beaches include B + SF (26%), B + RSF (27%) and B + TMF (8%) (Table 12.6) and mud flats. However, north of the Nassau River mouth, the higher wave energy switches the beaches to TM R + LTR. These rip-dominated beaches extend for 80 km all the way to the South Mitchell River with 320 beach rips usually present with an average spacing of 250 m. The formation of these rips is probably related to periods of higher wave energy as will be discussed in the next section.

There are ten relatively long wide barriers along this compartment (mean length = 19 km; width = 3.7–7.7 km) (Table 12.5). Most consist of inner Holocene

Table 12.6 PC:QLD 02.01 (southeast Gulf of Carpentaria) beach types and states

BS	BS	No.	%	Length (km)	%	Mean (km)	σ (km)
6	R	1	3.7	1	0.5	1.0	–
8	R + LTR	5	18.5	79.5	39.4	15.9	2.01
10	B + RSF	7	25.9	53.8	26.6	7.69	5.97
11	R + SF	11	40.7	52.1	25.8	7.74	4.9
13	B + TMF	3	11.1	15.5	7.7	5.17	4.45
		27	100	201.9	100		

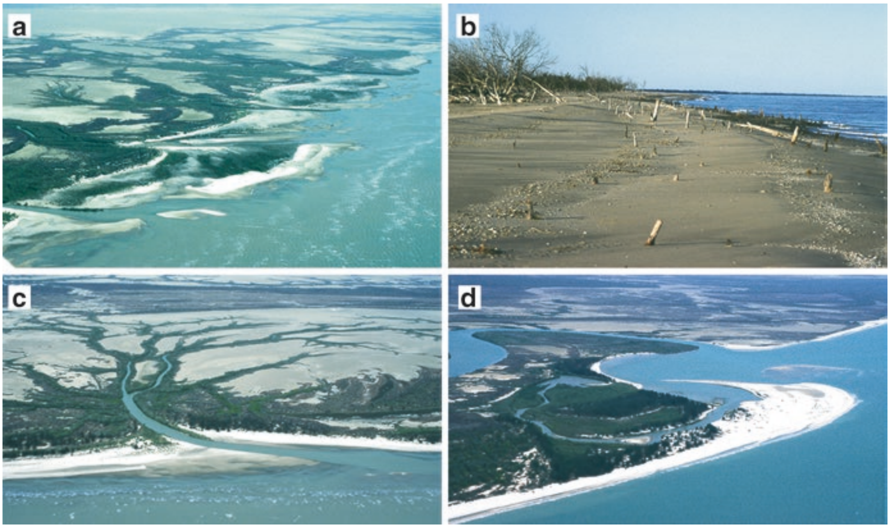

Fig. 12.5 SC:QLD02.02.01 coast: (**a**) very low energy tidal flat shoreline at Brannigan Creek (QLD 31); (**b**) dynamic and eroding river mouth beach at Duck Creek exposing mangrove roots (QLD 39); (**c**) typical mangrove-lined tidal creek draining Jacks Pocket (QLD 46–7); and (**d**) well-developed recurved spit at the mouth of the Mitchell River (QLD 56). (Photos: AD Short)

and outer Pleistocene regressive beach ridge plains, with the barriers and many of the ridges separated by salt flats (Fig. 12.5a). The low ridges average 4.6 m in height and are usually vegetated with *casuarina* trees. The barriers have a total volume of 420 M m^3, with a unit volume of 22,340 m^3 m^{-1}, with the relatively high volumes can be attributed to the initial shelf-derived sediment and particularly the ongoing fluvial supply. While this is a prograding coast, most of the low barriers and beach ridges are prone to overwashing during periods of elevated water levels and in particular tropical cyclone storm surges which are exacerbated by the elevated summer sea level. In addition, the creek and river mouths tend to be both migratory and dynamic leading to updrift accretion and downdrift erosion (Fig. 12.5b). Sediment transport appears to be predominately onshore with the river and creek mouths showing evidence of both southerly and northerly transports.

12.3 PC:QLD02.02: South Mitchell River-Van Spoult Head

The northern PC (QLD02.02) continues north of the South Mitchell River to the northwest tip of the Peninsula at Van Spoult Point, a distance of 732 km. It contains two SCs (QLD02.02.01 and 02 (Table 12.1 and Fig. 12.4b)). Apart from Albatross Bay at Weipa, the coast is a relatively straight coast, with a crenulation ratio of 1.55. Beaches occupy 544 km (74%) of the coast and barriers 480 km (66%), the remainder occupied by bright red laterite bluffs, usually less than 20 m high, and 42 creek and river mouths, including 11 generally small rivers. These are from the south of the Edward (8092 km^2), Kirke (1365 km^2), Archer (16,310 km^2), Mission (1290 km^2), Pine (535 km^2), Ducie (3454 km^2), Skardon (353 km^2), Jackson (1699 km^2), MacDonald (212 km^2), Doughboy (525 km^2) and Crystal (353 km^2). The decrease in catchment size can be attributed to the decreasing width of the Peninsula towards the north.

While the waves average only 0.3 m (T = 3 s), the coast is exposed to periods of higher waves (Table 12.2) which are sufficient to imprint themselves on the beach and surf zone morphology on the most exposed beaches. The beach morphology then remains largely intact during the ensuing predominately lower energy periods, the energy too low to significantly rework the higher energy bar and beach morphology. The results are manifest in the range of beach types discussed below.

With a mean wave height of 0.3 m and tide range ranging between 2.5 and 3.5 m, the RTR ranges from 8 to 12, the transition from TM to TD. The periods of higher 3 m + waves (T = 8–11 s) however temporally shift the RTR to 1 and into the WD domain. These conditions produce a highly rhythmic WD RBB, the rhythmic topography imprinted both on the bar and beach morphologies (Fig. 12.6). As Table 12.7 indicates, TM R + LTT (38%) and R + LTR (26%) dominate the shore, being the TM version of the RBB which the beach reverts to once the higher waves decrease. There are usually a total of 620 beach rips operating along the 144 km of rip-dominated shore, with rip spacing averaging 220 m (σ = 80 m). The lower

Fig. 12.6 (**a**) Highly rhythmic beach and (inactive) bars and (**b**) beach megacusps extending north of Jantz Point (both QLD 140). (Photos: AD Short)

Table 12.7 Western Cape York Peninsula PCQLD02.02 beach types and states

BS	BS	No.	%	Length (km)	%	Mean (km)	σ (km)
6	R	6	5	7.3	1.3	1.22	0.63
7	T + LTT	20	16.7	205.7	37.8	10.29	12.92
8	R + LTR	14	11.7	143.9	26.4	10.28	9.36
10	B + RSF	12	10.0	36.95	6.8	3.08	2.37
11	B + SF	38	31.7	108.0	19.9	2.48	3.24
12	B + TSF	20	16.7	16.5	3.0	0.83	0.64
13	B + TMF	6	5.0	18.5	3.4	3.7	2.33
14	R + EF	4	3.3	7.25	1.3	1.81	1.8
		120	100	544.2	100	33.69	

energy sections have TD B + RSF (7%), B + SF (20%), B + TSF (3%) and B + TMF (3.4%) flats, together with 7 km (1.2%) of beaches fronted by laterite rock flats. While this is a lee shore during the stronger winter trade winds, it has some of the highest energy beaches in the Gulf owing to the prolonged (days) periods of long, high waves, probably generated by occasional tropical cyclones.

There are 36 barrier systems located along this PC, which have an average length of 13.4 km and width between 0.8 and 1.8 km (Table 12.4), with larger inner Pleistocene and outer Holocene regressive beach-foredune ridge plains in the north and south, some containing up to 70 ridges (Fig. 12.7a). Along the central section, they tend to be narrower averaging 6.3 m in height, with the majority consisting of several up to as many as 20 foredune ridges. Many of the ridges terminate as dynamic recurved spits at the creek and river mouths (Fig. 12.7c and d). The barriers have a total volume of 547 M m^3, with a unit volume of 11,394 m^3 m^{-1}. As the prevailing winds blowing offshore (Fig. 12.8), dune transgression is absent from the coast.

Rhodes (1980, 1982) investigated the regressive beach-foredune ridge barriers at Edward River (QLD 63) and Christmas Creek (QLD 66). The 12 Edward River ridges and 25 Christmas Creek ridges sit on top of low tide and subtidal muds. The inner ridges date ~5 ka, the outermost Christmas Creek at 1.5 ka, and the Edward River at 0.16 ka. Rhodes estimated they prograded seaward at rates between 0.5 and 1.5 m $year^{-1}$ for Christmas Creek and 0.4 and 1.6 m $year^{-1}$ for Edward River, while the seaward sloping boundary between the mud and sand of the ridges indicated a ~1 m fall in sea level during the past 5 ka.

Eighty kilometres to the north, Smart (1976) found the beach ridges at Cape Keerweer (QLD 74) consist of an inner Pleistocene ridge 4–5 m above sea level which dates ~120 ka and an outer Holocene barrier. The outer barrier underwent rapid progradation from 7 to 6.5 ka, becoming a barrier island-lagoonal complex between 6 and 4 ka, with 6 km of rapid mud flat-chenier progradation between 4 and 1.25 ka, with the outer ridge dating 1.25–0 ka. The switch from lagoonal to mud flats and rapid progradation would agree with Rhodes proposed fall in sea level, which is also supported by Woodroffe and Chappell (1993) and Jones et al. (2003).

Fig. 12.7 PC:QLD02.02 coast: (**a**) a regressive barrier fronted by dead and live mangroves at Malaman Creek (QLD 61); (**b**) the reflective beach at Boyd Point is backed by 10 km high laterite bluffs (QLD 102); (**c**) longshore transport has deflected Trillick Creek 12 km to the north, with a series of foredune ridges extending east of the creek (QLD 112); and (**d**) the highly irregular mouth of Crystal Creek is a product of wave and tide processes (QLD 171). (Photos: AD Short)

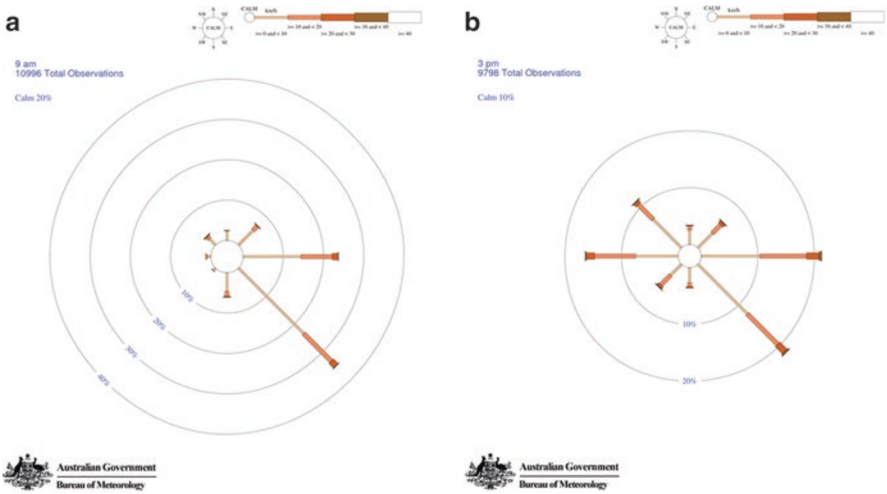

Fig. 12.8 Weipa 0900 and 1500 wind roses. (Reproduced with permission of Bureau of Meteorology, © 2018 Commonwealth of Australia)

Lees et al. (1993) investigated the 2.5 km wide barrier to the south of the Pennefather River (QLD 141). They found that the barrier contains three episodes of dune transgression, with the inner dunes dating 11.2 ka indicating it accompanied the marine transgression. They then proposed that two latter episodes of dune transgression occurred at 8.3 ka and 5.2 ka both triggered by the rising sea level. These would all predate the subsequent fall in sea level proposed by Rhodes (1982).

The southern SC:QLD02.02.01 trends due north for 239 km between the South Mitchell River and Worbody Point. It contains two large protrusions where the rivers have fanned out delivering sediment to the coast during the Quaternary. The southern protrusion contains the Coleman-Edward-Holroyd-Kendall rivers, the northern series of creek and the Kirke and Archer rivers. This is a near continuous sedimentary coast, with the beaches occupying 92% of the shore, the remainder river and creek mouths. Likewise, the regressive barriers occupy 87% of the shore. Sediment transport is predominately northwards.

The northern SC:QLD02.02.02 continues north to Van Spoult Head but is interrupted by the large Albatross Bay and Port Musgrave. While the open coast is dominated by beaches and barriers, mangroves occupy much of the bay shores. Beaches occupy 66% of the shore and regressive barriers 53%, the remainder a mix of mangroves, laterite bluffs and creek and river mouths. While sediment transport is predominately northwards, there are reversals at many creek mouths. The region however terminates at the end of a 40 km long series of inner and outer north-trending spits that have combined to form the protruding sandy Van Spoult Head.

12.4 Regional Overview

This is a relatively long straight sediment-rich coast, with meso-tides and wave energy increasing northwards, together with short periods of high waves (>3 m). Seventy creeks and 19 small- to moderate-sized rivers deliver sediment to the coast, with beach sand rich in terrigenous material. The shoreline is predominately sandy (53% beaches and 65% barriers), with only a few sections of mangroves in the south and in the northern bays, while in the north low laterite bluffs and reefs occupy the points and back some of the beaches, the remainder river and creek mouths. Sediment transport has been onshore with the sea-level rise, point source with the rivers and longshore to both the north and south along the beaches. However, based on the orientation of the many creek and river mouth spits, it is generally to the north, with some local reversals, particularly on the south side of some of the river mouths, with northerly rates estimated to be on the order of 10,000–30,000 m^3 $year^{-1}$.

Rising sea level will have a range of impacts on this coast. The elevated laterite bluffs have a low level of vulnerability, though they will be exposed to increased bluff erosion. The generally low barrier plains (~6 m elevation) will be moderately exposed particularly during tropical cyclone storm surges which are predicted to be between 2 and 3 m along this coast (Fig. 1.14). The highest level of vulnerability will be associated with the creek and river mouths and the extensive inter- and supratidal flats they drain. These will become increasingly inundated leading to as Asbridge et al. (2016) predicts an expansion of the mangroves along the tidal creeks and rivers and ultimately onto the supratidal flats.

References

Asbridge E, Lucas R, Ticehurst C, Bunting P (2016) Mangrove response to environmental change in the Gulf of Carpentaria. Ecol Evol 6(11):3523–3539

Jones BG, Martin GR, Senapati N (1993) Riverine-tidal interactions on the monsoonal Gilbert River fan delta, Northern Australia. Sediment Geol 83:319–337

Jones BG, Woodroffe CD, Martin GR (2003) Deltas in the Gulf of Carpentaria, Australia: forms, processes and products. SEPM Special Publ 76:21–43

Lees BG, Hayne M, Price D (1993) Marine transgression and dune initiation on western Cape York, northern Australia. Mar Geol 114:81–89

Poiner IR, Staples DJ, Kenyon R (1987) Seagrass communities of the Gulf of Carpentaria, Australia. Aust J Mar Freshwater Res 38:121–131

Rhodes EG (1980) Modes of Holocene coastal progradation, Gulf of Carpentaria. Ph.D. thesis, Department of Biogeography and Geomorphology, ANU, Canberra

Rhodes EG (1982) Depositional model for a chenier plain, Gulf of Carpentaria, Australia. Sedimentology 29:201–222

Short AD (2006a) Australian beach systems – nature and distribution. J Coast Res 22:11–27

Short AD (2006b) Beaches of the Northern Australia coast: the Kimberley, Northern Territory and Cape York. Sydney University Press, Sydney, 463 p

Smart J (1976) The nature and origin of beach ridges, western Cape York Peninsula, Queensland. BMR J Aust Geol Geophys 1:211–218

Woodroffe CD, Chappell J (1993) Holocene emergence and evolution of the McArthur River delta, southwestern Gulf of Carpentaria, Australia. Sediment Geol 83:303–317

Websites

https://data.qld.gov.au/dataset/coastal-data-system-historical-wave-data

Chapter 13
Northeast Division

Abstract The northeast division extends from Cape York for 4205 km to Hervey Bay-Fraser Island. This is a long division unified by its humid tropical to subtropical climate, onshore trade winds and protection afforded by the Great Barrier Reef. The coastal orientation and structure is controlled by its geology, a mix of blocks and basins, all paralleled by the eastern highlands, from which several moderate to large rivers and numerous streams flow to the coast depositing deltas and supplying terrigenous material, with beach sediments a combination of shelf and terrigenous (fluvial) quartz sand. Waves are low to moderate, and tides range from meso to mega and beaches from tide-modified to tide-dominated. Barrier type depends on exposure and ranges from cheniers to massive Pleistocene and Holocene transgressive dunes. Sediment transport is northwards though interrupted by numerous obstacles including headland, changes in coastal orientation and rivers and inlets. This chapter describes the northeast's geology, climate, coastal processes, sediment supply and transport, beaches and barriers.

Keywords Cape York Peninsula · Northeast Australia · Humid tropics · Trade wind · Great Barrier Reef · Beaches · Barriers

13.1 Introduction

The northeast division extends from Van Spoult Head near the tip of Cape York Peninsula, south along the east Queensland coast to Sandy Cape at the northern tip of Fraser Island in Hervey Bay, a distance of 4205 km (Fig. 13.1). It contains all the east Queensland coast in lee of the Great Barrier Reef (GBR) and in the far south, in lee of Fraser Island, occupying 69% of the entire Queensland coast, including 90% of the east Queensland coast. This is a long and highly variable division that contains 2 regions (Table 13.1), 12 PCs and 55 SCs. The division also contains 1357 beaches, which occupy 2091 km or 50% of the coast, the remainder made up of rocky shore, mangrove-lined tidal flats and river and creek mouths. This chapter will provide an overview of the division's geology, climate and coastal processes,

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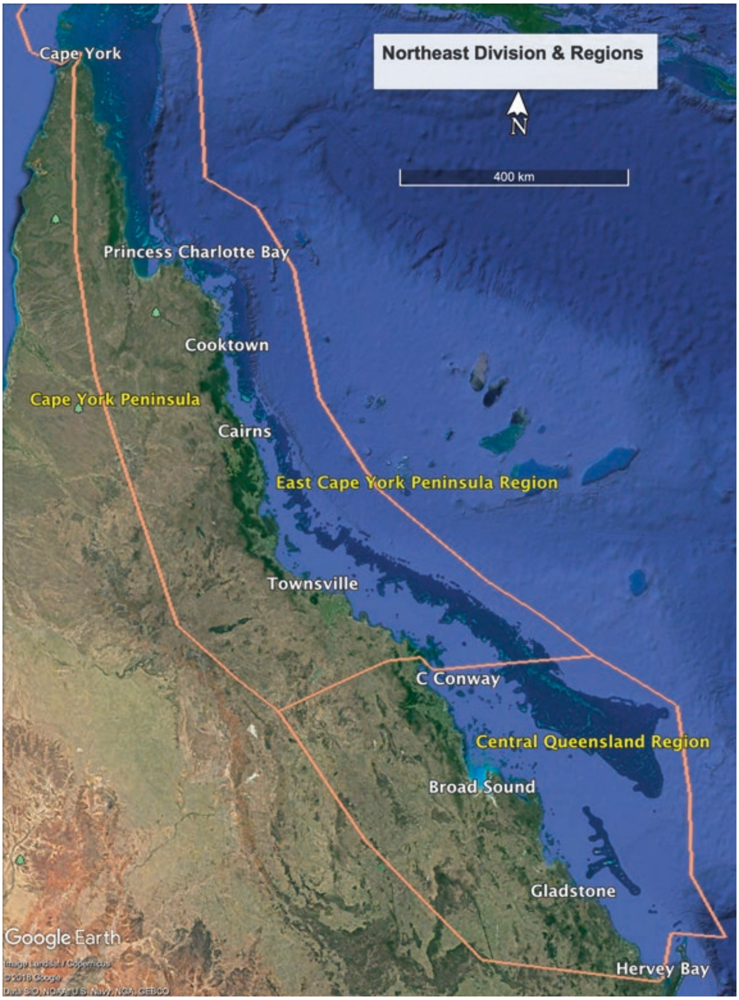

Fig. 13.1 The northeast division extends from Cape York to Hervey Bay and has two regions, the eastern Cape York Peninsula (QLD03) between the Cape and Cape Conway and central Queensland (QLD04) between Cape Conway and Hervey Bay. (Source: Google Earth)

with the regions PCs and SCs presented in Chaps. 14 and 15. For a general overview of the coast, see Hopley and Smithers (2003).

13.2 Queensland Geology

The geology of eastern Queensland is a combination of the easternmost part of the ancient Australian Craton and the younger accretionary orogens of the Tasman Fold Belt (Fig. 1.2). The great Australian Craton, which encompasses all of western and

Table 13.1 Northeast division and regions (QLD 03 and 04)

Region/ comp. no.[a]	Region	Primary compartment boundaries	Beach ID[b]	No. beaches	km[c]	Total km
QLD 03	Eastern Cape York Peninsula	Van Spoult Pt - C. Conway	QLD 178-1037	860	1399–3777	2378
QLD 04	Central Queensland	C. Conway - Sandy Cape+W Fraser Is	QLD 1037-1527	497	3777–5492	1827
			FIs 11–17			
	Division total			**1357**		**4205**

[a]NCCARF compartment number
[b]ABSAMP beach ID, FIs = Fraser Island
[c]Distance from NT/QLD border

central Australia, extends to the northeast to include much of western and northern Cape York Peninsula, including the Carpentaria Basin and the Cape York and Coen Inliers. To the east and south of these inliers runs the Tasman Line, east of which the eastern third of Australia accreted in a series of orogens, or episodes of mountain building, over the past 600 Ma. This is known generally as the Tasman Fold Belt. Figure 13.2 illustrates the geological elements of the coast, while Table 13.2 lists the elements and their age, coastal location and major rock types.

13.2.1 Geological Evolution

The Queensland coast has a long and interesting geological history which is reviewed by Wellman (1997). The bedrock that forms the headlands and cliffs ranges from 1500 Ma to 100 Ma in age, while the coastline began taking on its present shape between 75 Ma and 50 Ma. The evolution of the coast can be divided into three broad geological periods. Four hundred million years ago, the Queensland region consisted of ancient low-lying shield rocks in the western Peninsula and Gulf regions, while the entire eastern third of Australia from the Peninsula to Tasmania was deep ocean. Sedimentation was active in this region until about 200 Ma.

During and following this marine phase were two periods of tectonic activity. The first, between 300 Ma and 200 Ma, included a volcanic chain extending from Bowen south to Newcastle, with the Bowen and Moreton marine sedimentary basins located to either side. This was followed by a period of continental stability until 100 Ma. During this period the massive Gondwanaland complex, centred on Antarctica, of which Australia was part, began to break up about 155 Ma. Australia separated from Antarctica about 100 Ma and began moving northwards at a rate of 5–6 cm year^{-1}. This initiated the opening of the Southern Ocean, followed by rifting that commenced in the Bass Strait region about 85 Ma and spread north, opening up the Tasman and southern Coral Seas by 60 Ma and forming the eastern seaboard of southeast Queensland and NSW. Finally, about 50 Ma rifting in the northeast region opened up the remainder of the Coral Sea (Fig. 13.3).

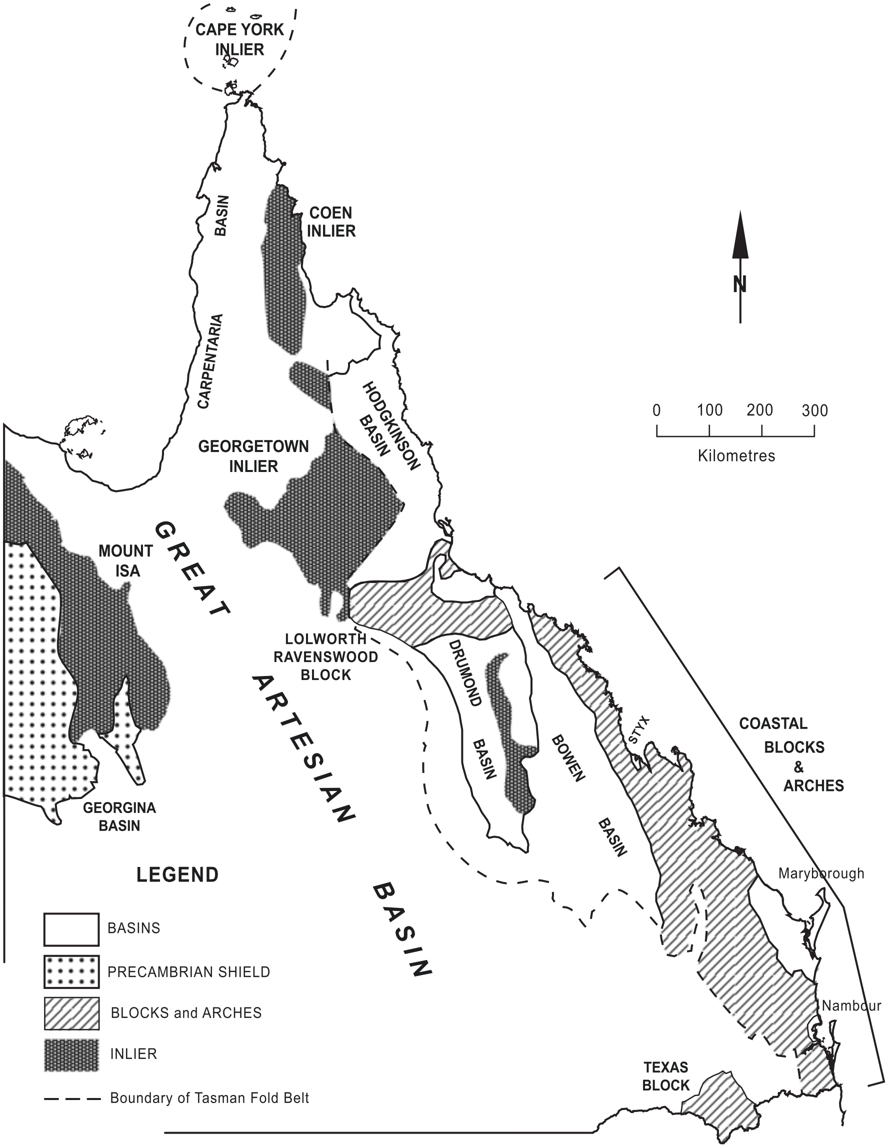

Fig. 13.2 Major geological units of the Queensland coast. (Source: Short 2000)

The two periods of rifting also resulted in the uplift of the eastern highlands and associated volcanic activity along the Great Dividing Range. The present geology east of the range, including the coast and continental shelf, consists of a series of uplifted basins (Laura, Hodgkinson and Bowen), separated by higher block and arch regions (Ravenswood and coastal blocks) (Fig. 13.2), with the drainage divide located relatively close to the coast. The coastal geology is discussed below.

Table 13.2 Queensland coastal geology (north to south)

Coastal geological element (west to east)	Age (Ma)	Coastal location/ boundaries	Rock types
Arunta Craton:			
Great Artesian Basin/ Carpentaria Subbasin	180–100	NT border-W Cape York Pen.	Continental and marine sediments
Precambrian Shield			
Cape York Inlier	300	Torres Strait (high islands)	Granite and metamorphic
Coen Inlier	1500	Temple Bay-Cape Sidmouth	Clastic and chemical sediments, volcanics
Laura Basin	180–100	Princess Charlotte Bay	Continental and marine sediments
Tasman Fold Belt:			
North Coast Structural High (Hodgkinson Basin)	410–350	Cape Melville-Hinchinbrook Is	Volcaniclastic and carbonate sediments, volcanics
Lolworth-Ravenswood Block	500	North Halifax Bay	Volcanics and clastic sediments
Burdekin Basin	370–320	Mid Halifax Bay	Clastic and carbonate sediments
Bowen Basin	270–200	Townsville-Upstart Bay	Clastic sediments, limestone
Connor Arch	350	Cape Upstart to Bowen	Volcanics
Strathmuir Syncline	270	Edgecumbe Bay	Volcaniclastic
Campwyn Block	360–250	Gloucester Is-Broad Sound	Volcaniclastic sediments, limestone
Whitsunday Block	130	Whitsunday Islands and Coast	Volcanics
Styx Basin	130	St Lawrence (Broad Sound)	Clastic sediments
Stanage Block	410–370	Long Island (Broad Sound)	Volcanics, limestone
Coastal Block	400–300	Stanage Point-Rodds Bay	Arenite, chert, basalt, conglomerate, limestone
Gympie Block	270–200	Rodds Bay-Wreck Pt and Caloundra	Clastic sediments, volcanics, limestone
Maryborough Basin	200–100	Wreck Pt-Coolum	Clastic sediments and volcanics
Nambour Basin	200–160	Moreton Bay	Clastic sediments
Beenleigh Block	400–300	Gold Coast	Arenite, chert, basalt, conglomerate, limestone

Major source: Day et al. (1983)

13.2.2 Coastal Geology

The oldest rocks in Queensland are generally not exposed at the coast. They lie in three areas of ancient *Precambrian Shield* located in the northern part of the state, namely, the Mt. Isa-Cloncurry area (1700 Ma), the Georgetown region and the Cape York (300 Ma) and Coen Inliers (1500 Ma) (Figs. 2.1 and 13.2). The *Cape York Inlier* forms the granitic high islands of Torres Strait including Prince of Wales, Thursday and Horn islands, as well as Cape York itself. The granites were intruded during the Carboniferous and subsequently exposed by erosion. The Holocene flooding of the Strait left the high points as bedrock islands.

The *Coen Inlier* is exposed on the east coast between Temple Bay and Cape Sidmouth and contains the oldest rocks on the Queensland coast. The rocks date from 1500 Ma and are granitic at the coast grading inland to volcanics, clastic and chemical sediments.

The large *Tasman Fold Belt* commences south of the Coen Inlier and initially consists of a sequence of uplifted basins (Laura, Hodgkinson, Burdekin and Bowen) and then a long section of folded blocks and arches that dominate much of the coast between Cape Upstart and the NSW border. In amongst the blocks are the small Styx Basin, around St Lawrence, and the Marlborough and Nambour Basins in the southeast (Table 13.2).

The *Laura Basin* is centred on Princess Charlotte Bay with deposits extending from Cape Sidmouth to Bathurst Bay. It contains continental and marine sediments between 180 and 100 Ma in age. The *Hodgkinson Basin*, also known as the Peninsula Ridge, contains north-trending Palaeozoic volcaniclastic and carbonate sediments deposited between 410 and 350 Ma and uplifted during the opening of the Coral Sea about 50 Ma (Fig. 13.3). These now form a ridge of high rocks extending south from Cape Melville to Hinchinbrook Island and include many prominent headlands including Cape Melville, Cape Flattery, Cape Bedford and Cape Grafton.

The structural trend of the rifting and the rocks of the Tasman Fold Belt is north-northwest to south-southeast. This trend is evident in the orientation of the entire east coast, as well as the trend of many structural and drainage systems along the coast, which often form large north-facing bays (e.g. Broad Sound, Shoalwater Bay, Princess Charlotte Bay). These bays contain a range of shorelines from very sheltered low energy to exposed higher energy and are major obstacles to the generally northerly longshore sand transport. The structural trends extend offshore, with the shelf geology related to the onshore geology.

13.2.3 Great Barrier Reef

Corals began growing on plateaus in the Coral Sea as it formed during the period of rifting that opened up the sea (Fig. 13.3), with the earliest reef deposits dating back 60 Ma. Extensive coral growth began about 30 Ma and by 18 Ma was well

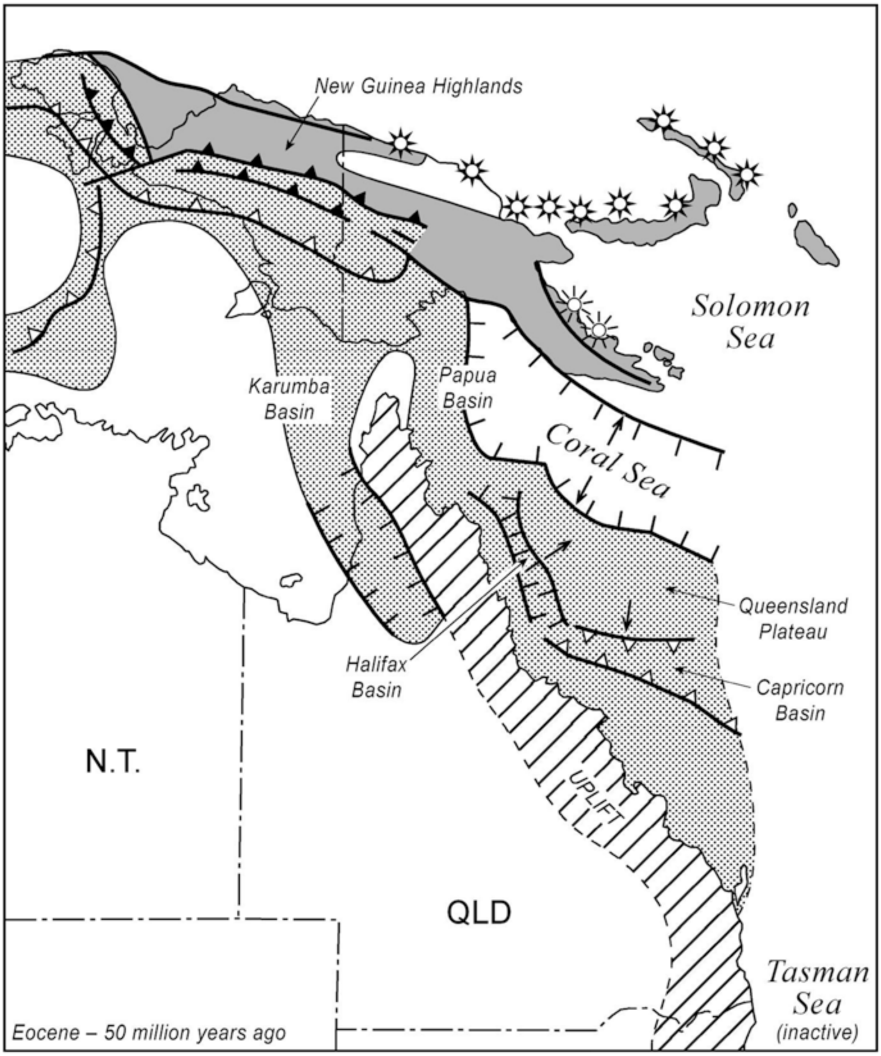

Fig. 13.3 Seafloor rifting during the Eocene (~50 Ma) led to the opening of the Coral Sea, together with deepening (shading) of the Capricorn and Karumba basins and uplift of the Eastern Highlands. The general shape of the Queensland coast evolved about this time. (Source: Short 2000)

established along the subsiding Queensland continental shelf. Shelf subsidence continued until about 1 Ma, by which time coral reefs occupied essentially the entire GBR area (Hopley et al. 2007). The long history of the GBR attests to its resilience during periods of both climate change and fluctuating sea level.

Today the GBR extends from the Torres Strait at 9°15′S to Lady Elliot Island at 24°07′S, a distance of about 2300 km, and covers an area of 230,000 km^2 with the outer reefs lying between 23 km and 260 m east of the coast (Fig. 13.4). The reef

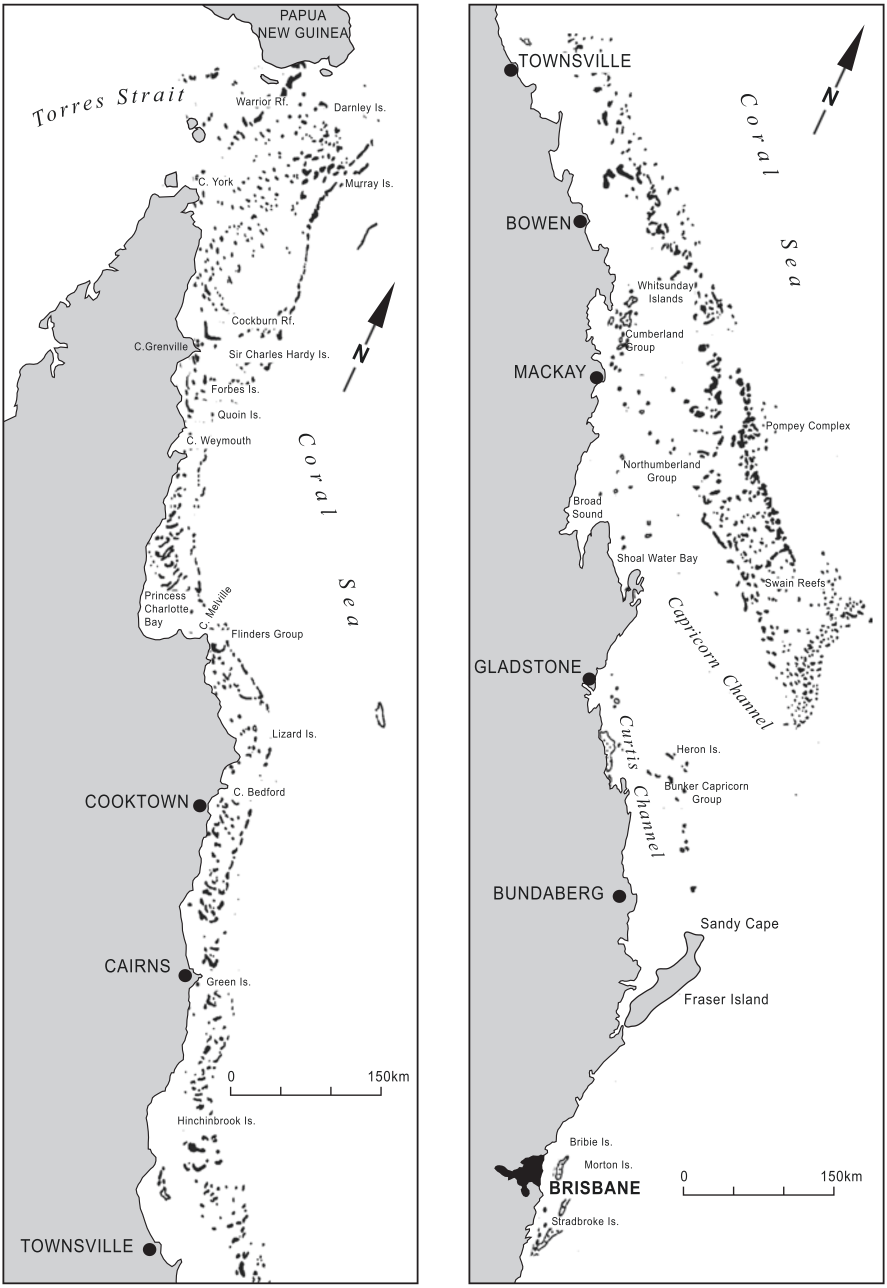

Fig. 13.4 The Great Barrier Reef consists of about 2500 coral reefs and islands located across and along the outer edge of the continental shelf. (Source: Short 2000)

contains over 2500 individual reefs ranging in size from small reefs to larger reefs up to 25 km long and 125 km^2 in area.

While this book is not directly concerned with the GBR, the GBR does have a tremendous impact on the coast and beaches of Queensland between Torres Strait and Bundaberg. The GBR, combined with Fraser Island, essentially prevents ocean swell from reaching the mainland coast, resulting in a lower energy coast. For a detailed and excellent study of the GBR and its geomorphology, see Hopley et al. (2007).

13.2.4 Geology, Sediments and Beaches

The geology of the northeast division provides the structure that is the Queensland coast. In addition, the bedrock forms approximately 2890 km of the coast, much of which is exposed as headlands, bluffs and cliffs, while 350 'high' rocky islands, such as the Whitsunday Group, lie off the coast. On the Queensland coast where beaches average about 2 km in length, many are bounded by prominent rock headlands, while others occupy drowned coastal river valleys. The bedrock or geology therefore provides what is called the coastal boundary within which, or on which, the coastal sediments are deposited.

The hinterland geology is also a source of much of the beach sand. Most beaches on the mainland coast are composed predominantly of quartz (silica) sand grains (75–90%), together with other heavy minerals and rock fragments. These sediments originated in the coastal hinterland and have been delivered to the east coast by 32 rivers and over 200 smaller creeks and streams (see Sect. 13.7), in addition to minor local sources from eroding headlands. The river sediments have two routes to the modern shoreline. Some have been delivered to the coast and continental shelf during periods of lower sea level and subsequently, during periods of rising sea level, moved by waves on- or alongshore to be deposited as beaches and dunes and in estuaries. This is particularly the case in southeast Queensland, where the great sand islands have been built up over the past two million years by successive layers of sand added during each rise in sea level. In addition, along most of the coast, many rivers and streams are also supplying Holocene sediment directly to the coast, particularly during floods, continuing to build out the numerous river and stream mouths and supply the adjoining beaches with sand (Fig. 13.5). The regional and hinterland geology is therefore the major source of sand for all Queensland's mainland and most high island beaches, while the inner continental shelf is also dominated by river-derived sediments.

Salles et al. (2018) developed a model of Holocene sedimentation and coral growth along the northeast coast whereby during the PMT, high sediment loads were delivered to the shelf preventing coral growth during the early transgression phase. This was followed by limited shelf sedimentation after ~6 ka which allowed coral reefs to thrive. After 3 ka reduced vertical reef growth has led to lateral reef extension.

Fig. 13.5 The mouth of the Pascoe River showing the sand-filled river and extensive ebb tide delta (QLD 393-4). (Photo: AD Short)

The outer continental shelf and the low coral-algal islands have a very different source of sediments. The low islands are a product of coral and algal growth over the past 7 ka, and these organisms not only build up the islands but as they erode supply carbonate detritus to be deposited on the island beaches, lagoons and adjacent shelf. Therefore, unlike the predominately quartz-rich mainland beaches, the low islands are dominated by locally produced coral, algal and shell detritus and often have sands that are 100% carbonate. Finally, wherever fringing reefs occur along the coast (Fig. 13.6), they also supply carbonate material to the adjoining mainland beaches leading to a mixture of quartz and carbonate sands, with the mainland beaches averaging between 10% and 25% carbonate material, but significantly higher in lee of fringing reefs.

Queensland's beaches are therefore closely intertwined with the longer-term geological history and setting of the coast and continental shelf and, in the case of the GBR, with the biological production on the shelf. On the mainland and high islands, the geology provides the basic boundaries, shape and often the bulk of the beach sand, while on the low islands, the geology provided the shelf foundations for the reefs, while the reefs themselves provide the structure and sediments that make up the massive reef systems their cays and beaches.

Fig. 13.6 Beach fronted by a fringing coral reef near Hunter Creek (QLD 293), with tidally driven north-trending transverse sand waves extending seawards of the reef. The sand waves are a permanent feature of this section of coast. (Photo: AD Short)

13.3 Climate

The general climate of northern Australia has been presented in Chap. 2. This section focuses on the climate of the northeast division which extends down the east Queensland coast from the tropics to the sub-tropics (10–25°S). This is a windward coast dominated by the prevailing humid southeast trade winds. The summer climate is characterised by hot, humid conditions and periods of heavy rain and exposure to tropical cyclones. The winters are warm in the north with extended dry periods, particularly in the Gulf and on the Peninsula, while conditions are milder in the southeast, with some rain occurring along the eastern coastal fringe.

13.3.1 High-Pressure Systems

The sub-tropical high-pressure system dominates Australia's climate including the northeast. In summer the high is centred around 36°S allowing the equatorial low to centre itself over west-central Queensland. On the northern side of the low, the northwest monsoons bring summer rain to the Gulf and Peninsula. The counter-clockwise flow of air around the high also delivers a southeasterly flow of humid Coral Sea air onto the east coast, also attracted by the inland low pressure. The moist air brings humid conditions and summer rain to the east coast. In winter the low moves to the northern hemisphere, and the high moves north to 30°S, centred below the Queensland border. Queensland is largely impacted by the northern and northeast section of the high-pressure systems, which is manifest by a broad strong flow of southeast to easterly air, originating in the Tasman and Coral Seas bringing light to moderate winter rainfall.

The rainfall along the coast varies from a low of 600 mm in the southern gulf, with most of this rain falling in summer, to a maximum of over 3000 mm in the Cairns-Tully region. Figure 1.5 shows the annual rainfall for Queensland, with its distinctive coastal maximum. The rainfall maximum for the entire state occurs in summer in association with the monsoons in the Gulf, the trades along the east coast and occasional tropical cyclones. Rainfall peaks along the coast and in the Cairns-Tully region (>3000 mm), decreasing northwards and particularly to the south. Cairns (16.9°S) has a tropical humid climate (Koppen: Am) with 2000 mm of precipitation, 75% of which fall during the summer (November–March) months. Townsville (19.25°S; 1135 mm) has a tropical savanna climate (Aw) and receives 84% of its rainfall in summer. Rockhampton (23.4°S; 812 mm) has a humid subtropical climate (Cfa) and receives 68% of its rainfall during summer (Fig. 1.5a). Temperatures along the coast range from the high 20s to low 30s during summer to the mid-20s during winter (Fig. 1.5c, d).

The southeast trades are the most dominant feature of Queensland weather systems and the source of most of the wind and wave energy along the east and Gulf coasts, particularly in the winter months (Figs. 1.7 and 13.7). In summer the trade winds dominate south of Cooktown, while the northwest monsoons dominate in the Gulf and northern Peninsula. In winter the trade winds increase in velocity and dominate the entire state north of Mackay, while to the south, southwesterly winds increasingly dominate, associated with the southern half of the high-pressure system.

13.3.2 Sea Breeze Systems

The entire coast is impacted by onshore sea breezes particularly during the warmer summer months. Around the Queensland coast, the direction of the sea breeze depends on coastal orientation. They are predominantly southeasterly along the east coast, while they are westerly on the western Peninsula shore (Fig. 13.8). The sea breezes are more frequent and intense in summer and consequently make an important contribution to the Queensland coastal environment, particularly through the generation of low seas, which reinforce the trade winds on the east coast and monsoonal winds on the west coast.

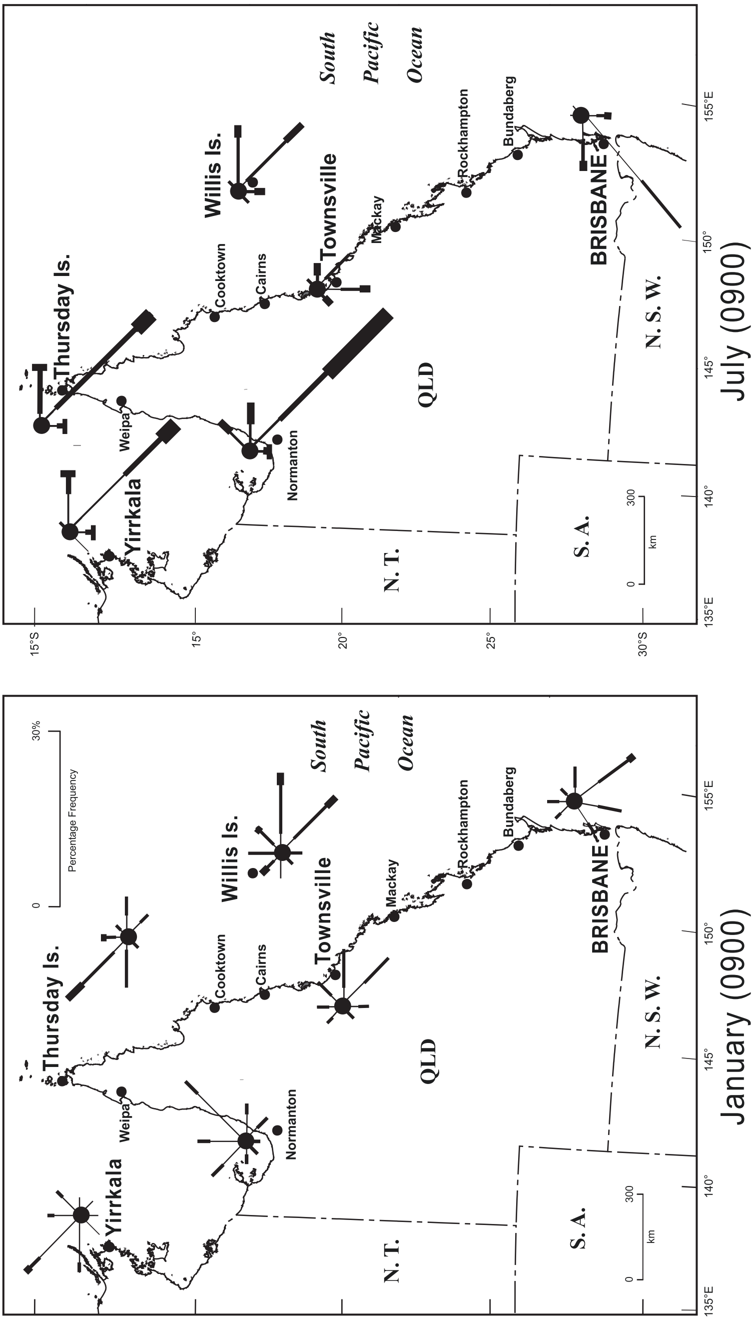

Fig. 13.7 Queensland wind roses for 9 am January and July. (Source: Short 2000)

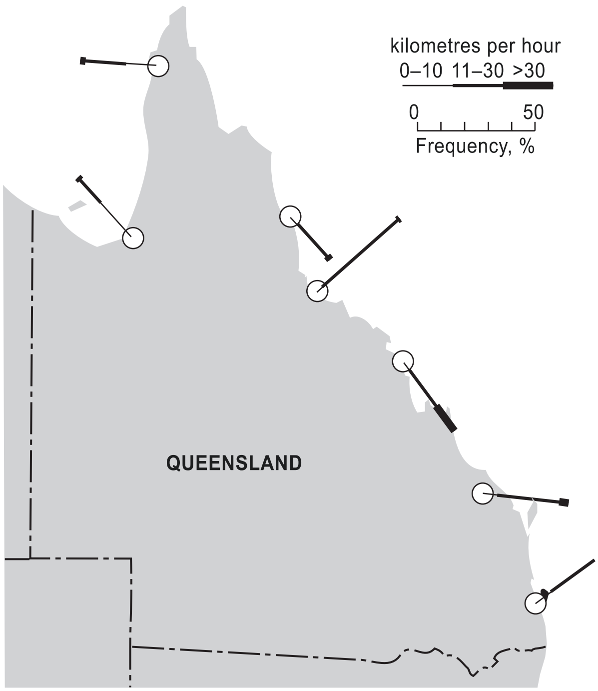

Fig. 13.8 Afternoon (15.00) wind roses along the Queensland coast. (Source: Short 2000)

13.3.3 Cyclonic Systems

In addition to the high-pressure systems, three types of low-pressure cyclones impact on the Queensland coast. They are summer tropical cyclones which form in the northern Coral Sea and Gulf and directly impact the coast, east coast cyclones or lows which form off the NSW coast and midlatitude cyclones which track across the Southern Ocean. The east coast and midlatitude cyclones only deliver swell to the more exposed sections of the eastern and southern Queensland coast.

Tropical cyclones are intense cyclonic systems that form across northern Australia in the Arafura Sea, the Gulf and northern Coral Sea, generally between 10° and 15°S (Fig. 1.6a). They usually occur between November and May, with most occurring in February and March (Fig. 1.6b). Once formed, they rapidly intensify and tend to move initially westerly under the influence of the southeast trades and then, under the influence of the Coriolis force, may move towards the south and can make landfall along much of the Gulf and northern to central Queensland coast between 10° and 24°S (Fig. 1.6b). At the coast they are typically accompanied by very strong winds, storm surges up to 5.5 m (Harper and Robinson 1997) and waves up to several metres, as well as heavy rains and coastal flooding. They tend to weaken into tropical depressions when moving over land; however if they remain over the Coral Sea, they can maintain their integrity as far south as the

Tasman Sea, bringing big seas to southeast Queensland and northern NSW coast. In southeast Queensland they are responsible for 27% of waves greater than 2.5 m in height. One of the most recent cyclones, Yasi in 2009, reached category 5 strength and delivered a storm surge of 5.33 m at Caldwell (Schwartz et al. 2011) and inflicted considerable damage along the coast.

Harris and Heap (2009) found evidence of cyclone-deposited talus in lee of reefs in the southern Gulf, which they inferred showed evidence of net along-coast sediment transport. They suggest that similar inner to mid-shelf sediment pathways may possibly extend over the entire length of the northern Australian coastline.

13.4 Coastal Processes

13.4.1 Waves

The southeast trades are the major source of wave energy for the east coast north of Bundaberg, particularly in lee of the GBR, which essentially filters out all ocean swell. Table 13.3 lists the deepwater wave characteristics for sites around the Queensland coast (also see Tables 11.3 and 11.4 for Karumba and 12.2 for Weipa). The waves arrive almost exclusively from the southeast and are short with periods between 4 and 6 s and average about 0.7 m in height at Gladstone and Mackay, dropping to 0.5 m at Bowen and Cairns. In addition, southeast to easterly sea breeze along the east coast acts to reinforce the trade winds and their waves. Gallop et al. (2014) studied the impact of the GBR on wave attenuation and found that the reef

Table 13.3 Deepwater wave characteristics on the east Queensland coast

Location	Latitude (S)	Average 50% wave height (m)	Max 10% wave height (m)	Average wave period (sec)	Dominant wave direction
Gulf of Carpentaria					
Weipa	12°37′	0.38	0.9	4	W
Great Barrier Reef Lagoon					
Cairns	16°55′	0.50	0.9	4	SE
Bowen	20°04′	0.50	0.9	4	SE
Mackay	21°09′	0.65	1.4	5	SE
Gladstone	23°51′	0.70	1.3	6	SE
Burnett Heads	24°46′	0.85	1.5	5	SE
Coral Sea					
Sunshine Coast	26°00′	1.30	2.4	10	SE
Stradbroke Is	27°30′	1.40	2.2	9	SE
Mean		0.77	1.4	5.6	SE

Source: Beach Protection Authority, Wave Data Recording Program was a very efficient wave absorber and that in lee of the reef wave conditions depend on local wind speed and direction.

Wave height at shoreline is generally lower as they refract, attenuate and shoal around headlands and islands, over reefs and tidal shoals. Table 13.4 lists the observed breaker wave heights at all Queensland COPE sites. Beaches more fully exposed to the trades have H_b averaging 0.69 m with a H_{max} of 0.75 m. Those in lee of headlands and islands and/or facing north average 0.41 m, with a H_{max} of 0.7 m. The impact of Fraser Island is indicated by the decrease in wave height from 0.8 m at Baffle Creek to 0.12 m at Urangan. These are all significantly lower than the more exposed southeast ocean beaches, which average 1.2 m on Fraser Island, together with longer periods (8–10 s). Estimates of breaker wave height (Table 2.4) indicate that beaches around Cape York Peninsula have a modal breaker wave height of 0.4 m and range from 0.1 to 1 m, while along the central Queensland coast, they decrease to 0.3 m on the open coast and drop to 0.1 m in the many sheltered bays.

Table 13.4 Breaker wave characteristics at Queensland COPE sites, listed north to south

	Latitude (S)	H_b (m) 50%	H_b 10% (m)	*T* (s)	Dir[a]	Comment
Noah Ck	16°10′	0.15	0.75	6.5	3	In lee of GBR
Newell	16°26′	0.11	0.42	5	3	In lee of GBR
Machans	16°51′	0.2	0.48	4	3	In lee of GBR
Flying Fish Pt	17°30′	0.35	0.6	6	3	In lee of GBR
Mission	17°52′	0.1	0.7	4	3	In lee of GBR and dunk Is
Cardwell	18°16′	0.05	0.35	3	4	In lee of GBR and Hinchinbrook Is
Shingly	20°16′	0.05	0.25	3	3	In lee of GBR, faces north
Yeppoon	23°08′	0.05	0.37	6	3	In lee of GBR and great Keppel Is
Lammermoor	23°10′	0.3	0.7	7	3	In lee of GBR
Baffle Creek	24°31′	0.8	1.5	8	3	Some protection from Fraser Is
Bargara	24°49′	0.39	0.92	5	3	Moderate protection from Fraser Is
Woodgate	25°07′	0.4	0.8	5	3	In lee of Fraser Is
Urangan	25°20′	0.15	0.5	6	2	In lee of Fraser Is
Eurong (Fraser Is)	25°31′	1.2	1.8	10	3	Fully exposed
Noosa	26°23′	0.3	0.77	8	3	In lee of Noosa Head
Shelly (Caloundra)	26°48′	0.8	1.4	9	3	In lee of Caloundra Head
South Stradbroke	27°55′	1.1	1.9	10	3	Fully exposed
Surfers Paradise	28°00′	1.2	1.85	10	3	Fully exposed
Mean		0.42	0.87	6.5	E	

Source: Beach Protection Authority, Coastal Observation Program – Engineering
[a]Direction: 1, NE; 2, E; 3, SE

Ocean swell arrives along much of the Queensland outer shelf; however in north of Fraser Island, most of it breaks on the outer GBR. Large swell does occasionally move north of Fraser Island to reach the mainland as far north as Round Hill (24.1°S), and some large swell does move through gaps in the reef, permitting swell to occasionally reach parts of the southeast-facing shoreline south of Mackay (21.1°S). Only south of Sandy Cape (24.7°S) does the full force of the predominately southeast swell arrive unimpeded at the coast.

Queensland, therefore, has three deepwater or offshore wave climates:

1. The *western Cape York Peninsula* with low, short waves (H, 0.25 m; T, 2 s; dir, W) generated by the summer northwest monsoons, with calms or low trade wind seas the rest of the year
2. *Cape York to Hervey Bay*, where ocean swell breaks on the GBR and Fraser Island, with low to moderate trade wind waves generated in their lee (H, 0.5–0.8 m; T, 5–6 s; dir, SE)
3. The *southeast islands – Sunshine and Gold coasts* – which receive predominantly east to southerly ocean sea and swell averaging 1–1.2 m and T, 9–10 s

As indicated in Table 13.4, many sections of the coast receive considerably lower waves at the shore owing to protection from offshore reefs, islands, headlands, orientation and wave attenuation and refraction maintaining a relatively low energy wave climate for most of the northeast coast.

13.4.2 Tides

Northeastern Queensland coast receives its tides from a system located in the Coral Sea/Pacific Ocean. The tidal wave arrives from the southeast, first reaching the border at Point Danger, and 1 h later at Brisbane. The wave then arrives about 1–2 h later along much of the east coast south of Cooktown, apart from Broad Sound-Shoalwater Bay, where it is slowed by up to 4 h as well as being amplified. It then slows as it moves north of Cooktown, taking up to 6 h to move from the Coral Sea through Torres Strait to the Gulf. The tide is also amplified by the shallow shelf waters of the GBR Lagoon and it is further amplified in large embayments to 3 m in Moreton Bay, 8 m in Broad Sound and 3 m in Torres Strait. As a consequence, there is a substantial variation in both the height of the tide around the Queensland coast and its time of arrival (Table 13.5, Fig. 13.9).

Tidal currents are an important process along of much of the Queensland coast and continental shelf. The combination of higher tide ranges and a relatively shallow shelf, together with flows also constrained by the islands and reefs of the GBR, and over 200 inlets results in both substantial shore parallel and shore normal tidal flows.

In general, tidal currents along the east coast flow to the north with the flooding or rising tide and reverse to the south with the ebbing tide. The flooding tides are sufficient to generate north-trending sand waves along parts of the northern coast

Table 13.5 Tidal characteristics of east Queensland ports

Location	Mean spring tide range (m)	Max spring tide range (m)	Relative time of arrival 0 h = Point danger + = after, add hours
Thursday Is	1.9	2.8	+5
Albany Island	2.6	3.1	−1
Turtle Head Is	2.8	3.5	−1.7
Cairncross Is	2.6	3.6	+1.2
C. Grenville	2.2	3.0	+0.7
Portland Road	1.9	2.5	+0.3
Cape Melville	1.9	2.5	+0.2
Cape Flattery	2.0	2.5	+0.0
Cooktown	1.8	2.2	+2
Cairns	1.1	2.5	+2
Lucinda	2.3	2.7	+2
Townsville	2.5	2.9	+2
Bowen	2.1	2.7	+2
Mackay	4.9	5.5	+2.5
Broad Sound	6.3	8.0	+4
Port Clinton	3.9	4.1	+2
Gladstone	3.2	3.9	+1.5
Bundaberg	1.7	2.5	+1.5
Brisbane Bar	1.8	2.1	+1
Pt Danger	1.1	1.5	0

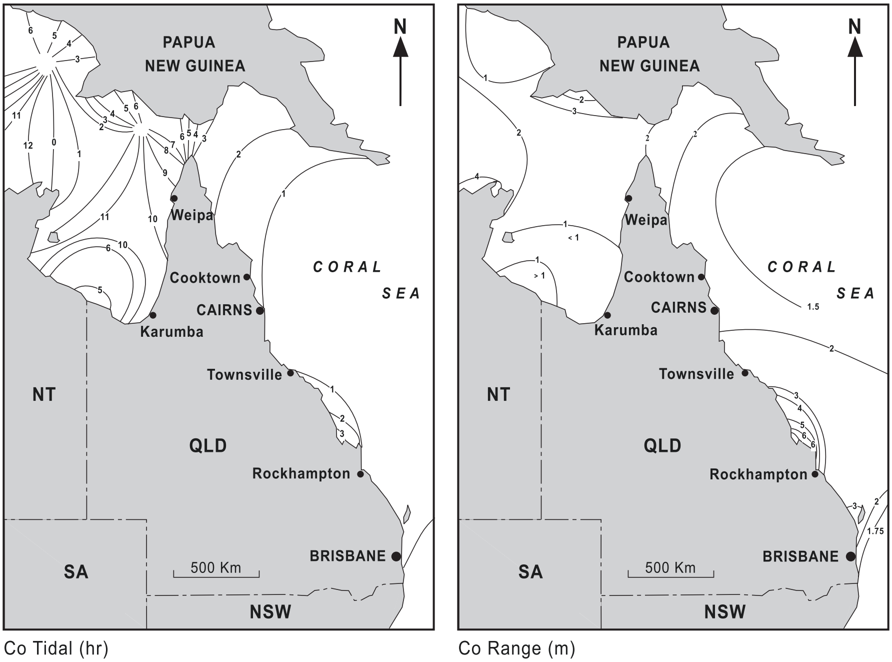

Fig. 13.9 Co-tidal and co-range lines for the Queensland and Gulf coasts. (Source: Short 2000)

(Fig. 13.6). The flow is modified when the currents flow through reef channels, into large bays and into all inlets and creek mouths where flow tends to parallel the direction of the major channel, passage or inlets, often perpendicular to the coast. In coastal inlets, the tidal currents commonly dominate over the wave processes, producing extensive tidal sand deltas, particularly ebb tide deltas on the seaward side of the inlets (Fig. 13.5). The constricted tidal flows can average 1–2 m s^{-1} (3–7 km h^{-1}) and can, in places like Torres Strait, reach 10 km h^{-1}.

13.4.3 Sea Level

The first review of sea level along the Queensland coast was undertaken by Hopley (1983) who found along the northeast coast sea level reached its present level prior to 6 ka, followed by small emergence due to hydro-isostatic mechanisms. Flood (1983) working in the southern GBR and southeast coast found that the marine transgression ceased 6.5–6 ka and sea level was +0.7 m between 6 and 3 ka. Hopley and Smithers (2003) found a Holocene high stand of 1.5 m on the east coast, while Hopley et al. (2007) reviewed all evidence along the Queensland coast and divided the coast into four zones:

- Torres Strait-Cairns: mid-Holocene sea level of ~1 m before 5.5 ka.
- Cairns-Palm Islands: sea level reached a level of 1–1.5 m between 6.2 and 5.5 ka.
- Palm Islands to Whitsundays: sea level reached its maximum between 6 and 5 ka at around 1–1.5 m.
- Whitsundays to Bundaberg: present sea level reached prior to 6 ka followed by variable emergence along the coast possible due to tectonic influences.

They attribute the variation in level of emergence along most of the coast to variable hydro-isostatic adjustment following the PMT and loading of the shelf with seawater, with shelf morphology controlling the amount of adjustment. There has also been considerable debate about the timing and nature (smooth or oscillating) of the mid-late Holocene fall to present sea level, which Hopley et al. (2007) concluded could not be determined with confidence. The most recent evidence obtained by Lewis et al. (2015) who dated oyster reefs at Ramsay Bay and Magnetic Island suggested there was a rapid fall in sea level (~1 m) between 1200 and 800 year BP.

Hopley (1983) also concluded that at the sea level maxima ~6 ka, not only was sea level higher (1–2 m) but the extensive inshore tidal flats were not well developed and the GBR was still in its formative stages with some reefs yet to 'catch up' to the sea level rise. This allowed more ocean energy to penetrate the reef and arrive at the deeper, steeper shoreline, producing 'high energy' mid-Holocene window along the northeast-central Queensland coast. The reefs had 'caught up' by 3 ka (Salles et al. 2018) closing the wave window. As a consequence, many higher energy shoreline features were deposited between 6-3 ka, features that now lie in lee of considerably lower energy modern shores.

13.4.4 Ocean Currents

The northeast coast is located on the western side of the Pacific Ocean and receives tropical waters that have flowed across the Pacific in the Equatorial Drift. The drift pools in the Coral Sea as warm (25–30 °C, Fig. 1.17) tropical water and is deflected southwards (towards Australia) by the land masses of New Guinea and northern Australia. As this warm water moves south, it is joined by equally warm water from the GBR lagoon, to form the warm *East Australian Current* (EAC). The current flows south outside the GBR (Fig. 1.18) at speeds of 2–5 km h^{-1}. It only directly impacts the coast, where the cointinental shelf narrows, from Sandy Cape on Fraser Island to the south.

Inside the GBR the ocean currents have limited direct impact. The depths are generally less than 100 m, and much of the GBR lagoon is blocked by the reef. Consequently, currents in the GBR are dependent on local to regional winds, especially the southeast trades, and tidal currents, particularly close to the coast and in all areas of restricted flows. Along the east coast, the trades tend to generate a northerly current along the coast which reinforces the flooding tidal current. The currents are however modulated by the prevailing tide and wind conditions.

Wolanski (1981) observed that the persistent southeast trade winds drive continental shelf waves, inside the GBR, with an amplitude of up to 0.3 m. These can generate currents over the shallow continental shelf that can exceed the tidal flows.

13.4.5 Sea Surface Temperature

The sea temperature along the Queensland coast is a product of three main processes. The latitudinal location of the coast between 9 and 28°S determines the overhead position of the sun and the amount of solar radiation available to warm the ocean water; the seasonal movement of the sun producing summer warming and winter cooling (Figs. 1.17, 13.10); and the El Niño-Southern Oscillation Index (ENSO), produces pulses of relatively warmer (positive SOI/La Nina) and cooler water (negative SOI/El Nino) across the western Pacific every few years. Temperatures range from 25 to 30 °C in summer to the low 20s in winter (Figs. 1.17 and 13.10, Table 13.6).

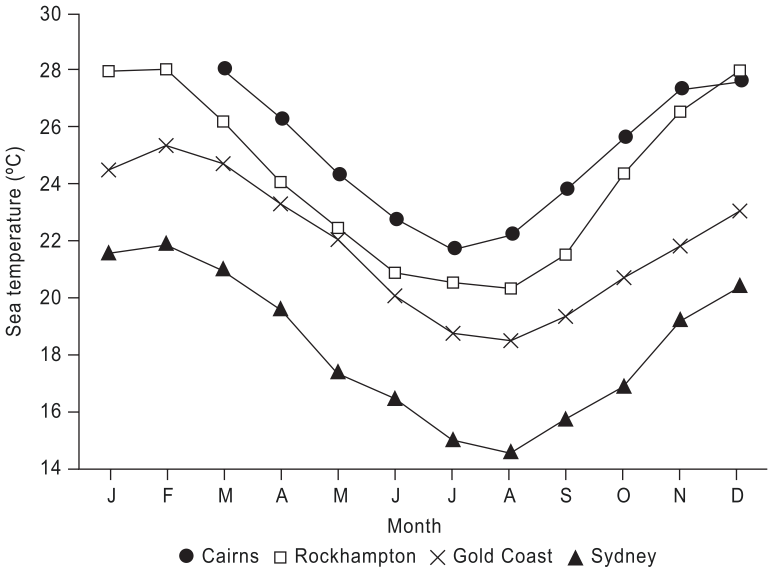

Fig. 13.10 Mean monthly sea surface temperature at sites along the east Australian coast

Table 13.6 Queensland sea temperatures

	Summer max. (°C)	Winter min. (°C)
Cairns	30	23
Rockhampton	28	21
Gold Coast	25	19

13.5 Rivers and Sediment Supply

The combination of a humid east coast backed by the Great Dividing Range, which rises to over 1000 m and is located close to the coast, results in numerous generally small drainage catchments flowing east to the coast. Along the east Queensland coast, there are approximately 460 creeks and rivers, including 35 moderate to large rivers and their deltas. These systems deliver nutrient-rich freshwater and suspended and bedload terrigenous sediment to the coast. The sand and in place gravel bedload contribute directly to the coastal sediment budget, supplying sand to build deltas, spits, beaches and dunes, much ultimately transported north by the prevailing wave and tide conditions. The largest rivers are the Fitzroy (catchment 142,537 km^2) and the Burdekin (130,126 km^2), which have both built large deltas at their mouths. These drainage systems and their deltas contribute substantial bedload sediment to the coastal systems, as well as being a major component of the coastal landscape, and will be discussed in more detail in Chaps. 14 and 15.

Table 13.7 Some estimated rates of longshore sand transport along the Queensland coast

Location	Transport rates m^3 year^{-1}	Comments	Source
Cairns	5000–90,000	CERC formula	BPA (1984)
Mackay	11,000–44,000		EPA (2004)
Capricorn	30,000–300,000	CERC formula	BPA (1979)
Hervey Bay	300–15,000		Pattearson and Carter (1987)

East Queensland beach sediments are predominately composed of medium to coarse (0.4–1 mm), moderately well to moderately sorted (0.6–1) quartz sand, with carbonate ranging from 5% to 30%. The general coarseness of the sand is a product of the hinterland geology, while its moderate sorting is a product of the generally lower energy shoreline conditions. Details of the regional beach sediments are provided in Chaps. 14 and 15.

13.5.1 Sediment Transport

There have been a few studies of longshore sediment transport along the east Queensland coast. Studies south from the Cairns include BPA (1984), Mackay (EPA 2004), Capricorn Coast (BPA 1979) and Hervey Bay (Pattearson and Carter 1987). Most transport is to the north with some local reversals. The results of these studies are listed in Table 13.7. They show both locally highly variable rates and overall low to moderate rates of a few tens of thousands of cubic metres per year. The variability is due to local changes in orientation and wave sheltering which modulate wave energy, while the overall rates reflect the general low to moderate wave energy along the coast. More recently Salles et al. (2018) predict that along the northeast coast, wave-induced northward transport mobilises terrigenous sediments out to depths of 20 m.

13.6 Biological Processes

Northern Australia has the richest coastal biota on the continent, which includes the intertidal mangroves and subtidal seagrass meadows and coral reef systems. In addition, the beaches support in and epi-fauna and the backing coastal dunes have a succession of vegetation ranging from the primary grasses and succulents to tropical rain forests on the hind dunes.

Mangroves are a common feature of the east Queensland coast occurring in most sheltered locations. The coast has 805 km^2 of mangrove systems, which represents 18% of Australia's mangroves (Table 2.9). North Queensland also has the greatest number of mangrove species (35), with species numbers decreasing into the Gulf (19) and to the south with 21 species along the central Queensland coast reducing to

Fig. 13.11 Ten metre high mangroves on the Lockhart River, Cape York Peninsula. (Photo: AD Short)

8 species in Moreton Bay (Table 2.10, Short and Woodroffe 2009). The mangroves also tend to be high in biomass reaching 10 m and more in height (Fig. 13.11).

The most extensive and diverse Australian seagrass communities are in the waters of Torres Strait and northeastern Queensland where between 10 and 14 tropical species are present (Tables 2.11 and 2.12). *Halodule uninervis* is the most prominent of the tropical species, particularly where the large tides expose the substrate. *Halodule pinifolia* and *Halophila ovata* prefer the intertidal and shallow subtidal with *Halophila ovalis* preferring muddy intertidal areas. *Thalassia* sp. is associated with coarser sediments, and *Thalassodendron ciliatum* grows directly on coral and calcarenite reefs.

Seagrass meadows support a rich epibiota and contribute a high proportion of red algae, foraminifera and bivalve fragments to the beach sediments, as well as seagrass roots and detritus. They also help stabilise nearshore sands and in the tropics are grazed by dugongs and green turtles, both of which are most extensive across northern Australia and down the east coast as far as Moreton Bay.

The GBR dominates the east Queensland coast and shelf extending for 2300 km between Torres Strait and Lady Elliot Island (Fig. 13.4). It supports the highest number and greatest diversity of coral species in the Australian region (Table 2.13). Most of the reef is located on the outer shelf remote from the coast, with only some fringing and patch reef closer to shore. Its main physical impact on the coast is to block ocean waves and substantially reduce wave energy along the coast. Locally the fringing reefs contribute to inshore wave modification as well as supplying carbonate detritus to the coastal sediment system. See Hopley et al. (2007) for a comprehensive description of the geomorphology of the GBR.

13.7 Beach Systems

The northeast division contains 1357 sandy beach systems, which occupy 50% of the coast. The beaches are spread along the entire coast, with the remainder consisting of rocky shore, plus areas of mangrove-lined tidal flats in sheltered bays together with creek and river mouths. Eight-hundred and sixty beaches are located in region QLD03 and 497 in region QLD04. Some of their characteristics are listed in Table 13.8. Their length averages around 1.5 km, with a mean orientation to the southeast (115°) facing into the prevailing southeast wind and waves. They are typically moderately embayed (0.7–0.8), with a 15 m wide high tide beach, 4–5° beach slope and 300–400 m wide intertidal zone, the latter assisted by the higher tide ranges. As waves average <0.5 m and tides are generally greater than 2 m, RTR is usually >4, increasing substantially in sheltered embayments. The higher RTR results in a dominance of TM and TD beaches along the entire coast. TM beaches dominate with 54% (by length) and TD comprising 42.5%. The most common beach states are the TM R + LTT (27.7%) and the TD B + SF (24%) (Table 13.9). Only 1% of the beaches are WD R, with the remainder made up of beaches fronted by rock flats (0.8%), fringing coral reefs (0.7%), plus 12 beaches fronted by active tide-generated transverse sand waves (1%) (Fig. 13.6). The dominance of wide tide TM and TD beaches is also reflected in the average width of the intertidal zone, which averages 276 m and 438 m in regions QLD03 and QLD04, respectively. The low number of beaches fronted by fringing reefs indicates the general unsuitability of the mainland coast for reef formation, a result of seasonal freshwater flooding and high sediment loads and turbidity. More details of the regional and PC and SC beaches are provided Chaps. 14 and 15, while Short (2000, 2006) provides a description of all beaches in the division.

Table 13.8 Northeast division and regions QLD03 and QLD04 beach characteristics

	Region QLD 03		Region QLD 04		Division
	n	Mean	*n*	Mean	Total/mean
Total beach length	1264 km	–	827 km	–	2091 km
Number	860	–	497	–	1357
Mean beach length (km)	860	1.47	497	1.7	1.54
Orientation (deg)	860	116	497	114	115
Embaymentisation	860	0.84	497	0.72	0.8
Gradient (deg)	860	4.7	497	4.3	4.6
Beach width (m)	860	17.2	497	14.	16.1
Sand ridges (m)	160	6.4	36	7.6	6.6
Intertidal/sand flats (m)	860	276	497	438	335

Table 13.9 Northeast division beach types and states

BS	BS	*n*	No. (%)	Total (km)	Mean (km)	σ (km)	% (km)
6	R	15	1.1	23.6	1.6	5.2	1.1
7	R + LTT	436	32.1	578.9	1.3	2.3	27.7
8	R + LTR	108	8.0	349.3	3.3	4.1	16.7
9	UD	95	7.0	201.1	2.1	2.8	9.6
10	B + RSF	161	11.9	310.9	1.9	1.8	14.9
11	B + SF	396	29.2	501.3	1.3	1.9	24.0
12	B + TSF	62	4.6	76.2	1.2	2.3	3.6
14	R + RF	51	3.8	15.9	0.3	0.3	0.8
15	R + CF	21	1.5	13.8	0.7	1.0	0.7
16	R + SW	12	0.9	20.3	1.7	1.2	1.0
		1357	100	2091.3	1.54	2.44	100

Table 13.10 Dimensions of northeast division and regions QLD03 and QLD04 barrier systems

NE division	QLD03	QLD04	NE division
Number	231	183	414
Total length (km)	1124	673	1797
Mean width (m)	110–7900	120–1670	110–7900
Mean height (m)	11.2	8.3	9.8
Area (ha)	215,374	97,556	311,964
Unstable (ha)	27,127	1319	28,446
Total volume (M m^3)	18,473	15,343	33,816
Unit volume (m^3 m^{-1})	16,435	22,791	18,818

13.8 Barrier Systems

The northeast division has a total of 414 barrier systems that occupy 1797 km (43%) of the coast (Table 13.10). They average 5 km in length in region QLD03 with a mean width from 0.1 to 8 km; in region QLD04 they average 3.7 km in length and between 100 and 700 m in width, the wider barrier generally associated with large transgressive dune fields. The presence of dunes is also reflected in the higher (mean = 11 m) and less stable (13% unstable) QLD04 barriers, while the large total and unit volumes are also a product of the large volume associated with the dune fields. The per metre volumes are also the highest in northern Australia (16,000–22,000 m^3 m^{-1}), a result of the abundant shelf and river-supplied sand, and on exposed shores the higher wave and wind energy and that has generated massive transgressive dune systems.

Figure 13.12 presents a generalised sketch of a typical northeast Queensland embayed beach-barrier system to illustrate the range of beach-barrier systems that occur along the coast and the gradation in beach-barrier form that can occur within embayments. The barriers can grade from mangrove-lined tidal sand-mud flats in

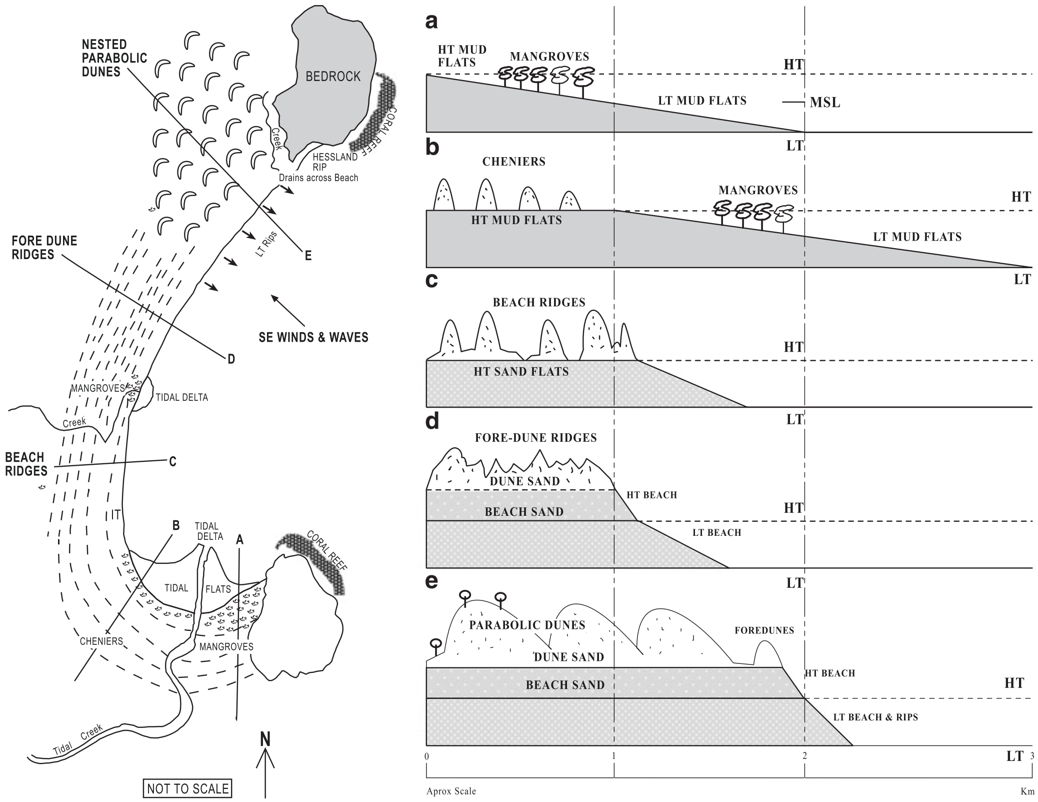

Fig. 13.12 Schematic sketch of generalised northeast Queensland embayed barrier systems, which can grade from a sheltered low energy southern corner to an exposed high energy northern section. (Source: Short 2000)

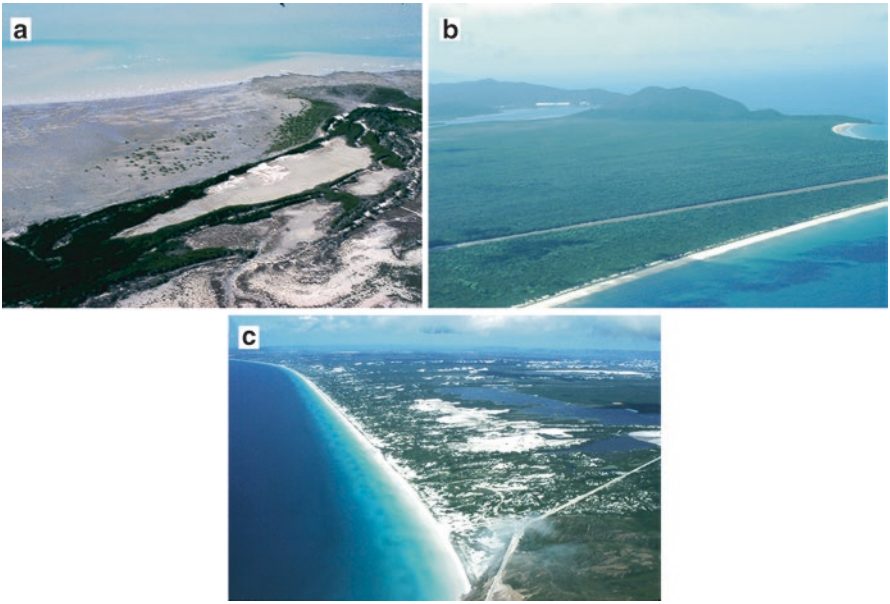

Fig. 13.13 Barrier types: (**a**) cheniers and wide sand-mud flats at Charon Point (QLD 1216); (**b**) regressive foredune ridge plain at Cowley Beach (QLD 773); and (**c**) transgressive dunes at Cape Flattery (QLD 621). (Photos: AD Short)

the most sheltered (southern) environments, to cheniers (Fig. 13.13a) and beach ridges as exposure increases slightly, to LTT beaches and regressive foredune ride plains (Fig. 13.13b) on moderate energy sections, to rip-dominated beaches and massive transgressive dunes (Fig. 13.13c) on the most exposed southeast-facing sections, usually located towards the northern end of the embayments.

13.9 Summary

The northeast division extends for 4205 km from Van Spoult Head (near Cape York) to Hervey Bay and occupies all the Queensland coast in lee of the GBR. The GBR shelters the coast from ocean waves, which consequently receives only wind waves generated within the GBR lagoon. The southeast trade winds are the main source of energy delivering both wind and waves. As the waves average <1 m and the tides range from meso to mega, the beach systems are predominately TM on exposed location and TD in the many sheltered bays. This is also a tropical coast with mangroves proliferating in sheltered bays and estuaries, while the GBR dominates the mid to outer shelf. Sediment transport is predominately to the north and ultimately to Cape York and Torres Strait; however, it is interrupted by several large promontories and bays and numerous headlands. The sand is transported primarily by waves and in some locations north-trending flooding tides, while the trade wind has deposited massive transgressive dune systems in exposed locations, all the way up to Cape York.

References

BPA (1979) Capricorn coast beaches. Beach Protection Authority, Brisbane, 238 p

BPA (1984) Mulgrave Shire Northern beaches. Beach Protection Authority Queensland, Brisbane, 366 p

Day RW, Whitaker WG, Murray CG, Wilson IH, Grimes KG (1983) Queensland geology. The Geological survey of Queensland, publication 383, 194 p

EPA (2004) Mackay coast study. Environment Protection Agency, Brisbane, 113 p

Flood PG (1983) Holocene sea level data from the southern Great Barrier Reef and southeastern Queensland – a review. In: Hopley D (ed) Australian sea levels in the last 15,000 years. Mono Series No 3. Department of Geography, James Cook University, Townsville, pp 85–92

Gallop SL, Young IR, Ranasinghe R, Durrant TH, Haigh ID (2014) The large-scale influence of the Great Barrier Reef matrix on wave attenuation. Coral Reefs. Published online Sept 2014. https://doi.org/10.1007/s00338-014-1205-7

Harper B, Robinson DA (1997) Storm tide threat in Queensland. In: 13th Australasian coastal and ocean engineering conference, Christchurch, Institution of Engineers Australia, pp 1053–1058

Harris PT, Heap AD (2009) Cyclone-induced net sediment transport pathway on the continental shelf of tropical Australia inferred from reef talus deposits. Cont Shelf Res 29:2011–2019

Hopley D (1983) Evidence of 15000 years of sea level change in tropical Queensland. In: Hopley D (ed) Australian sea levels in the last 15 000 years: a review. Mono Series No 3, Department of Geography, James Cook University, Townsville, pp 93–104

Hopley D, Smithers SG (2003) Queensland. In: Bird ECF, Schwartz M (eds) The world's coasts. Available online at http://wkap.nl/subjects/TWCO

Hopley D, Smithers SG, Parnell KE (2007) The geomorphology of the Great Barrier Reef. Cambridge University Press, Cambridge, 532 p

Lewis SE, Wüst RAJ, Webster JK, Collins J, Wright SA, Jacobsen G (2015) Rapid sea-level fall along north-eastern Australia between 100 and 800 cal. yr BP: an appraisal of the oyster evidence. Mar Geol 370:20–30

Pattearson CC, Carter TB (1987) Coastal process studies for the Hervey Bay region, south east Queensland. In: 8th Australasian coastal ocean engineering conference, Launceston, Institution of Engineers, pp 128–133

Salles T, Ding X, Webster JM, Vila-Concejo A, Bocard G, Pall J (2018) A unified framework for modelling sediment fate from source to sink and its interactions with reef systems over geological time. Sci Rep 8:5252. https://doi.org/10.1038/s41598-018-23519-8. Published online 27 March 2018

Schwartz R, Nielsen K, Mohoupt J (2011) Tropical cyclone Yasi: coastal inundation levels. In: 20th Australasian coastal ocean engineering conference, pp 658–663

Short AD (2000) Beaches of the Queensland coast: Cooktown to Coolangatta. Sydney University Press, Sydney, 360 p

Short AD (2006) Beaches of the northern Australia coast: the Kimberley, Northern Territory and Cape York. Sydney University Press, Sydney, 463 p

Short AD, Woodroffe CD (2009) The Coast of Australia. Cambridge University Press, Melbourne, 288 p

Wellman P (1997) Geological and geophysical framework. In: Bain JHC, Draper JJ (ed) North Queensland geology. Aust. Geol. Survey. Org. Bull 240/9, Ch 2

Wolanski E (1981) The influence of atmospheric activities on engineering activities in coastal waters. In: 5th Australian conference on coastal and ocean engineering, Perth, pp 225–229

Chapter 14
Eastern Cape York Peninsula Region

Abstract The eastern Cape York Peninsula region extends for 2400 km from Cape York south along the tropical Queensland coast to Cape Conway in the Whitsundays. The coast has a variable geology, which plays a major role in coastal orientation, the formation of several large bays and comprises the rocky shore which occupies 50% of the coast. A range of rivers and streams drain the Great Dividing Range which parallels the coast delivering terrigenous material and building deltas along this sediment-rich coast. The climate is humid ranging from monsoonal to tropical to sub-tropical, together with seasonal tropical cyclones. The Great Barrier Reef (GBR) shelters the entire coast from ocean swell, with the onshore trades generating short low to moderate seas across the GBR lagoon. Tides are meso, and the coast is dominated by tide-modified beaches in exposed location, tide-dominated in the bays and more sheltered locations together with mangroves along the very sheltered shore and in many inlets. Longshore transport is to the north with many interruptions, and barriers range from cheniers in sheltered bays to massive transgressive dunes in exposed locations. This chapter describes the beaches, barriers and sediment transport along the entire coast set within the framework of sediment compartments.

Keywords Cape York Peninsula. Great Barrier Reef · East Queensland · Trade winds · Mangroves · Beaches · Barriers · Sediment transport · Sediment compartments

14.1 Introduction

The northeast division contains two regions, eastern Cape York Peninsula (QLD03), which extends from Van Spoult Head to Cape Conway, and central Queensland (QLD04) which continues south to Hervey Bay (Fig. 13.1). The larger QLD03 has 2378 km of coast contained in 8 PCs (Fig. 14.1, Table 14.1), 34 SCs and 860 beach systems and is the subject of this chapter, while the central Queensland region (QLD04) is presented in Chap. 15. The Peninsula region includes the entire east coast of Cape York Peninsula which extends 1463 km south to Innisfail,

A. D. Short, *Australian Coastal Systems*, Coastal Research Library 32,
https://doi.org/10.1007/978-3-030-14294-0_14

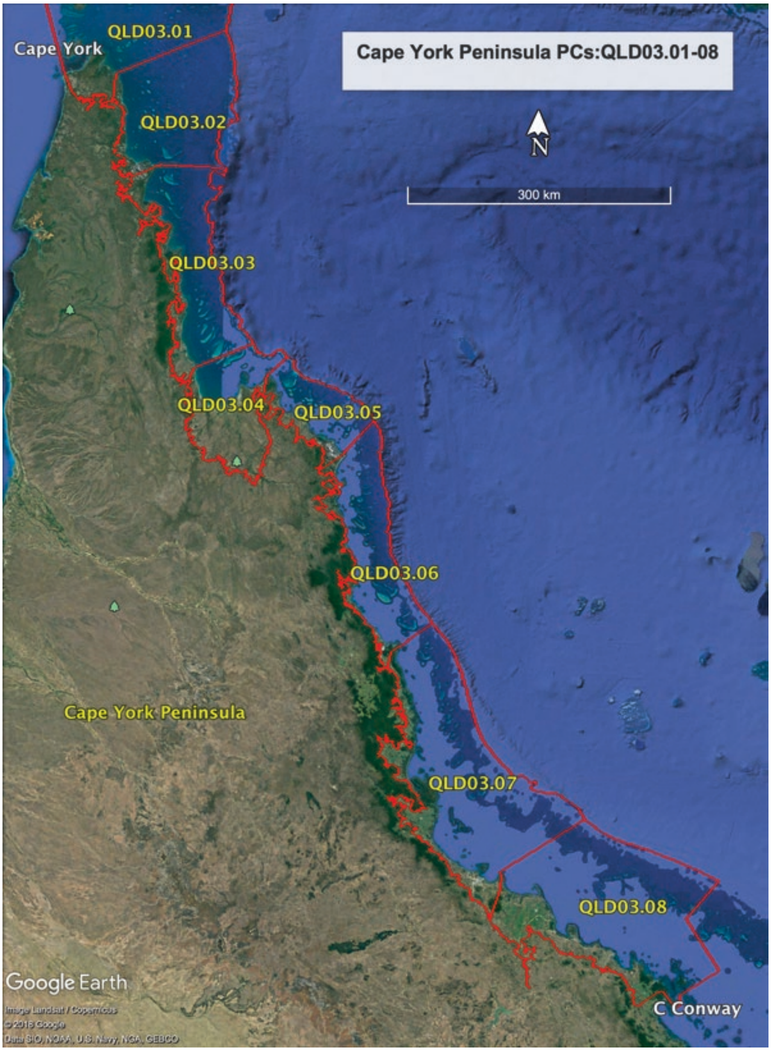

Fig. 14.1 The eastern Cape York Peninsula region (QLD03) and its eight PCs QLD03.01-08

then continues south for another 915 km to Cape Conway. This is a tropical coast located between 10.6 and 20.5°S and exposed to the southeast trades along its entire length, which bring humid conditions and low to moderate seas generated inside the GBR lagoon (Tables 13.3 and 13.4). It receives tides ranging from meso to macro (Table 13.5) and is also exposed to tropical cyclones which can make landfalls along the entire region (Fig. 1.6). It is also a sediment-rich coast with more than 300 streams and rivers delivering bedload to the coast, which combine with the shelf-derived sediment, to build the beach, barriers and in places massive dune systems. The trade wind and waves and flooding tides maintain a generally northerly sand

Table 14.1 Eastern Cape York region QLD03, its 8 PCs and 36 SCs

Region/comp. no.[a]	Region	PC boundaries	Beach ID[b]	No. beaches	Km[c]	Total km
QLD 03	Eastern Cape York Peninsula					
QLD03.01.01		Van Spoult Pt-Cape York	QLD 178–213	36	1399–1469	70
QLD 03.01.02		Cape York-Sharp Pt	QLD 214–231	18	1469–1573	104
QLD 03.01		*Van Spoult Pt-Sharp Pt*	*QLD 178–231*	*54*	*1399–1573*	*174*
QLD 03.02.01		Sharp Pt-F Orford Ness	QLD 231–288	57	1573–1633	60
QLD 03.02.02		F Orford Ness-Red Cliffs	QLD 289–309	21	1633–1688	55
QLD 03.02.03		Red Cliffs-C Grenville	QLD 310–338	29	1688–1747	59
QLD 03.02		*Sharp Pt-C Grenville*	*QLD 232–338*	*107*	*1573–1747*	*174*
QLD 03.03.01		C Grenville-Bolt Head	QLD 339–362	24	1747–1802	55
QLD03.03.02		Bolt Head-C Weymouth	QLD 363–405	43	1802–1867	65
QLD 03.03.03		C Weymouth-C Direction	QLD 406–425	20	1867–1928	61
QLD 03.03.04		C Direction-C Sidmouth	QLD 426–464	39	1928–2004	76
QLD 03.03.05		C Sidmouth-Stewart R	QLD 465–486	22	2004–2082	78
QLD 03.03		*C Grenville-Stewart R*	*QLD 339–486*	*148*	*1747–2082*	*335*
QLD 03.04.01		Stewart R-Bathurst Hd	QLD 487–498	12	2082–2187	105
QLD 03.04.02		Bathurst Hd-C Melville	QLD 499–516	18	2187–2234	47
QLD 03.04	*(Princess Charlotte Bay)*	*Stewart R-C Melville*	*QLD 487–516*	*30*	*2082–2234*	*152*
QLD 03.05.01		C Melville-Murdoch Pt	QLD 517–582	66	2234–2333	99
QLD 03.05.02		Murdoch Pt- C Flattery	QLD 583–614	32	2333–2412	79
QLD 03.05		*C Melville-C Flattery*	*QLD 517–614*	*98*	*2234–2412*	*178*
QLD 03.06.01		C Flattery-Endeavour R	QLD 615–640	26	2412–2501	89
QLD 03.06.02		Endeavour R-C Kimberley	QLD 641–690	50	2501–2624	123
QLD 03.06.03		C Kimberley-Port Douglas	QLD 691–696	6	2624–2658	34

(continued)

Table 14.1 (continued)

Region/comp. no.[a]	Region	PC boundaries	Beach ID[b]	No. beaches	Km[c]	Total km
QLD 03.06.04		Port Douglas-C Grafton	QLD 697–734	38	2658–2759	101
QLD 03.06		*C Flattery-C Grafton*	*QLD 615–734*	*120*	*2412–2759*	*347*
QLD 03.07.01		C Grafton-Saltwater Ck	QLD 735–741	7	2759–2781	22
QLD 03.07.02		Saltwater Ck-Cooper Pt	QLD 742–759	18	2781–2830	49
QLD 03.07.03		Cooper Pt-Double Pt	QLD 760–772	13	2830–2864	34
QLD 03.07.04		Double Pt-T O'Shanter Pt	QLD 773–787	15	2864–2908	44
QLD 03.07.05		T O'Shanter Pt-C Richards	QLD 788–799	12	2908–3022	114
QLD 03.07.06		C Richards-Lucinda	QLD 800–827	28	3022–3082	60
QLD 03.07.07		Hinchinbrook Channel	–		–	
QLD 03.07.08		Lucinda-Eleanor Ck	QLD 828–835	8	3082–3124	42
QLD 03.07.09		Eleanor Ck-C Pallarenda	QLD 836–858	23	3124–3197	73
QLD 03.07.10		C Pallarenda-C Cleveland	QLD 859–874	16	3197–3244	47
QLD 03.07		*C. Grafton-C Cleveland*	*QLD 735–874*	*140*	*2759–3244*	*485*
QLD 03.08.01		C Cleveland-C Bowling G	QLD 875–889	15	3244–3336	92
QLD 03.08.02		C Bowling G-C Upstart	QLD 890–921	32	3336–3445	109
QLD 03.08.03		C Upstart-Abbott Pt	QLD 922–942	21	3445–3502	57
QLD 03.08.04		Abbott Pt-C Edgecumbe	QLD 943–954	12	3503–3531	29
QLD 03.08.05		C Edgecumbe-C Gloucester	QLD 955–979	25	3532–3595	64
QLD 03.08.06		C Gloucester-Pioneer Pt	QLD 980–1019	40	3596–3711	116
QLD 03.08.07		Pioneer Pt-C Conway	QLD 1020–1037	18	3712–3777	66
QLD 03.08		*C Cleveland-C Conway*	*QLD 875–1037*	*163*	*3244–3777*	*533*
		Region		**860**		**2378**

[a]NCCARF compartment number
[b]ABSAMP beach ID
[c]Distance from NT/QLD border

transport, with an ultimate sink in Torres Strait. The region contains 860 beaches which occupy 1264 km (53%) of the coast and in places are a major conduit for longshore sand transport, primarily to the north. They also act as a source for the dune systems including several massive transgressive dune systems. In all there are 224 barrier systems in the region occupying 1124 km (47%) of the coast and range from cheniers to the large dune systems. Details of all the beaches in this region are provided by Short (2000, 2006).

Sediments along the coast are primarily quartz-rich moderate to moderately well-sorted, fine to coarse sand, with carbonate averaging between 5 and 15% for most of the coast (Table 14.2; Fig. 14.2). While carbonate content is usually low, locally it can reach 80–100%, particularly on some of the major headlands and in the south along the Whitsunday coast and on the offshore islands (PC:QLD03.08). The high degree of longshore variation, particularly in sand size, is indicative of the numerous local fluvial sources, as well as the limited and interrupted longshore sand transport, together with the injection of generally coarse carbonate material.

The region contains eight PCs and their SCs which are discussed below.

14.2 PC:QLD03.01 Van Spoult Head–Sharp Point

PC:QLD03.01 occupies the northern tip of Cape York Peninsula, extending for 174 km from Van Spoult Point in the west, up to Peak Point, then across to Cape York and Fly Point, then south to Sharp Point (Fig. 14.3). Beside containing the iconic Cape York, the northern tip of the Australian continent, it is also home to the aboriginal and islander settlements of Cowal Creek, Bamaga (700), New Mapoon (400) and Seisia (300) (Fig. 14.4b), as well as several tourist camps, while offshore lie the Torres Strait islands and their communities. This PC has considerable variation in its orientation, geomorphology and processes. The west coast is a low energy lee coast, facing northwest towards Muralug Island together with other smaller island sand reefs. The northern section between Peak Point and Fly Point faces north into Torres Strait, while the eastern section while more exposed to the trade winds contains the large mangrove-lined Kennedy Inlet-Newcastle Bay (Fig. 14.4e).

Table 14.2 Sediment characteristics of region QLD03 primary compartments, together with Magnetic and Whitsunday islands

Q 03	03.01	03.02	03.03	03.04	03.05	03.06	03.07	03.08	Mag Is	Whit Is
n	20	31	50	1	24	51	66	54	11	6
Size (mm)	0.7	1.0	1.0	–	–	0.4	0.5	0.9	0.8	2
σ (mm)	0.3	–	–	–	–	0.4	0.4	1.1	0.4	1.9
Sorting	1.0	0.7	0.8	–	–	0.6	0.8	0.9	1.2	0.5
σ (sorting)	0.3	–	–	–	–	0.4	0.4	0.4	0.4	0.2
Carb (%)	5.8	13.6	13.5	14.3	9.5	7.8	5.4	27.6	26.9	61.7
σ (%)	6.7	29.4	24.9	–	15.2	15.7	10	29.8	15.7	36.2
Range (%)	0–93	0–88	0–99	–	0–59	0–65	0–58	1–92	1–60	1–100

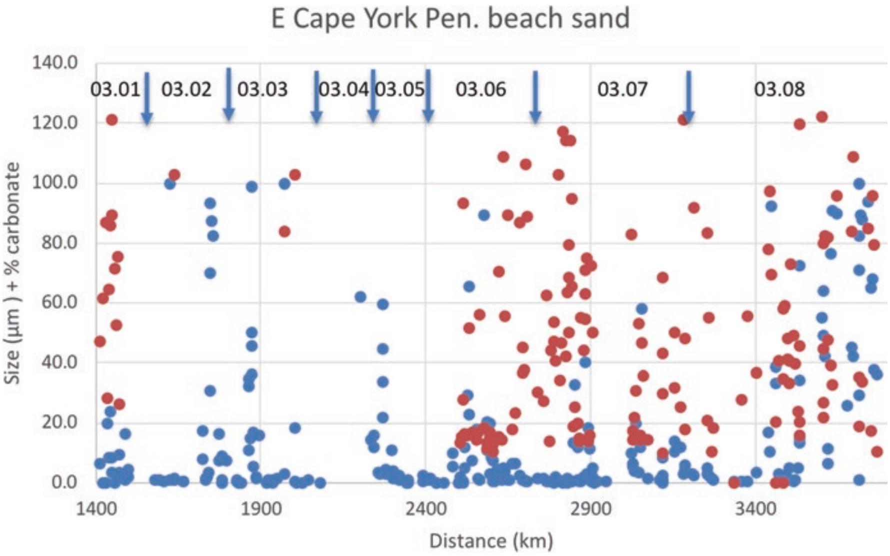

Fig. 14.2 Eastern Cape York Peninsula (region QLD03) beach sand size (red, µm,) and percent carbonate (blue). Sand size varies from fine to coarse, and while carbonate is predominately low, there is significant local enrichment. Arrows indicate PC boundaries. Distance is from NT/QLD border

Fig. 14.3 PC:QLD03.01 extends either side of Cape York and contains SCs:QLD03.01.01-02. (Source: Google Earth)

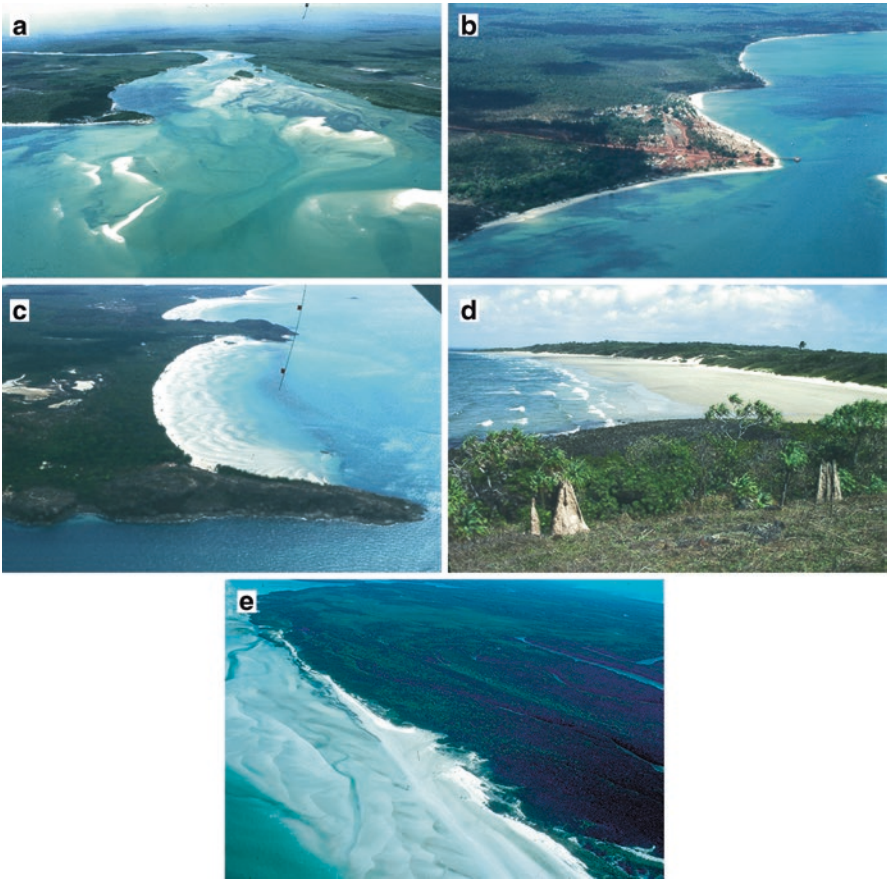

Fig. 14.4 PC:QLD03.01 coast: (**a**) the sand-choked mouth of the Jardine River (QLD 178-9); (**b**) Seisia is located on a cuspate foreland located in lee of Red Island (QLD 195–6); (**c**) Frangipani Beach (QLD 213) and Cape York with ridged sand flats occupying the intertidal zone; (**d**) the exposed rip-dominated Narau Beach (QLD 224) is backed by vegetated transgressive dune extending 3.5 km inland; and (**e**) QLD 231 at the mouth of Kennedy Inlet-Newcastle Bay illustrates the abundant sand moving north into the inlet. (Photos: AD Short)

The PC is divided into two SCs (QLD03.01.01-02) with their boundary at Cape York (Fig. 14.3; Table 14.3). This is, as will be seen below, a leaky compartment, with sediment transport from the east to west around the Cape and into Torres Strait.

14.2.1 Rivers and Creeks

There are a total of 21 mainly small unnamed tidal creeks and streams flowing into the compartment and just 1 major river, the Jardine, on its western boundary (Fig. 14.4a). The Jardine has a catchment of 2828 km^2 and may be supplying sand

Table 14.3 PC:QLD03.01 beach types and states

BS	BS	No.	%	Length (km)	%	Mean (km)	σ (km)
8	R + LTR	2	3.8	2	3.0	1	–
9	UD	5	9.4	4	6.1	0.8	1.1
10	B + RSF	10	18.9	16.4	24.9	1.6	1.0
11	B + SF	31	58.5	37.5	56.9	1.2	1.8
12	B + TSF	2	3.8	1.8	2.7	0.6	0.1
14	B + TMF	2	3.8	0.9	1.4	0.5	–
15	R + CF	1	1.9	3.2	4.9	3.2	–
		53	100.0	65.8	100		

to the coast, as its shallow funnel-shaped channel and 2 km wide entrance is choked with sand. The large funnel-shaped Jackey Jackey Creek (721 km^2) on the eastern shore flows through Kennedy Inlet into Newcastle Bay, but appears to be more a sink rather than a source for sediment. Likewise, the small funnel-shaped Escape River (236 km^2) reaches the coast in lee of Middle Head Island and also appears to be a sediment sink.

14.2.2 Coastal Processes, Beaches and Sediments

Spring tides around the cape average around 3 m and drive strong tide current through Torres Strait. The westerly flowing flood current combined with easterly wave and wind-driven currents (Hemer et al. 2004) has developed a massive tidal delta extending up to 150 km west of Cape York (Harris 1994). The delta represents the final sink for the sediments that manages to make it all the way to Cape York. Waves range from low along the west and northern coast to low to moderate on the eastern shores depending on exposure. Sediments tend to be moderately to poorly sorted, coarse quartz-rich sands, with an average of 6% carbonate (Table 14.2), with the east coast beaches having finer, better-sorted sand. The 53 beaches average 1.24 km in length and occupy 38% of the coast, the remainder bedrock plus the Newcastle Bay-Kennedy Inlet mangroves. The beaches are predominately TD (85%), particularly B + SF (59%), with the 17 TM beaches primarily located on the more exposed eastern section, with just two more exposed beaches containing low tide rips (Table 14.3; Fig. 14.4d). While several coral reefs lie off the coast (Fig. 14.3), just one beach is fringed by reefs.

This PC represents a terminus for sediments moving northwards up the east coast, with its eastern boundary at Sharp Point consisting of a 2 km wide regressive series of northwest migrating spits, fronted by 0.5 km wide migratory sand flats (Fig. 14.4e) that are contributing to the infilling of Newcastle Bay. Just offshore the elongate, the teardrop shape of some of the coral reefs indicates strong northwesterly tidal currents that are driving sediment transport towards and around Cape York.

Harris (1989) monitored a coarse carbonate-rich sand wave field in Adolphus Strait, which averaged 4 m in height and 100 m in length and was migrating northwards at 0.25–0.75 m day^{-1}. Wolanski (1983) and Wolanski and Thomson (1984) observed both wind- and tide-driven currents in the northern GBR, and Wolanski et al. (1988) reported how tide ranges up to 6 m and sea-level gradients either side of Torres Strait drive strong tidal currents through the Strait. While there are strong tidal currents in the subtidal-offshore at the shore, the beaches are headland embayed with little evidence of longshore transport (Fig. 14.4c). The role of tidal currents becomes graphically evident once around Peak Point and along the western shore. Shore transverse sand waves and linear island and reef spits are visible in the 2–3 km wide channel between Possession Island and the coast, all evidence of southerly tide-driven sand transport. This sand is deposited in the up to 10 km wide series of regressive beach-foredune ridges and spits that form Slade Point and Crab Island, with Van Spoult Point and the sandy mouth of the Jardine River at their northern tip (Fig. 14.4a).

14.2.3 Barriers

This PC has 21 barrier systems which have a total length of 46 km (26% of coast). On the leeward western and northern shores, they consist of low (<5 m) regressive beach-foredune ridges, as at Van Spoult Point, which average 0.2–0.5 km in width and have generally low volumes. On the exposed eastern shore, there are large densely vegetated transgressive dunes in lee of the exposed east coast beaches (Fig. 14.4d; QLD 224–230). The dunes average 10 m in height and extend up to 4 km inland and represent 90% of the barrier volume (594 M m^3) indicated in Table 14.4. They also act as another sink for the northerly sand transport. With the transgressive dunes included, the compartment has a unit barrier volume of

Table 14.4 Region QLD 03 barrier dimensions

		Primary compartments							Total
PC:QLD	03.01	03.02	03.03	03.04	03.05	03.06	03.07	03.08	QLD03
No.	21	9	30	14	27	35	57	38	231
Total length (km)	46	140	200	107	85	128	254	164	1124
Mean width (km)	0.2–0.5	0.8–7.9	0.3–0.9	0.3–1.8	0.5–2.1	0.1–0.7	0.6–1.1	0.2–0.9	–
Mean height (m)	7.3	38	8.2	5.1	9.7	10.8	5.8	4.5	–
Area (ha)	2803	26,420	60,368	13,567	6540	67,135	23,368	15,173	215,374
Unstable (ha)	58	1261	106	10	394	22,546	40	2712	27,127
Total volume (M m^3)	594	2642	5379	681	540	6390	1501	746	18,473
Unit volume (m^3 m^{-1})	12,945	27,870	26,922	6364	6352	49,800	5934	4550	16,435

12,945 m^3 m^{-1}; when the transgressive dunes are removed, it drops to just 1411 m^3 m^{-1}, indicative of the small size of the lower energy barriers.

14.2.4 PC Overview

This compartment is one of the more significant on the Australian coast and not just because of its iconic location at the tip of the continent. It represents the terminus of one of the major sediment transport paths on the continent. Sediment is transported northwards, albeit in a spatially and temporally haphazard fashion, along the entire eastern Queensland coast. It is transported primarily by waves and tidal currents and to a lesser degree by wind via dunes and headland overpassing. While Fraser Island represents the major and final terminus for the southeast division, Torres Strait and its massive tidal delta represents a major and final terminus for the northeast division.

SC:QLD03.01.02 is a sediment sink for sand moving north along the relatively continuous coast north of Cape Grenville, driven by both waves and tidal currents. Substantial volumes of this sand has been deposited in transgressive dunes in PC:QLD03.02. The sand that arrives at Sharp Point is then transported by tidal currents into Newcastle Bay-Kennedy Inlet where substantial tidal flats have developed. On the northern side of the inlet, some sand has been deposited in now stable transgressive dune systems, while other sand is being transported by tidal currents around Cape York into SC:QLD03.01.01, where it appears to continue down the west coast to accumulate in the large Van Spoult Head-Crab Island regressive beach ridge-spit complex. This complex also receives sand from the Jardine River and from longshore transport from the south and appears to be a secondary wave-deposited coastal sediment sink and a subaerial component of the Torres Strait tidal delta.

The *Torres Strait Islands* are not considered in this book. It should however be noted that the low reef islands are at extreme risk to present storm surge inundation (Fig. 1.14) and to the impact of rising sea level, which will substantially increase the inundation risk. TSRA (2011) predicts the main impacts will be permanent inundation of lower-lying areas and island and an increased frequency and extent of inundation, which will also exacerbate shoreline erosion and recession.

14.3 PC:QLD03.02 Sharp Point–Cape Grenville

PC:QLD03.02 is located on the northeastern corner of Cape York Peninsula extending south from Sharp Point for 120 km to Red Cliffs before tending east into Shelburne and Margaret Bays, to terminate at the protruding Cape Grenville

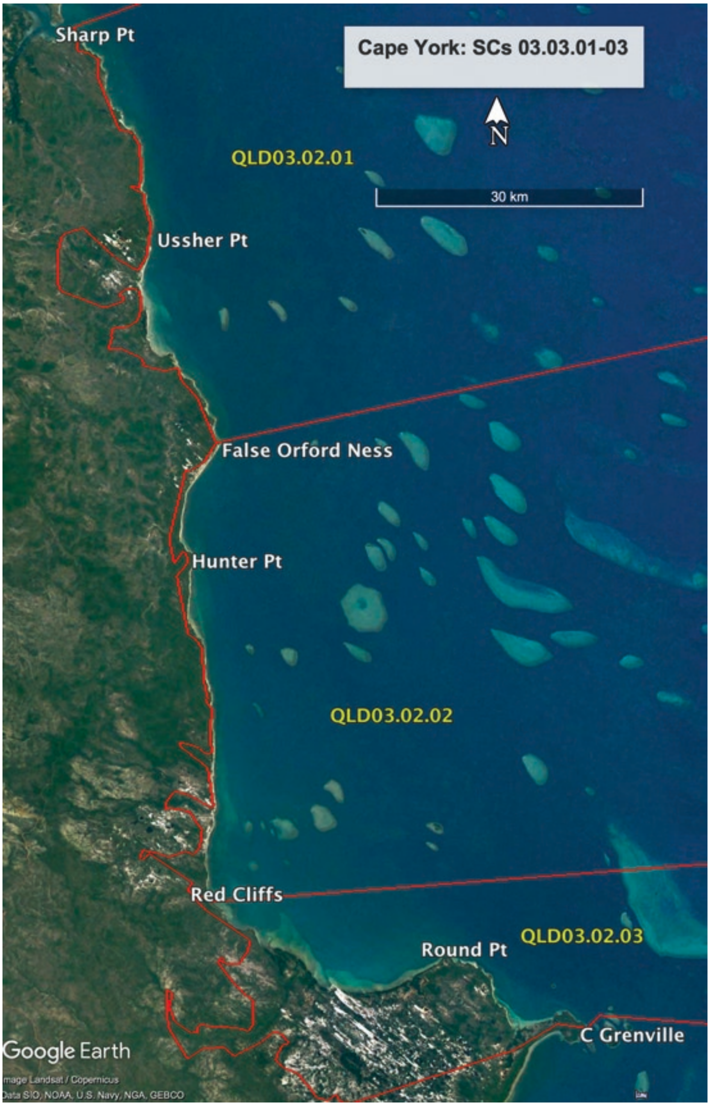

Fig. 14.5 SCs:QLD03.02.01-03 extend from Sharp Point to Cape Grenville. (Source: Google Earth)

(Fig. 14.5), a total shoreline distance of 174 km. The GBR is located well offshore, 130 km off Sharp Point and 70 km off Cape Grenville, with scattered reefs across the inner shelf. The shoreline is a mix of east-facing sandy beaches with a mean length of 1.1 km, most of which are embayed and bordered by sandstone headlands, with the longest extending for 12 km south of False Orford Ness, together with sections of mangrove-lined sand flats in the bays and rhyolite headlands out on Cape Grenville. This is a leaky PC with sediment both entering the compartment from the south and exiting around and over Sharp Point into Newcastle Bay. It contains three leaky SCs with boundaries at False Orford Ness and Red Cliffs (Table 14.1). The northern two compartments (QLD03.02.01-02) are well exposed, while the southern (QLD03.02.03) occupies the sheltered bay shores. There is no development on the coast; however the coastal fishing fleet moor and refuel at Margaret Bay in lee of Cape Grenville, with small planes land on Margaret Bay beach (QLD 327) to take high-value catch to Cairns.

14.3.1 Rivers and Creeks

The Great Dividing Range drainage divide lies from 2 to 30 km from the coast along this PC, with much of the northern hinterland draining west into the Jardine River. As the range moves inland south of Hunter Point, the eastern slopes are drained by Hamer Creek (778 km^2) which is delivering sediment to the coast in Shelburne Bay. Extensive sand shoals extend 1.5 km off the mouth and up to 10 km to the north. They are covered with shore transverse sand waves indicative of northward sediment transport. The other 28 streams and tidal creeks are largely small and unnamed.

14.3.2 Sediments and Processes

This is a sediment-rich compartment composed of moderately well-sorted, coarse quartz sand, containing on average 14% carbonate (Table 14.2). The northern more exposed SCs receive the full force of the southeast winds and waves, which average about 1 m from the southeast with a period of 4–6 s. Spring tide range is 3 m at Cape Grenville and greater than 3 m north towards Cape York. Wave height drops substantially in lee of Cape Grenville the southern SC, with its north-facing lee shores fringed by mangroves.

14.3.3 Beaches

There are 107 largely embayed beaches along the coast, which occupy 66% (115 km) of the shore, the remainder consisting of bedrock along the eastern shore and extensive mangrove-lined sand flats in Shelburne and Margaret Bays. The beaches are a mix of higher energy TM (55%) along the exposed east coast including 30 km of rip-dominated beaches (Fig. 14.6d) and lower energy TD (36%) in lee

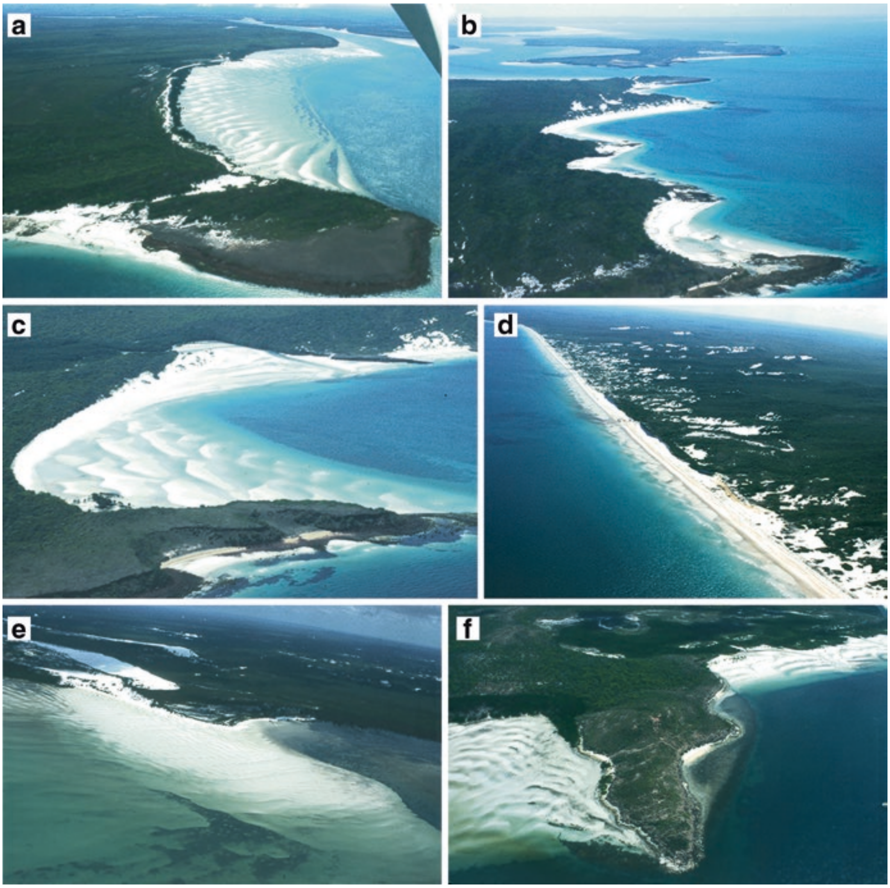

Fig. 14.6 PC:QLD03.02 coast: (**a**) Sharp Point (QLD232) showing headland overpassing and the extensive sand waves on the tidal flats in its lee; (**b**) a series of embayed beaches (QLD 237–233) at the northern end of the compartment; (**c**) Furze Point with QLD 250 in its lee with the sand wave-covered sand flats indicative of sand transport; (**d**) part of the 12 km long beach (QLD 289) extending south of False Orford Ness showing the low tide rip channels and backing transgressive dune field; (**e**) the northern end of a longwalled parabolic dunes extending into Shelburne Bay as the subtidal White Point (QLD 315); and (**f**) ridged sand flats in Waterhole Bay, Cape Grenville (QLD 328). (Photos: AD Short)

of many of the headlands and particularly along the sheltered southern bay shores, together with some fronted by rock flats (7%) and fringing reefs (2%) (Table 14.5). The extensive sand flats have provided an ideal site for the development of ridged sand flats (Fig. 14.6e and f), with 24 km of shore containing well-developed sand ridges with up to 15 ridges extending off the Shelburne Bay shore.

Table 14.5 PC:QLD03.02 beach types and states

BS	BS	No.	%	Length (km)	%	Mean (km)	σ (km)
7	R + LTT	24	22.4	28.3	24.6	1.2	1.8
8	R + LTR	21	19.6	30	26.1	1.4	2.7
9	UD	5	4.7	4.7	4.1	0.9	0.6
10	B + RSF	23	21.5	27.5	23.9	1.2	0.8
11	B + SF	10	9.3	13.7	11.9	1.3	1.9
12	B + TSF	1	0.9	0.3	0.3	0.4	–
14	R + RF	14	13.1	8.2	7.1	0.6	0.3
15	R + CF	9	8.4	2.3	2.0	0.3	0.2
		107	100	114.9	100	1.07	

14.3.4 Barriers

The abundance of sand in this PC is evident in the extensive barrier systems, some of the largest in the northeast division (Table 14.4). Nine large barriers dominated by longwalled parabolics occupy 80% (140 km) of the coast. They range in width from 0.8 to 8 km, covering an area of 24,430 ha. They are largely vegetated and stable (95%) and have a total volume of 2642 M m^3, with a unit volume of 27,870 m^3 m^{-1}, one of the larger in the division and in northern Australia.

14.3.5 Sediment Transport

This PC has an abundance of sediment as evident in the number of beaches, the extensive and massive barrier systems and the wide sand flats in all sheltered location. There is also abundant visual evidence of significant northerly sand transport by waves, tides and wind. The southeast waves drive net northerly longshore sand transport along the beaches and via headland bypassing around the many subdued headlands, with extensive spits and linear bars extending downdrift of the many headlands (Fig. 14.6a, b, c). Immediately seawards of some of the beaches and tidal flats are shore transverse sand waves spaced about 250 m apart and extending from 0.5 to 2 km offshore, which are expected to be driven northwards by tidal currents, possibly assisted by wind-driven currents. The persistent trade winds act both as a mechanism for longshore transport both via headland overpassing and wind-driven coastal currents, and by transporting sand out of the system and into the transgressive dune fields.

Starting in the south at SC:QLD03.02.03, both Pleistocene and Holocene sand has overpassed Cape Grenville to be deposited as 1–2 km wide sand flats in Margaret Bay and particularly Shelburne Bay. Sand appears to be moving west out of Margaret Bay and along the western more exposed beaches and around the sand-rich Round Point and into Shelburne Bay. One of the more interesting evidence of headland overpassing is located at White Point in Shelburne Bay (Fig. 14.6e). The point is white because it is composed of white Pleistocene dune sand that has be transported from the southern Temple Bay 23 km across the base of Cape Grenville to Shelburne Bay. The active longwalled parabolic supplying the point is 5 km long and extends as the point nearly 2 km into the bay terminating as a subtidal sand spit. From there a series of recurved spits and sand waves transport the sand from White Point to Harmer Creek mouth as a large subtidal sand sheet for 10 km to the northwest, with mangroves lining the shoreline. At Red Cliffs wave energy is sufficient for beaches to occupy the shore and northerly wave-driven transport resumes. From here north through SCs:QLD03.02.02 and 01, both waves and tide transport the sand northwards (Fig. 13.6), with minor interruptions at creek mouths and the generally subdued headlands.

14.3.6 PC Overview

PC:QLD03.02 loosely follows the model for east Queensland embayed beach-barrier systems (Fig. 13.12). In lee of Cape Greenville are low energy mangrove-lined sand flats and TD beaches. As the coast turns to face the trade winds, wave and wind energy increase, and higher energy TM beaches prevail, with the higher energy beaches backed by massive transgressive longwalled parabolics. At a secondary level within the embayed beaches, there is also a transition from TD beaches in lee of the headlands to TM up the beach. Throughout the entire system, sand is being transported northwards by wind (headland overpassing), waves (longshore transport and headland bypassing), tides and wind-driven currents (nearshore sand waves). While there have been no studies of this PC, it is expected transport rates would be on the order of 10,000 m^3 $year^{-1}$, with the ultimate destination Newcastle Bay and Torres Strait.

14.4 PC:QLD03.03 Cape Grenville–Stewart River

PC:QLD03.03 trends south from Cape Grenville for 335 km to the mouth of the Stewart River. It contains five SCs:QLD03.03.01-05, with boundaries in Temple Bay, in Cape Weymouth, at the prominent Cape Direction and at Cape Sidmouth (Fig. 14.7; Table 14.1). The inner edge of the GBR lies between 30 and 70 km offshore with extensive reefs occupying the mid-shelf south of Cape Sidmouth. The coast consists of a series of embayed beaches (mean length = 1.4 km), with the longest just 10 km extending south of Cape Villas. The beaches are primarily bordered by Permian granite headland rocks and reefs, with all the capes composed of granite. The only development in the region is the small fishing community at Portland Roads in lee of Cape Weymouth (~20 population), the Lockhart aboriginal community (650) located 2 km in from the coast north of the Lockhart River mouth,

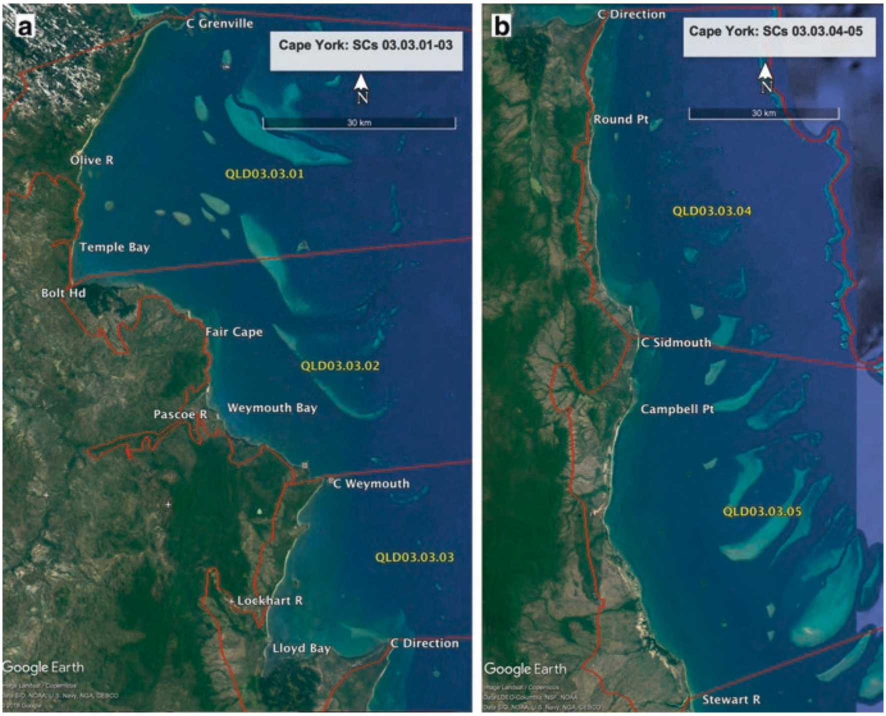

Fig. 14.7 (**a**) SCs:QLD03.03.01-03 and (**b**) SCs:QLD03.03.04-05 extend from Cape Grenville to the Stewart River and contain five SCs. (Source: Google Earth)

together with a smaller community at the Old Lockhart settlement, and the Silver Plains camping and fishing area (<10) at the mouth of the Stewart River. All are accessible by 4WD tracks.

14.4.1 Rivers and Creeks

The Great Dividing Range lies between 20 and 40 km inland, and while all the major rivers drain west to the Gulf, there are a series of smaller rivers draining east to the coast and delivering sediment to the shore. These are the Olive (1681 km^2, Fig. 14.8a), Pascoe (2077 km^2, Fig. 14.8b), Lockhart (900 km^2), Chester (233 km^2), Rocky (71 km^2) and the Stewart (880 km^2). In addition, there are 35 smaller upland streams, including some draining the Cape Grenville dune fields in the north, grading to more tidal creeks with migratory inlets in the south.

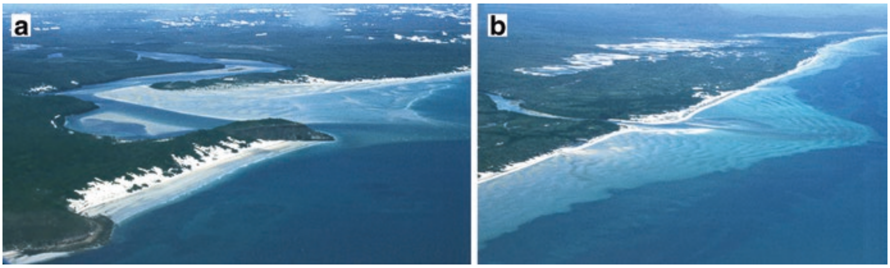

Fig. 14.8 (**a**) Mouth of the Olive River with transgressive dunes to either side (QLD 349–50) and (**b**) the Chester River mouth with its protruding ebb tide delta and ridged sand flats (QLD 473-4) and extensive ebb tide delta. (Photos: AD Short)

14.4.2 Coastal Processes

The beach sediments are similar to PC:QLD03.02, namely, moderately well-sorted, coarse quartz sand with slightly higher carbonate at 14% (Table 14.2). Spring tides average 3 m at Cape Grenville dropping to 2.5 m at Portland Roads. Exposure to the southeast wind and waves ranges from fully exposed on the east to southeast-facing sections, to sheltered in Temple and Lloyd bays and in lee of some of the larger headlands, with the exposed beaches receiving waves averaging <1 m.

14.4.3 Beaches

There are 148 beaches that occupy 63% (212 km) of the coast, with an average length of 1.4 km. Their boundaries are a mix of granite headlands, rocks and reefs and tidal creeks, streams and some rivers. They are a mix of TM (43.5%) on the more exposed sections, with 30% of the beaches the more exposed R + LTR (Fig. 14.9), while TD (42.4%) dominate the sheltered locations, with 29% B + RSF (Table 14.6). The ridged sand flats average 7 ridges (the Australian average), with a maximum of 22 ridges located off beach QLD 275 in lee of First Stony Point. Seventeen beaches are fronted by rock flats and ten by fringing reefs, together with ten with transverse sand waves occupying their subtidal sand flats (Fig. 13.6), the latter indicative of tide-driven sediment sand transport.

14.4.4 Barriers

Barriers occupy 200 km (60%) of the coast, with the northernmost Cape Grenville system one of the larger on the east Queensland coast. It occupies 22 km of the coast and extends inland for up to 29 km as a series of multiple longwalled parabolic

Fig. 14.9 Beach QLD 350 on the southern side of the Olive River mouth at low tide with rips in the surf zone and an unstable foredune leading to blowouts. (Photo: AD Short)

Table 14.6 PC:QLD03.03 beach types and states

BS	BS	No.	%	Length (km)	%	Mean (km)	σ (km)
7	R + LTT	22	14.9	63.1	29.7	2.9	2.9
8	R + LTR	6	4.1	21.9	10.3	3.6	3.7
9	UD	4	2.7	7.4	3.5	1.9	1.8
10	B + RSF	38	25.7	61.1	28.8	1.6	1.6
11	B + SF	29	19.6	26.2	12.3	1.6	2
12	B + TSF	12	8.1	2.8	1.3	0.2	0.2
14	R + RF	17	11.5	2.2	1.0	0.1	0.1
15	R + CF	10	6.8	8.4	4.0	0.8	1.1
16	R + SW	10	6.8	19.2	9.0	1.9	1.2
		148	100	212.3	100	1.43	

dunes, which overpass all the way to Shelburne Bay and are actively supplying sand to the bay at White Point (Fig. 14.6e). The white colour of the dune sand, compared to the yellow beach sand, suggests they are reactivated Pleistocene dunes. This barrier dominates the compartment comprising 92% of the barrier volume and 70% of the barrier area. The remaining barriers tend to be relatively short and/or small in size, with none extending more than 2.5 km inland. They are a mix of small regressive chenier to foredune ridge plains, cuspate forelands and tombolos, a few smaller transgressive systems and in the south migratory recurved spits at creek mouths.

Lees et al. (1990) and Lees (1992) identified five phases of dune building in the Cape Grenville-Shelburne Bay dune field. These occurred during the sea-level lowstand at 29 ka and 24–18 ka, accompanying the PMT and stillstand between 6.1 and

5.5 ka, with two episodes since at 3.6–3.5 ka and 0.8 ka. Lee concluded the latter two episodes may have been related to drier climate conditions. The large volumes of quartz-rich sand also suggest a shelf origin.

The following sections (Sects. 14.4.5–9) examine the nature and sand transport within each of the five SCs.

14.4.5 SC:QLD03.03.01 Cape Grenville–Bolt Head

The northernmost SC (QLD03.03.01) extends from Cape Grenville for 55 km to the creek mouth at Bolt Head. A 3 km long series of south-trending spits indicate some sand is moving south of Bolt Head into the creek region. A series of beaches and headlands extend north to the mouth of the Olive River, with minor dune transgression on most of the beaches. The Olive appears to be delivering sand to the coast, which may supply in part the massive dune systems that extend to the north. At the river mouth the coast turns and faces southeast into the prevailing wind and waves. The waves have supplied massive volumes of sand to the shore which in turn have been blown inland and across the base of the base of the Cape Grenville dune field (Fig. 14.10), one of the larger in the division with an area of 42,500 ha, volume of 4250 M m^3 and a large per metre volume of 94,400 m^3 m^{-1}. Given the leached white colour of the dunes, these appear to the Pleistocene in age and reactivated by Holocene processes. It is uncertain how much of this sand has been supplied during the Holocene. The dune field is the major sink for this PC with some leakage via headland overpassing at White Point to the next compartment, but little if any rounding the reef-sheltered Cape Grenville.

Fig. 14.10 Part of the Cape Grenville transgressive dune field fronted by an UD beach (QLD 349). (Photo: AD Short)

14.4.6 SC:QLD03.03.02 Bolt Head–Cape Weymouth

The Weymouth Bay (SC:QLD03.03.02) is another smaller apparently more stable SC. Most of the northeast-facing southern shore extends west for 30 km to the mouth of the Pascoe River and is mangrove-lined and stable. The Pascoe River delivers sand to the shore (Fig. 14.8b), and this appears to be transported northwards to and off Fair Cape in 14 km long and up to 4 km wide sand shoals covered by north-trending sand wave field (Fig. 14.11a). The sand waves have a wave length of about 180 m and a transverse crest length averaging about 1 km. At Fair Cape and First Stony Point, there is evidence of headland bypassing (and overpassing) with sand moving subaqueously all the way to Mosquito Point, where it appears to terminate at the north-facing 10 km wide mangrove-lined mouth of Kangaroo Creek, with the SC terminating at the western end of the mangroves.

14.4.7 SC:QLD03.03.03 Cape Weymouth–Cape Direction

The smaller Lloyd Bay-Cape Weymouth SC (QLD03.03.03) is dominated in the south by 7 km wide, mangrove-lined funnel-shaped mouth of the Lockhart River. Recurved spits immediately north of the river mouth indicate that sand is being transported south into the bay. The beaches extending up to Cape Griffith and then

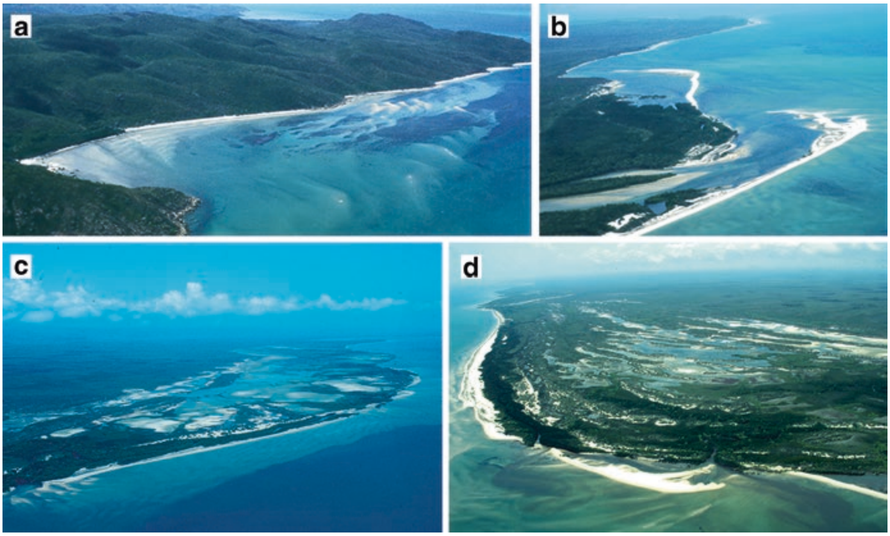

Fig. 14.11 PC:QLD03.03 coast: (**a**) sand waves approaching Fair Cape (QLD 386); (**b**) migratory elongate recurved spits at Campbell Point (QLD 469); (**c**) barrier islands lying off Massey Creek (QLD 480); and (**d**) Claremont Point where up to 15 recurved spits have prograded the shore up to 3.5 km seaward (QLD 483). (Photos: AD Short)

Cape Weymouth appear to be more stable and show little evidence of longshore transport. This SC appears to be a sink with sand moving from the east and north into the bay.

14.4.8 SC:QLD03.03.04 Cape Direction–Cape Sidmouth

SC:QLD03.03.04 has a continuous sedimentary shoreline occupying the entire 78 km long SC, with Holocene barriers having an area of 5750 ha and volume of 287 M m^3 which represents 3685 m^3 m^{-1}. It also represents sand that has been taken out of the northerly transport system and a secondary sediment sink on this otherwise open coast. North of Friendly Point sand continues to move up the coast with a series of minor interruptions at headland and points, a regressive barrier at Bobardt Point and finally minor dune transgression along southeast-facing Cape Direction. On the southern side of the cape, sand wave-covered shoals extend 4 km east of the cape, and a subaqueous sand spit trends 8 km west of the tip of the cape into Lloyd Bay, indicating tidally driven transport to and around the cape. However, these sand shoals and the spit may represent the terminus for sand transport, as it does not appear to be crossing the Lockhart River mouth to reach the western shore of the bay, the cape acting as an obstacle to ongoing transport.

14.4.9 SC:QLD03.03.05 Cape Sidmouth–Stewart River

The southernmost SC (QLD03.03.05) is receiving sediment in the south from the Stewart River and probably out of Princess Charlotte Bay. Extending north of the river is a series of interrupted north-trending recurved spits (Fig. 14.11b, c and d) backed by barriers up to 2 km wide that continue all the way to its boundary at Cape Sidmouth. A recurved spit extends north of Cape Sidmouth, linking with the Friendly Point barrier system. This is a regressive spit complex containing up to 15 spits that have prograded the cuspate point up to 2.5 km seawards. The spits and regressive barriers continue uninterrupted, apart from creek mouths, to Cape Direction, the northern boundary of SC:QLD03.03.04.

14.4.10 PC Overview

This is a somewhat variable PC that begins in the south by trending north for 150 km from Princess Charlotte Bay to Cape Direction, the shoreline near continuous beaches, barriers and northerly sand transport. It then breaks into a series of more stable SCs at Cape Direction-Lloyd Bay and Cape Weymouth-Temple Bay, to finish as the coast turns into the trades with the massive sand sink of the Cape Grenville dune fields. The two southern SCs (QLD03.03.04 and 5) show evidence of significant northerly longshore sand transport by waves, tides and possibly wind-driven currents. While sand appears to be moving around the boundary at Cape Direction, it does not appear to be feeding into the Lloyd Bay SC (QLD03.03.03), which appears to be a sediment sink and relatively stable SC. The Weymouth Bay SC (QLD03.03.02) does show evidence of longshore wave and tidal transport between the mouth of the Pascoe River and Fair Cape and First Stony Point, but then appears to terminate here. The northern Temple Bay SC (QLD03.03.01) has the mangrove-filled Temple Bay in the south acting as a sediment sink, but may have limited longshore transport north of the Kangaroo River mouth, with some evidence of headland bypassing. North of the Olive River mouth as the coast turns to face south-east, that wave and wind have delivered sand to the massive sink of the Cape Grenville dune field. However, this sand appears to be Pleistocene in age and off the shelf, rather than of longshore origin. This PC therefore from the south has open, though interrupted, SCs (QLD03.03.04-05), then a leaky QLD03.03.02 and finally QLD03.03.01 with a southern sink (Temple Bay) and a northern shore that terminates in the large Cape Grenville dune sink, with sand transported longshore by waves, tides, wind-driven currents and by wind across the dune fields.

14.5 PC:QLD03.04 Stewart River–Cape Melville

PC:QLD03.04 marks a major change in the orientation and nature of the coast as it trends due east for 152 km from the Stewart River to Cape Melville. In between is a relatively open, but sheltered PC consisting of two open U-shaped north-facing bays (Princess Charlotte and Bathurst) bordered by the towering boulder granite slopes of Bathurst Head and the Flinders Group of islands, Bald Hill and Cape Melville (Fig. 14.12). Because of its northerly orientation and sheltering by Cape Melville and the islands, it is a low wave energy, TD shoreline, particularly in eastern Princess Charlotte Bay where mangrove-lined mud flats form most of the shore. Bathurst Bay receives some southerly waves which are refracted around Cape Melville as well as summer northeast winds and waves. It has a predominately sandy shoreline. The PC contains two SCs:QLD03.04.01 (Princess Charlotte Bay) and QLD03.04.02 (Bathurst Bay) (Table 14.1).

14.5.1 River and Creeks

Twenty generally small- to moderate-sized tidal creeks are located along the coast, together with the larger North Kennedy (11,854 km), Normandy (10,880 km^2) and Marrett (1295 km^2) rivers which flow into Princess Charlotte Bay, while Bathurst Bay has no significant rivers or creeks. The North Kennedy drains the Great Divide to the west, while the Normandy-Marrett drain the coastal range to the south and

Fig. 14.12 PC QLD:03.04 extends from the Stewart River to Cape Melville, with two SCs divided by Bathurst Head. (Source: Google Earth)

east. The rivers are located along a curving 30 km section of the southern shore of the bay and have combined to build a substantial TD delta consisting of extensive tidal flats extending along 60 km of shore, with active flats extending 1 km inland and raised flats up to 30 km inland.

14.5.2 Coastal Processes

This is a TD section of coast. Its northerly orientation and protecting headland and islands, combined with the predominately southeast winds and waves, maintain a sheltered lee shore with calms to low waves along much of Princess Charlotte Bay rising to perhaps a few decimetres in Bathurst Bay, which is also more exposed to summer and sea breeze northeasterlies. Spring tide range is 2.5 m at Cape Melville. The PC is well exposed to tropical cyclone winds, waves and storm surges, which as will be seen below probably play a role in chenier formation. Bathurst Bay was also the site of one of the most devastating cyclones in modern Australian history, when category 5 tropical cyclone Mahina hit in 1899. In Princess Charlotte Bay-Bathurst Bay, the storm surge reportedly reached 13 m and swept 5 km inland. It destroyed the pearling fleet sheltering in the Flinders Group, where 54 vessels sank with the loss of more than 300 lives. More recently Nott et al. (2013) re-examined the evidence and suggest the cyclone, while the most intense recorded in the southern hemisphere reached a height of 7 km in Bathurst Bay and 9 m in Ninian Bay, still the highest recorded in Australia.

14.5.3 Beaches

There are 30 beaches along the shore which occupy 67 km (44%) of the PC, primarily on the west coast south of Stewart River and in Bathurst Bay. They are all TD, with sand flats averaging 420 m in width fronting most of the beaches (68%) followed by the lower energy B + RSF (28%) (Table 14.7). The 10 km long beach extending west of Melville Head (Fig. 14.13c) has 15% carbonate material with beachrock exposed along parts of the shore. The beach type confirms the low energy nature of the shore, much of the remainder being tidal mud flats in Princess Charlotte Bay, river and creek mouths and the rocky headlands.

Table 14.7 PC:QLD03.04 beach types and states

BS	BS	No.	%	Length (km)	%	Mean (km)	σ (km)
10	B + RSR	1	3.3	2.4	3.6	2.4	–
11	B + SF	26	86.7	45.4	68.0	1.8	2.3
12	B + TSF	3	10	18.9	28.4	6.3	9.7
		30	100	66.7	100	2.2	

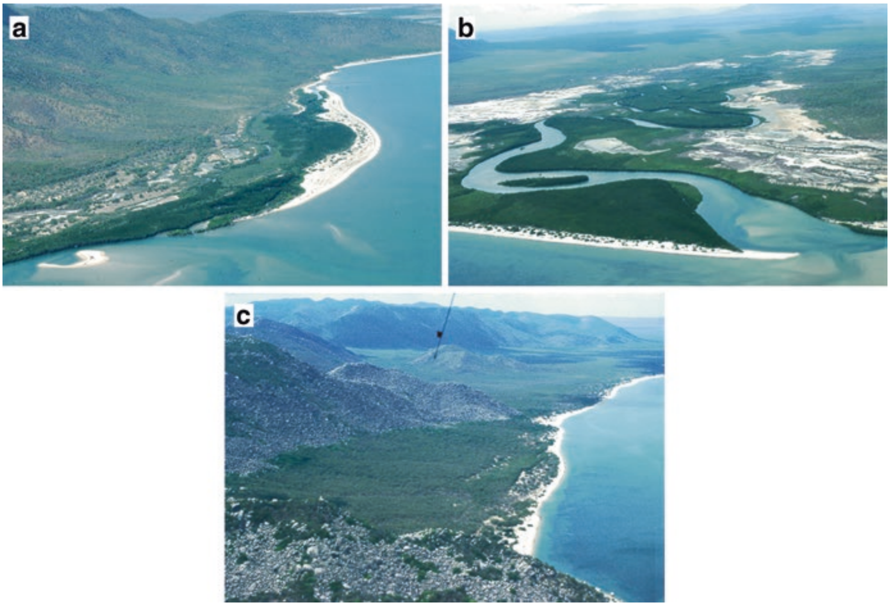

Fig. 14.13 PC:QLD03.04 coast: (**a**) 2.5 km long barrier spit (QLD 509) at the base of Bald Hill; (**b**) deflected creek mouth (QLD 513); and (**c**) the crenulate10 km long QLD 516 backed by the boulder granite slopes rising to the Melville Range. (Photos: AD Short)

14.5.4 Barriers

Fourteen barriers occupy 107 km (70%) of the shore. These are located in Princess Charlotte Bay between the Stewart River and the start of the bay mud flats (48 km) and on the eastern side of the bay south of Bathurst Head (32 km). In Bathurst Bay smaller regressive beach ridge systems occupy 28 km (60%) of the curving bay shore, the remainder mainly granite bedrock. For 30 km south of Stewart River, regressive beach-foredune ridge plains have prograded up to 1.5 km into the bay. South of Running Creek, the decreasing wave energy sees these replaced by beach ridges, then cheniers and then mud flats with mud flats and scattered cheniers occupying the centre of the bay shoreline. The barriers, while extensive, tend to be low (mean height = 5 m) and range in width from 0.29 to 1.8 km. They cover an area of 13,577 ha, are largely stable and have a total volume of 681 M m^3, with a unit volume of 6364 $m^3\ m^{-1}$ (Table 14.4), with 95% of the sediment deposited in Princess Charlotte Bay.

The eastern Princess Charlotte Bay chenier plain was investigated by Chappell and Grindrod (1984) who found the regressive plain had prograded 2–3 km into the bay over the past 6 ka. They used the results of this study together with studies of cheniers in the Gulf of Carpentaria and Broad Sound to conclude that 'depositional geometry' (accommodation space) plays a major role in depositional trends without the need to invoke variations in terrigenous sediment flux. They also found that sea level appears to have fallen smoothly over the past 6 ka; the mangroves are essential for trapping both shelly and mud material; and that shell availability is a prime factor in chenier formation, which is in turn related to the rate of mud sedimentation, with higher rates inhibiting shell production. They then proposed two modes of progradation and episodic ridge building – the rapid progradation mode where fluctuations affect shell availability and the cut and recover mode, which involves interaction between storms (tropical cyclones), mud deposition and the mangrove fringe. Subsequently Horne et al. (2015) used OSL dating of 11 cheniers located in the southwestern section of the bay and found that the most landward chenier ridge formed no more than 4 ka, with ridges 2 and 3 built in the next ~1500 years and ridges 4 to 11 between 2.4 and 0.82 ka. They suggest that late Holocene sea-level fluctuations may have played a role in ridge formation.

14.5.5 SC:QLD03.04.01 Princess Charlotte Bay

The Princess Charlotte Bay SC is a major sink for the fine sediments delivered by the three river systems. There appears to be little sand being delivered as indicated by the absence of sand deposits and the dominance of shells in the cheniers. If sand is being deposited in the bay, it does not appear to be reaching or being transported up the increasingly higher energy western shore, until with ~10 km of Stewart River, where the first north-trending recurved spits occur at the creek mouths, indicating north sand transport.

14.5.6 SC:QLD03.04.02 Bathurst Head to Cape Melville

The Bathurst Bay SC is slightly higher energy and more active. There is a possibility of very limited amounts of sand moving around Cape Melville and into the eastern side of the bay. If so volumes would be small. There is evidence of limited transport down the eastern and along the southern shore of the bay, manifest in the predominance of west-trending spits at the many creek mouths (Fig. 14.13a and b) and 500 m wide regressive barriers occupying the two central embayments. Bald Head appears to be an obstacle to transport with spits trending east and west on either side of the head.

14.5.7 PC Overview

This is a reasonably closed deeply embayed north-facing PC containing two embayed SCs. While there may be some bypassing around Cape Melville and sand transport along the western and southern shore of Bathurst Bay, this appears to be minimal, with no apparent bypassing around Cape Bathurst, with Bathurst Bay appearing to be a small TC sink containing barriers with a volume of ~60 M m^3. Princess Charlotte Bay is a larger TC sink (~620 M m^3) for fine sediment delivered by the three upland river systems that have built the chenier plain and mud flats which, together with fringing mangroves, occupy the very low gradient 70 km long southern shore of the bay. Sandy beaches return along the western shore as wave energy increases northwards, with ridged sand flats beginning just south of the PC boundary at Stewart River. The low-lying Princess Charlotte Bay shore will be extremely vulnerable to rising sea level as its low gradient inter-supratidal zone is inundated, reactivating mangrove colonisation along the rivers and across the supratidal flats.

14.6 PC:QLD03.05 Cape Melville–Cape Flattery

PC:QLD03.05 is a northeast-facing compartment that extends for 178 km from the rocky Cape Melville to Cape Flattery (Fig. 14.14). In between however are several sections of coast bordered and/or embayed by protruding points largely formed of Palaeozoic metasedimentary rocks (Fig. 14.15a), with the central low sandy Murdoch Point dividing the compartment into two SCs (QLD03.05.01-02) (Table 14.1). The outer GBR parallels the coast, the distance offshore more a factor of the shoreline configuration and ranges from 25 to 50 km, with scattered low and high island on the mid-shelf (Fig. 14.14). The only development in the area is the Cape Flattery silica sand mining operation whose jetty and offices are located in lee of the cape.

Fig. 14.14 PC:QLD03.05 extends from Cape Melville to Cape Flattery, with two SCs located either side of Murdoch Point. (Source: Google Earth)

14.6.1 Rivers and Creeks

Twenty-five streams, tidal creeks and river reach the coast along this PC. Most are small unnamed streams draining the 200–400 m high range of hills that parallel the coast and form the headlands, together with tidal creeks draining the mangrove systems and some of the barriers, and two small rivers the Horwick (312 km^2) and Jeannie (486 km^2) which drain the coastal range. The Horwick flows into the tidal flats, cheniers and mangroves that have filled the embayment in lee of Red Point (Fig. 14.15b) and does not appear to be contributing sediment to the coast, while the Jeannie has built a small delta and has a 7 km long series of recurved quartz-rich spits (0–1% carbonate) grading into more recent blowouts extending north of the mouth up to Murdoch Point and appears be delivering sand to the shore.

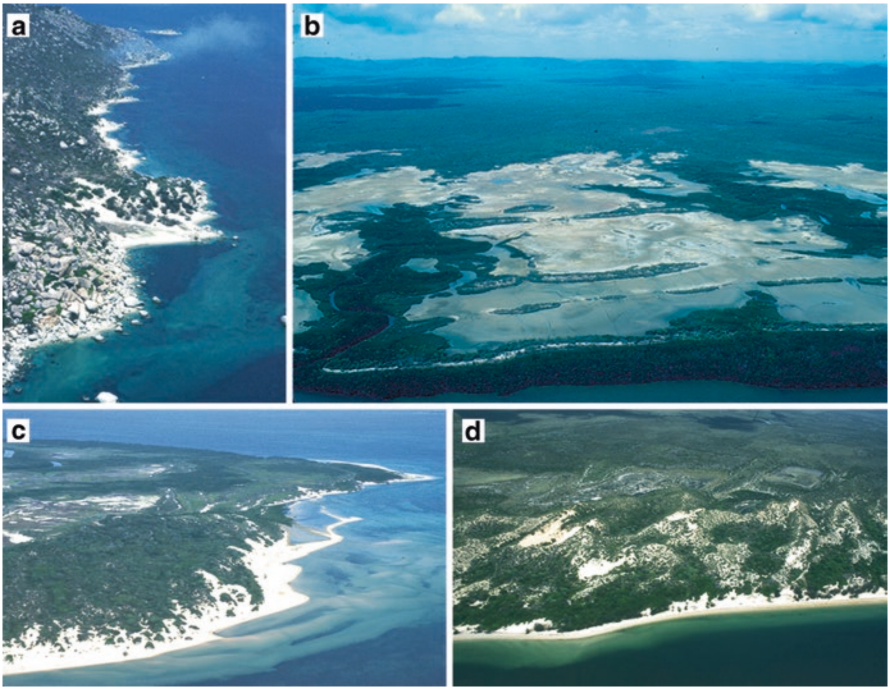

Fig. 14.15 PC:QLD03.05 coast: (**a**) the steep rocky granite coast of Cape Melville (QLD 525); (**b**) mangrove-fronted cheniers and tidal flats in lee of Red Point (QLD 570–1); (**c**) sand moving north from the Jeannie River (QLD 585 with Murdoch Point in the distance); and (**d**) vegetated Pleistocene and Holocene parabolic dunes south of the Jeannie River (QLD 592). (Photos: AD Short)

14.6.2 Coastal Processes and Sediments

This is at most a moderate energy section of coast, owing to the northeast orientation, combined with the number of protruding headland and inshore reefs that afford local protection from the prevailing southeast wind and waves. Consequently, wave energy varies alongshore from moderately exposed on the east-facing sections of North Bay, Barrow, Red, Jeannie and Lookout Points to very sheltered in their lee where the shore faces north and mangroves line parts shore. Spring tides are 2.5 m at both Cape Melville and Cape Flattery. The trade winds continue to dominate from the southeast (Fig. 13.7).

Sediments are predominantly quartz sand with carbonate ranging from between 2 and 15% down to Ninian Bay rising up to between 20 and 60% in Ninian Bay and then dropping to 1–3% south of Cape Bowen (Table 14.2). The Ninian Bay carbonate is derived from coral reefs which fringe the western shore of the bay.

Table 14.8 PC:QLD03.05 beach types and states

BS	BS	No.	%	Length (km)	%	Mean (km)	σ (km)
7	R + LTT	10	10.2	19.9	24.4	2	2.0
8	R + LTR	4	4.1	8.1	9.9	2.0	2.3
10	B + RSF	12	12.2	16.1	19.8	1.3	1.0
11	B + SF	44	44.9	27.3	33.6	0.6	0.7
12	B + TSF	9	9.2	4.6	5.7	0.5	0.4
14	R + RF	16	16.3	4.2	5.2	0.3	0.2
15	R + CF	3	3.1	1.1	1.4	0.4	0.4
		98	100	81.2	100	0.8	

14.6.3 Beaches

The 98 beaches in this PC occupy 81 km (46%) of the coast and reflect the variable orientation and level of wave energy along the shore. They tend to be short (mean = 0.8 km) and range from higher energy TM (34%) including R + LTR along four beaches and 8 km of coast, to the dominant TD (59%), with R + RF fronting 5% and R + CF fringing just three beaches (3%) in Ninian Bay. The dominant beach state is B + SF (34%), while B + RSF make up 20% (Table 14.8). The sand flats average 340 m in width (σ = 350 m), while the sand ridges average 7 (the Australian average), with σ = 4 and the maximum 17 ridges.

14.6.4 Barriers

There are 27 barriers along this PC which occupy 85 km (48%) of the shore (Table 14.4) and range from regressive beach ridges to transgressive dunes. Extending for 25 km south of Cape Melville are a series of small embayed barriers composed of either regressive beach-foredune ridge plains or on the more exposed sections minor dune transgression and minor headland overpassing at Rocky Point. Ninian Bay has remnant of a transgressive Pleistocene barrier that extends 2.5 km inland but is now fronted by a marsh and a narrow unstable foredune. A series of regressive barrier islands and spits extend for 10 km south of Barrow Point. The largest barriers are in the south associated with the spits extending north of the Jeannie River (Fig. 14.15c); the Pleistocene and Holocene transgressive dunes that extend south of the river (Fig. 14.15d); and the Lookout Point transgressive dune field. All the embayments and their barrier follow in general the embayed-barrier model presented in Fig. 13.12, with mangroves and tidal flats in lee of the more prominent points, grading northwards with exposure into beach ridges, foredune and on the most exposed section transgressive dunes. The barriers have a total volume of 540 M m^3 and per metre volume of 6452 m^3 m^{-1}.

14.6.5 SC:QLD03.05.01 Cape Melville to Murdoch Point

SC:QLD03.05.01 commences in the south at Murdoch Point, seaward of which is a large sand wave field in the 1.5 km wide channel between the point and Murdoch Island. The sand waves extend up to 5 km seawards and for 25 km northwest to Red Point. This may be transporting sand sourced from the Jeannie River and if so is transporting through the open SC boundary and as far as Red Point. The remainder of the coast up to Cape Melville appears to be more stable, consisting of two southern north-facing mangrove-lined bays, between Murdoch and Red points and Red Point-Cape Bowen, two curving north-trending bays north of Cape Bowen and Ninian Bay, and the final section of rocky shore and small beaches leading up to Cape Melville. Three small west-trending recurved spits occur in lee of Cape Melville, Barrow Point and Red Point indicating limited longshore transport in lee of the points and suggesting probable headland bypassing.

14.6.6 SC:QLD03.05.02 Murdoch Point–Cape Flattery

The southern SC (QLD03.05.02) commenced in the south at the large Cape Flattery transgressive dune field which extends 27 km to the rear of this SC, reaching the shore along the low energy Flattery Harbour where it has supplied fine sand to the 1 km wide sand flats that line the 12 km long harbour shore and reach the base of Lookout Point, where they are very likely incorporated in the smaller Lookout Point transgressive dune field. There appears to be headland bypassing around Lookout Point, as well as past overpassing via dunes, both of which have very likely contributed to the 4 km long, 1–1.5 km wide sand wave field that lies in lee of the point and is actively transporting sand for 4 km to the west, but not to the next section of the shore. However just west of this field are two discrete sand wave fields, the larger extending 6 km offshore which appears to show evidence of western tidal transport. These terminate before the small Starcke River which has built a 5 km long series of recurved spits that have prograded 2 km seawards, but which are now fronted by mangroves and another discrete sand wave field.

The next source of sediment is the Jeannie River which has supplied sand to its recurved spits and a transgressive dune field that extends for 7 km north of the river and which has formed the SC boundary at the low sandy Murdoch Point (Fig. 14.15c). The river shows evidence of former Pleistocene dunes and spits, as well as a double Holocene spit system (Fig. 14.16). The transformation of the Holocene barriers from inner beach ridge-spits to outer transgressive dunes may be a result of the more easterly rotation and orientation of the modern beach and greater exposure to the trade winds and waves.

Fig. 14.16 Jeannie River sand is being transported northwards by wind, waves and tidal currents to form beaches, dunes and elongate spits. There is evidence of earlier Pleistocene spits (P1) and transgressive dunes (P), as well as the Holocene spits (H1) and transgressive dunes (H2). (Source: Google Earth)

14.6.7 PC Overview

This is a relatively small PC that faces northeast but is highly variable in terms of its orientation owing to the several headland-bound embayments that have shorelines ranging from north-facing wide mangrove-lined sand flats, to barrier islands, regressive beach-foredune ridges, to east to southeast-facing transgressive dunes, as illustrated by Fig. 14.16. There are only two small rivers, with only the Jeannie actively delivering sand to the system. Sediment transport is occurring spatially intermittently along the shore. Overpassing from the Cape Flattery dunes is delivering sand to Flattery Harbour, which is transported as far as the Lookout Point dune field, wth discrete sand wave fields extends for 20 km west of Lookout Point. The Jeannie River is supplying sand to its north-trending delta deposits and apparently to a sand wave field that moves through the Murdoch Point channel and towards Red Point, with intermittent and interrupted transport beyond.

14.7 PC:QLD03.06 Cape Flattery to Cape Grafton

PC:QLD03.06 extends for 347 km between the major capes Flattery and Grafton (Fig. 14.17). It is an east-facing section of coast with the outer GBR located about 40 km offshore, together with mid-shelf reefs, with the outer GBR breaking into a series of larger shore transverse reefs south of Cape Kimberley. The PC contains four SCs with boundaries at Endeavour River (Cooktown), Cape Kimberley and Island Point (Port Douglas). This is the beginning of the more developed coastline that extends down the entire east coast, with the aboriginal settlement at Elim (750), town of Cooktown (2500), the Cape Tribulation-Daintree tourist region and the highly developed strip from Port Douglas to Cairns, with 160,000 living in the Cairns region.

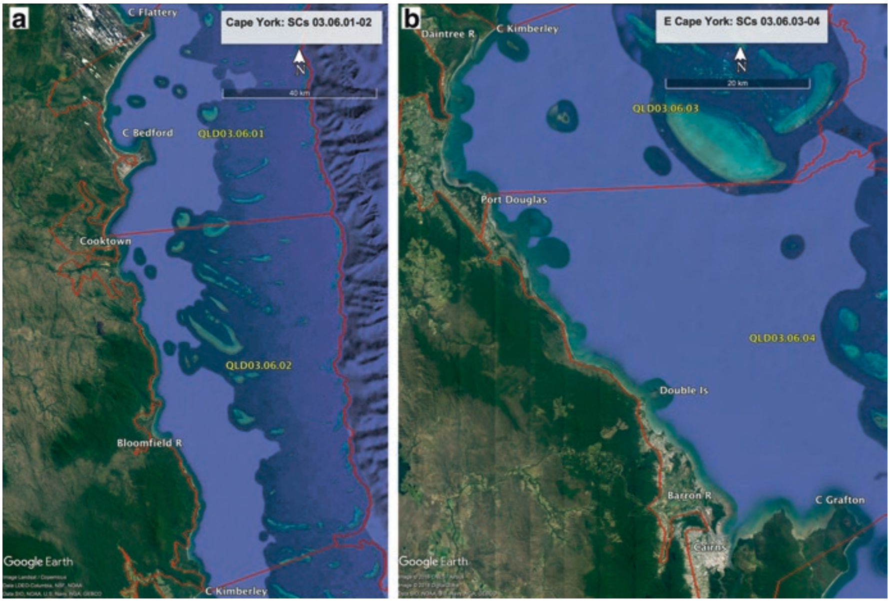

Fig. 14.17 PC:QLD03.06 extends from Cape Flattery to Cape Grafton and has four SCs, shown in (**a**) QLD03.06.01-02; and (**b**) QLD03.06.03-04). (Source: Google Earth)

14.7.1 Rivers and Creeks

Between Cape Flattery to Rocky Point, the coastal range lies about 30 km inland south of which it runs close to the coast around Cedar Bay, Cape Tribulation and between Port Douglas and Cairns. The rugged terrain combines with the high rainfall (Cairns 2000 mm) to produce numerous streams and several small- to moderate-sized rivers including the McIvor (516 km^2), Endeavour (918 km^2), Annan (992 km^2), Bloomfield (591 km^2), Daintree (1120 km^2), Mossman (256 km^2), Mowbray (119 km^2) and the largest the Barron (2159 km^2). All of the rivers and many of the streams are delivering sand to the coast from the sedimentary and granite rocks of the ranges.

14.7.2 Coastal Processes and Sediments

Coastal processes along this PC remain dominated by the meso-tides which range from 2.5 m at Cape Flattery, to 2.2 m at Cooktown and 2.5 m at Cairns combined with the southeast trade winds and waves. The waverider buoy off Cairns has recorded a modal deepwater wave height of 0.4 m and period of 4 s from the southeast, while at the shore COPE observations recorded significant breaker wave heights of between 0.4 and 0.7 m with periods of 4–5 s along the more exposed northern Cairns coast. As Fig. 13.7 indicates, winds are predominately from the southeast. Beach sediments are predominately moderately well-sorted, medium quartz sand, with carbonate averaging 8%, but ranging locally from 0 to 65% (Table 14.2). The lowest carbonate occurs between Endeavour River and the Cape Bedford dunes, with some beaches having no carbonate, suggesting the sand may be derived from reworked Pleistocene sand. The higher percentages occur between Walker Bay and Donovan Point where coral reefs parallel the shore and supply carbonate detritus to the beaches.

14.7.3 Beaches

The 120 beaches in this PC occupy 187 km (54%) of the shore, the remainder predominately bedrock, with just a few areas of mangroves, as well as the creek and river mouths. The beaches average 1.5 km in length, and their types reflect the generally more exposed nature of much of this section of coast, with a few WD reflective beaches (1%), a dominance of TM beaches (76%), particularly R + LTT (58.5%), followed by TD (23%) dominated by the relatively higher energy B + RSF (13%) (Table 14.9). Twenty-six of the beaches have coral reefs located just offshore, the reefs supplying carbonate detritus to the shore.

Table 14.9 PC:QLD03.06 beach types and states

BS	BS	No.	%	Length (km)	%	Mean (km)	σ (km)
6	R	7	5.8	1.7	0.9	0.2	0.2
7	R + LTT	68	56.7	109.1	58.5	1.6	1.9
8	R + LTR	4	3.3	29.9	16.0	7.5	5.6
9	UD	7	5.8	3.1	1.7	0.5	0.3
10	B + RSF	15	12.5	24.6	13.2	1.6	1.5
11	B + SF	13	10.8	8.9	4.8	0.7	0.8
12	B + TSF	4	3.3	8.8	4.7	2.2	1.0
14	B + RF	2	1.7	0.3	0.2	0.15	–
		120	100	186.5	100	1.5	–

14.7.4 Barriers

Thirty-five barriers occupy 128 km (37%) of the coast (Table 14.4), the relatively low percentage owing to the predominance of rocky shore, and south of Cape Flattery the lack of accommodation space on this generally steep coastline. The barriers can be grouped into two categories – the large Cape Flattery systems and the rest, with the Cape Flattery dunes representing 68% of the total PC barrier volume. With Cape Flattery included, the barriers have an area of 67,135 ha, 32% of which is unstable, and a volume of 6390 M m^3, with a unit volume of 49,800 m^3 m^{-1}. When the Cape Flattery dunes are removed, the remaining 107 km of barriers has an area of 23,635 ha, a total volume of 3740 M m^3 and a unit volume of 34,957m^3 m^{-1}, much of this made up of the Cape Bedford dune field (Fig. 14.18b and d). When these two large dune fields are removed, the volume drops to 340 M m^3 and the unit volume to 3474 m^3 m^{-1}. The Cape Flattery-Cape Bedford dune field represents a major sediment sink at the northern end of this compartment and the last major transgressive dunes system until Port Clinton 1000 km to the south.

The prevailing waves, winds and tides all favour northerly sediment transport throughout the PC; however geological control in the form of major headlands provides some obstacles, resulting in a disjointed series of SCs, which is discussed below.

14.7.5 SC:QLD03.06.01 Cape Flattery–Endeavour River

The northern SC:QLD03.06.01 commences at the tip of Cape Flattery and extends 90 km south to the mouth of the Endeavour River at Cooktown (Fig. 14.17a). Beginning in the south a curving 10 km long stable barrier extends north of the river mouth past Mount Sanders to Indian Head (Fig. 14.18d). Seven kilometres to the north, just past Knob Head, the coast changes dramatically as the large Cape Bedford transgressive dunes commence, with some of the longwalled parabolics

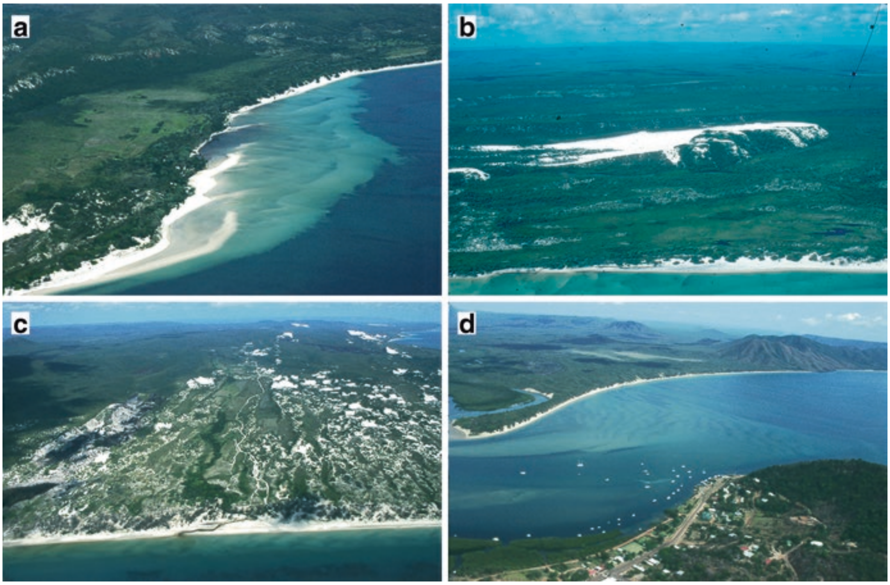

Fig. 14.18 PC:QLD03.06 coast: (**a**) north-trending spits along Elim beach (QLD 624) which link the Cape Bedford overpassing with the southern end of the Cape Flattery dune field; (**b**) leading edge of a longwalled parabolic dune (QLD 625); (**c**) part of the Cape Bedford dune field; and (**d**) Cooktown and Sanders beach (QLD 640) extending north of the Endeavour River (QLD 631). (Photos: AD Short)

extending up to 18 km inland (Fig. 14.18b, c). Headland overpassing has occurred at Cape Bedford with the sand contributing to the extensive sand flats that line the lee shore of the cape, though it is unlikely there is any headland bypassing. The overpassed sand is then being moved west along Elim beach by waves and possibly tidal currents (Fig. 14.18a), past the small McIvor River mouth and into the large Cape Flattery dune field. This is one of the largest dune fields on the east Queensland coast, with the dune extending up to 30 km inland. These dunes overpass the rear of the cape and feed into Flattery Harbour to supply SC03.05.02, as discussed in Sect. 14.6.5.

The Cape Bedford-Cape Flattery dune field was investigated by Pye (1982). He attributes their large size to the abundant sand supply derived ultimately from the Mesozoic sandstones and older granites, combined with their exposed southeast orientation into the prevailing southeast winds. He also found they consisted of both Pleistocene and Holocene dunes and proposed an evolutionary model of the development of 'elongate' (longwalled) parabolic dunes. He recorded active dunes moving inland at an average of 2 m year^{-1}, with a maximum rate observed of 4.8 m year^{-1}. Pye and Bowman (1984) dated some of the Holocene dunes and found that they were active between 8 and 7 ka, at a time when sea level was still rising. At the mid-Holocene sea-level maximum (~ +1 m) the shoreline was 1.5 km inland, which was followed by shoreline regression (Pye and Switsur 1981) and then erosion at which time a second phase of dune transgression was initiated. Lees et al. (1990) cored the Cape Flattery dunes and found a sequence dating back to 171 ka, overlain by deposits at 22.7 ka, 19.8 ka, 19.2 ka and modern dunes at 2 ka and 0.2 ka, with Pye and Bowman's 8–7 ka unit not present. They concluded that dune emplacement has been episodic and, based on dates from other dune fields across northern Australia, has been synchronous, citing drier climate as the driving force.

14.7.6 SC:QLD03.06.02 Endeavour River–Cape Kimberley

SC:QLD03.06.02 extends south for 120 km from the Endeavour River to Cape Kimberley (Fig. 14.17a). This SC is backed for much of its length by the steep forested slopes of the coastal range, broken only by small valleys containing regressive barriers including Annan and Bloomfield rivers, Myall and Noah creeks and Alexandria Bay. The inner reefs of the GBR lie between 10 and 20 km offshore limiting fetch and waves. There are a few beaches and narrow barriers along the steep sections, with some fronted by fringing reefs (Fig. 14.19a). Fifty beaches occupy 50 km (41%) of the coast, the remainder mainly sloping bedrock covered in

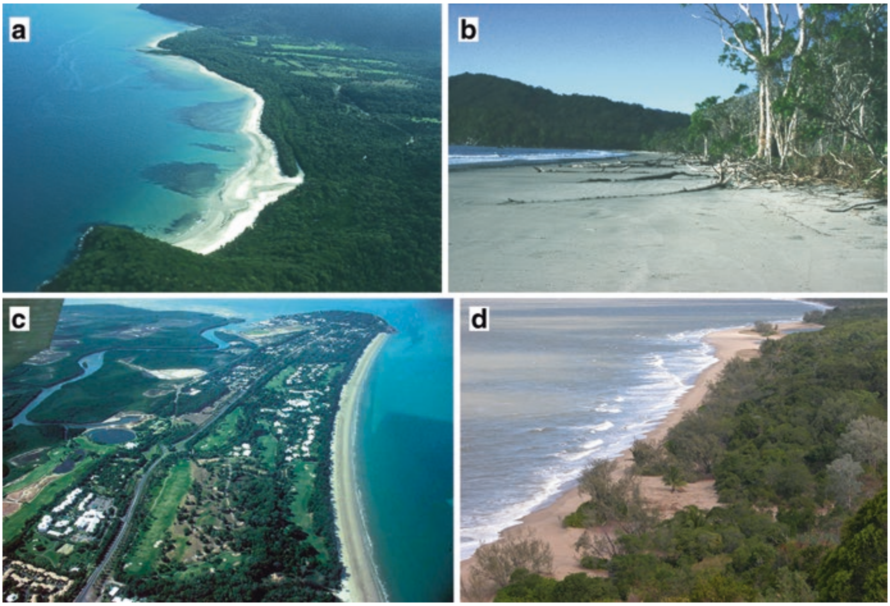

Fig. 14.19 PC:QLD03.06 coast: (**a**) Myall Beach (QLD 674) with some fringing reefs; (**b**) beach erosion encroaching in the backing trees in Alexandria Bay (QLD 681); (**c**) Four Mile Beach at Port Douglas and the first major development on the coast (QLD 697); and (**d**) Wangetti Beach (QLD 706) is typical of the steep narrow beaches that line the rugged parts of the coast. (Photos: AD Short)

dense tropical forests. The Bloomfield has built a 10 km long barrier that extends north to Rattlesnake Point, where bypassing may be occurring. The Annan has built a smaller barrier that extends to Monkhouse Point, which it also may be bypassed. Myall and Noah creeks have small regressive barriers, and Alexandria Bay has a 2 km wide disjointed series of beach ridges and salt flats, with erosion cutting into the vegetation on the low outer ridge (Fig. 14.19b). The SC terminates 10 km to the south at Cape Kimberley.

14.7.7 SC:QLD03.06.03 Cape Kimberley–Port Douglas

SC:QLD03.06.03 is an open east-facing 23 km embayment bordered by Cape Kimberley and Island Point and fed by the Daintree and Mossman Rivers (Fig. 14.17b). It contains 34 km of generally low sandy shoreline, with beaches occupying 23 km (68%) of the shore, together with 1 km wide mangrove-fringed sand flats occupying 8 km of shore to the west of Island Point. Sand appears to be bypassing Island Point and moving along the sand flats to link with the Mossman River. The river is bordered by two narrow WD barriers, suggesting little sediment accumulation at its mouth. These barriers extend up to Rocky Point, beyond which is the larger Daintree River and delta. Longshore transport continues north from the Mossman River, bypassing the subdued Rocky Point and into the Daintree system, where a combination of river and longshore sands has deposited a 1.2 km wide regressive beach-foredune ridge plain at Wonga beach (QLD 692). Leonard and Nott (2015) found that the Daintree is subject to extreme flood events that strip the floodplain followed by a longer period of accretion, with four major cycles during the past 6000 year. Forsyth et al. (2012) dated two transects across this regressive barrier and found the inner beach ridges dated 4.5 ka and 3.1 ka, while the outer foredune ridges were modern, indicating continuing shoreline regression. They attribute the beach ridges to low frequency tropical cyclone events, while the foredunes represent ongoing trade wind deposition. The Daintree River has a TD funnel-shaped mouth bordered by WD regressive barriers to either side. The northern barrier consists of a series of now stable south-trending recurved spits indicative of southerly transport. If this is the case, it is likely sand is being transported northwards to, but not around, the SC boundary at the protruding Cape Kimberley, making this a closed boundary.

14.7.8 SC:QLD03.06.04 Port Douglas–Cape Grafton

SC03.06.04 continues south from Island Point for 101 km to Cape Grafton which protrudes 17 km east of Cairns (Fig. 14.17b), forming an apparently closed southern boundary to the PC, as the cape and Mission Bay in its lee show no evidence of headland bypassing. The adjoining Trinity Bay has however received substantial input of sediment, primarily from the Barron River, which is delivering about 23,000 m^3 of bedload each year (Murray and Ford 1983), which would represent ~140 M m^3 during the Holocene. This sediment together with input from the local streams including the several small streams that flow into Trinity Inlet has partly infilled Trinity Inlet with tidal flats and mangroves and built the low energy regressive Cairns barrier with Bird (1970) dating the innermost ridge at 5.5 ka. Nott (2003) investigated the urban geology of the Cairns coastal plain and found the southern plain contains up to 23 regressive beach ridges, with the inner ridges deposited 5.5 ka when sea level was likely to be 1 m higher. He attributed the ridge deposition to periods of tropical cyclone storm surges and found the plain was subject to storm surges, landslides (near the ranges) and possibly tsunami. Immediately to the north is the larger Barron River delta which extends along 8 km of the coast. Tropical cyclones generate periodic river flooding resulting in considerably variation in water and sediment discharge from year to year. The flooding can also lead to channel switching and the location of sediment discharge. As a consequence, this is a dynamic low-lying deltaic plain, delivering sand to a WD delta front that is transporting it northwards building a series of small regressive barriers along the northern Cairns coast up to Palm Cove. Transport rates have been estimated between 8000 and 14,000 m^3 $year^{-1}$ including headland bypassing of Yorkeys Knob, Taylor Point and Buchan Point (BPA 1984, Fig. 14.20).

Robinson and Cook (1980) found that sediment at the river mouth ranged from fine to medium sand and mud, with a mean of 0.48 mm at the mouth. The sand then fines northwards to 0.19 mm at Thomatis Creek, 5 km north of the mouth. They estimated transport on the rate of 40,000 m^3 $year^{-1}$, substantially greater than BPA (1984) (Fig. 14.20). Murray and Ford (1983) reviewed the various estimates of longshore transport from the Barron and concluded that the Bijker formulae gave better results than the CERC formulae, with their results similar to those indicated in Fig. 14.20.

Jones and Stephens (1986) developed an evolutionary model for the Barron delta and found that floods and/or cyclones drive major changes in lower deltaic plain including regular (decadal) shifting of distributary mouth, by up to 5 km; infrequent distributary channel abandonment; infrequent stream channel pirating; continuous interception of longshore transport by stream flow; and coastal progradation by attachment of barrier spits. They found that the river supplies fluvial sand in two stages: first to the river mouth bar in the inter- to subtidal; these are then reworked by waves and sorted and the sand fraction transported landwards to build beach ridges and spits. The sand is then transported northwards as indicated in Fig. 14.20. The construction of Yorkeys Knob boat harbour is also trapping sand against its updrift attached breakwater. The result is a prograding, but dynamic shoreline, dependent on pulses of flood-borne river sand to supply the system that is then transported northwards. The entire deltaic-Cairns coast is vulnerable to periodic beach erosion, flooding and storm surges to 2.5 m (Heggie and Wallis 2001), and because of beach front development has largely been armoured with seawalls.

While sand is bypassing Buchan Point, the steep coast to the north constrains the development of beaches and barriers (Fig. 14.19d), apart from the narrow Ellis beach system, until the regressive Four Mile Beach at Port Douglas (Fig. 14.19c).

Fig. 14.20 View of the Cairns coast showing the sand volume delivered by the Barron River rates of longshore sand transport predicted by Murray and Ford (1983) and BPA (1984). (Source: Google Earth)

The small Mowbray River flows into the southern end of Four Mile Beach where it has built 1 km wide sand flats that have undoubtedly supplied sand to the predominately quartz-rich (94%) barrier immediately to the north. Sand appears to be bypassing the SC boundary at Island Point and contributing to the infilling of the Parker Creek with its 1 km wide tidal flat-mangrove system.

14.7.9 PC Overview

While this PC trends roughly north–south, it is somewhat variable both at the PC and SC level. The northern SC:QLD03.06.01 containing the Cape Flattery and Bedford dunes is a major sink, though as Pye (1983b, c) indicates the sand has been derived primarily from the shelf rather than longshore. Longshore transport is blocked by the capes, though overpassing occurs across both dune fields. South of Cooktown (SC:QLD:03.06.02), the coast is dominated by the steep coastal range with limited accommodation space and sedimentation except at the river mouths in Walker and Weary bays, and no evidence of longshore transport. SC:QLD03.06.03 is a more open compartment dominated by the Daintree River and its regressive barrier and the smaller Saltwater Creek and Mossman River in the south. It appears to be a sink for both fluvial sediment and sand moving north around the SC boundary at Island Point, but with a closed northern boundary at Cape Kimberley. The southern SC:QLD03.06.04 is receiving sand from the Barron River in the south that is both prograding the delta and being transported northwards at a rate on the order of 10,000 m^3 $year^{-1}$. As the sand is bypassing Buchan Point, it may well continue up the coast to Island Point, complemented by sand from the small Mowbray River, and into the next SC.

Much of this PC has high relief and relatively low vulnerability to the tropical cyclone-induced flooding and storm surges. However, the highly developed areas of Port Douglas and Cairns in particular are highly vulnerable, with Cairns exposed to river flooding, storm surges and rising sea level. In addition, any changes to the Barron River sediment discharge and longshore transport will impact both the delta and the downdrift coast.

14.8 PC:QLD03.07 Cape Grafton–Cape Cleveland

PC:QLD03.07 is one of the longer PCs on the east Queensland coast, extending south–southeast for 484 km from the prominent Cape Grafton to the equally prominent Cape Cleveland. It includes the large Hinchinbrook Island, as well as the Palm Islands and Magnetic Island off Townsville (Figs. 14.1 and 14.21). This is a reasonably exposed section of coast, with few major headlands or obstacles, apart from Hinchinbrook Island. The coastal geology is dominated by Permian and Carboniferous granites apart from a section of Devonian sedimentary and metasedimentary rocks between Cooper Point and Tully Heads. The GBR consists of a series of large separate reefs that lie between 40 and 50 km off the northern half of the compartment, moving up to 100 km offshore south of Mission Beach. The crest of the Great Dividing Range lies up to 20 km inland, and the coastal plain ranges in width from a few kilometres to 50 km and occupies most of the coast zone. The coast is paralleled throughout its length of the Bruce Highway and contains the major towns of Innisfail (7500), Tully (2500) and Ingham (5000), the large city of Townsville (190,000) as well as many smaller communities and coastal settlements. It contains 10 SCs (QLD03.07.01-10) which are discussed below.

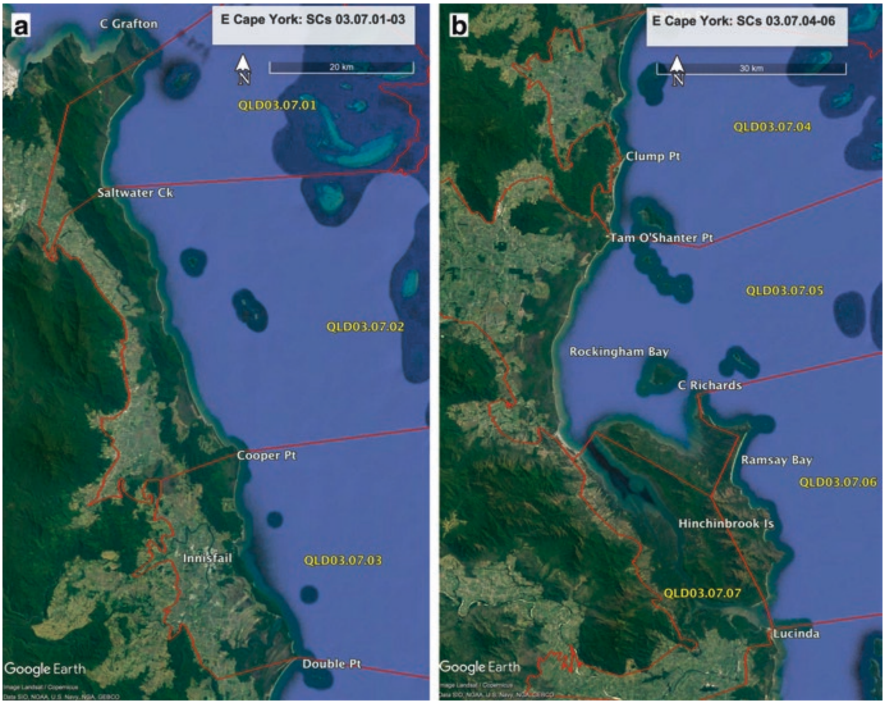

Fig. 14.21 (**a**) SCs:QLD03.07.01-03 and (**b**) QLD03.07.04-07 extend from Cape Grafton to Lucinda. (Source: Google Earth)

14.8.1 Rivers and Creeks

There are about 50 streams and rivers reaching the coast; however most of the major drainage flows west into the Burdekin, which reaches the coast to the south in PC:QLD08. The PC does have six small- to medium-sized rivers including the Mulgrave-Russell, Johnstone (167 km^2), Hull (155 km^2), Tully (1441 km^2), Herbert (2286 km^2), Black (293 km^2) and Ross (881 km^2). Leonard and Nott (2016) found that the Mulgrave River, like the Daintree to the north, is subject to extreme flood events, probably associated with heightened tropical cyclone activity, which strip the floodplain and deliver large volumes of sediment to the coast and GBR lagoon. The Tully flows into an exposed section of coast and has developed a 2 km wide WD regressive strand plain and appears to be delivering sand to the coast. The largest river, the Herbert, reaches the coast in the Hinchinbrook Channel sheltered in lee of Hinchinbrook Island. Its rich upper delta plain is intensively farmed, and it has a number of distributaries that reach the coast along a 25 km long delta front. The lower deltaic plain contains a 3–5 km wide mangrove fringe that extends in the north from the Seymour River to Lucinda in lee of the island and along the more exposed eastern shore between Lucinda and Taylors Beach.

14.8.2 Coastal Processes and Sediments

Coastal processes along this PC remain dominated by the southeast trades (Fig. 13.7) and meso-tides (Table 13.5) with spring range increasing southwards from 2.5 m at Cairns to 2.7 m at Lucinda and 2.9 m at Townsville. Deepwater waves average about 0.5 m, with a H_s of 0.9 m and period 4–5 s from the southeast (Table 13.3). Breaker wave height depends on location and degree of sheltering and ranges from zero in lee of Hinchinbrook Island to ~0.5 m on exposed sections (Table 13.4). Beach sediments are moderately well sorted but highly variable in size ranging from fine to coarse, with low carbonate averaging 5% (σ = 10%) and ranging locally from 0 to 58% (Table 14.2). Sand size varies considerably longshore (Fig. 14.2), while areas of higher carbonate include Etty Bay, Gardner-Mission Beach and southern Hinchinbrook Island.

14.8.3 Beaches

This is a reasonably exposed coast owing to its easterly orientation, lack of major headlands and relatively continuous south-trending shoreline. Sandy beaches occupy 292 km (60%) of the shore, the remainder predominately bedrock, creek and river mouths, with the only sections of mangroves at the Herbert River mouth and along the base of Cleveland Bay. The beaches average 2.1 km in length with many bordered by rounded granite boulders, points and headlands. The generally greater exposure is reflected in the beach type with 66% being TM, the remainder TD (34%) (Table 14.10). Of the TM the R + LTT occupy 34% of the sandy shore, the rip-dominated R + LTR (27%) and UD (6%), attesting to the level of exposure to the southeast waves and with the UD occurring where the sand is finer. Even the TD beaches are dominated by the B + RSF which occupy 21%. They have an average width of 0.67 km (σ = 0.6 km) and contain on average 5.7 ridges (σ = 3.2). B + SF make up the remaining TD beaches at 12%.

Table 14.10 PC:QLD03.07 beach types and states

BS	BS	No.	%	Length (km)	%	Mean (km)	σ (km)
6	R	3	2.1	0.3	0.1	0.1	0.01
7	R + LTT	58	41.1	98.5	33.1	1.7	2.2
8	R + LTR	16	11.3	77.9	26.1	4.9	4.0
9	UD	5	3.5	16.3	5.5	3.3	2.2
10	B + RSF	22	15.6	61.2	20.5	2.8	2.3
11	B + SF	34	24.1	36.7	12.3	1.1	1.5
12	B + TSF	2	1.4	0.9	0.3	0.4	–
13	B + TMF	1	0.7	6.2	2.1	6.2	–
		141	100	291.8	100	2.1	–

14.8.4 Barriers

There are 57 barrier systems, which occupy 254 km (52%) of the PC. They are predominately regressive beach-foredune ridge plains, averaging 0.6–1.07 km in width and 6 m in height. Unlike the northern PCs (QLD03.01-06), there are no transgressive dunes. The barriers have an area of 23,368 ha and are essentially 100% stable. They have a total volume of 1501 M m^3 with a unit volume of 5934 m^3 m^{-1}, one of the lowest on the east Queensland coast, which can be attributed to the lack of transgressive dune systems. Pye (1983a) examined this coast and discussed the lack of dunes, which he attributed to poor sediment sorting in the beach and nearshore zone, low wind energy at the shoreline due to the north-south coastal orientation and the high backing relief also lowering the onshore wind velocity at the shore. While all these are contributing factors, there are sections of this coast facing into the trade winds with reasonable wave energy and fine sand, such as King and Oombunghi Beaches (QLD 7378) on the southern side of Cape Grafton and Cowley Beach (QLD 773), that lack any dune transgression. An additional factor could be that this coast has generally stable to regressive barriers and has not reached a stage of erosion and associated shoreline retreat and dune transgression, as Pye (1982) observed at Cape Flattery. This is further confirmed by the fact the dunes are essentially 100% stable (Table 14.4).

14.8.5 SC:QLD03.07.01 Cape Grafton–Saltwater Creek

The easterly orientation of most of this section of coast and the prevailing waves, wind and tides all favour northerly longshore transport. Beginning in the north at SC:QLD03.07.01 is a 22 km long SC extending from the tip of Cape Grafton to the steep forested base of 1000 m high Bell Peak (Fig. 14.21a). This is an east to southeast-facing section containing three exposed embayed beaches, each backed by stable densely vegetated transgressive dunes, the largest extending possibly 1 km inland in lee of Kings Beach (QLD 737). The transgressive dunes are subdued and may be Pleistocene and are fronted by a narrow Holocene foredune. The absence of major Holocene dune transgression may also be related to the backing high terrain that would lower wind velocity at the shoreline couple with the stable nature of the barrier. The beaches appear stable (Fig. 14.22a) with the only evidence of longshore transport the deflection of the creeks in lee of Saltwater Beach (QLD 741) for 3 km to the northern end of the beach. There does not appear to be any bypassing of the northern Cape Grafton, making this a closed SC and PC boundary.

Fig. 14.22 (**a**) Saltwater beach (QLD 741) is typical of the steep high tide beaches backed by dense vegetation in this compartment; (**b**) mouth of the Mulgrave-Russell Rivers at Constantine Point QLD 751); (**c**) the Murdering Point cuspate foreland (QLD 774-775); and (**d**) sand wave moving northwards around Gardner Beach (QLD 778). (Photos: AD Short)

14.8.6 SC:QLD03.07.02 Saltwater Ck–Cooper Point

SC:QLD03.07.02 is a northeast-facing generally high relief densely vegetated coast, backed by granitic Malbon Thompson Range, which rises steeply between 600 and 1000 m. It extends for 49 km from Saltwater Creek down to the low rocky Cooper Point (Fig.14.21a). The Mulgrave-Russell Rivers reach the coast through a 1 km wide gap in the range (Fig. 14.22b) and have deposited a 2 km wide regressive barrier primarily on the northern side of the mouth, with the small beachfront Russell Head community located on the narrow barrier on the southern side of the mouth – a very vulnerable and hazardous location exposed to wave erosion, storm surge inundation and river flooding and barrier breeching. A second 1 km wide regressive barrier is located in the Bramston Beach embayment, with again the backing Wyvuri Creek deflected 2 km to the northern point. The location of the Mulgrave barrier and deflection of the creek mouths again point to northward wave-driven sand transport.

14.8.7 SC:QLD03.07.03 Cooper Point–Double Point

SC:Q03.07.03 is a 34 km long SC between Cooper and Double Points (Fig. 14.21a). It is largely backed by the 200 m high Seymour and Moresby Ranges, with the Johnstone River flowing through the gap between the two ranges to deposit a 2 km wide sandy ebb tide delta, with sand from the delta being transported northwards by wave and tidal currents. These sands probably contributed to the narrow barriers at the mouth of Ella Bay, Rocky Point and Bramston Beach, with sand bypassing each of the intervening headlands (Fig. 14.22d). South of the river mouth, the ranges dominate the shore down to Double Point, with Mourilyan Harbour occupying a 200 m wide gap in the range and small embayed beaches at Etty Bay and Robinson Beach.

14.8.8 SC:QLD03.07.04 Double Point–Tam O'Shanter Point

SC:QLD03.07.04 is an east-facing SC extending due south for 44 km from Double Point to Tam O'Shanter Point (Fig. 14.21b). It does however contain a number of embayments that have been infilled with low regressive barrier systems. Extending south of Double Point is the 4 km wide Cowley Beach ridge plain, south of which is the Kurrimine Beach-Murdering Point cuspate foreland in lee of King Reef (Fig. 14.22c). The 11 km long Mission Beach barrier is located between Clump and Tam O'Shanter Points and includes a foreland formed in lee of Dunk Island. While there has been considerable sediment accumulation within this SC, there appears to be little throughput, owing to the presence of cuspate forelands and the major sink at Cowley Beach; however now the beach has prograded out to the tip of Double Point, and sediment may be bypassing the point. Nott (2006) and Nott et al. (2009) dated the age the Cowley ridges with the inner dating 5.7 ka and the outer 0.2 ka, concluding the height of the 30 ridges preserved a history of high magnitude/low frequency storm surges and waves generated by extreme intensity tropical cyclones. Brooke et al. (2019) also examined the Cowley ridges and found their berm height correlated with the mid-Holocene sea-level highstand (+2 m at 6 ka), followed by a gradual decline to the present sea-level. Nott et al. (2013) examined ridges at Cowley Beach, Tully Heads and Caldwell after tropical cyclone Yasi where recent marine deposit associated with the cyclone could be identified by a coarser layer of quartz-rich sand and gravel, the coarse layers separated by fair-weather finer material, and concluded each ridge represented an accumulation of several episodes of storm deposition. Tamura et al. (2017) examined in detail the outer ten ridges which they also found were deposited over the last 2.7–2.5 ka. They however found the ridges were formed by both fair-weather swash and cyclone tidal inundation.

14.8.9 SC:QLD03.07.05 Tam O'Shanter Point–Cape Richards

The Rockingham Bay SC (QLD03.07.05) commences at Tam O'Shanter Point and gently curves to the south-south east and then south for 39 km to Caldwell and then turns east to incorporate the northwestern shore of Hinchinbrook Island out to its northern tip at Cape Richards (Fig. 14.21b). It is sheltered in the south by Hinchinbrook Island and to the north by Goold and the Family islands all lowering wave energy at the shore. As a result this is a compartment of two parts, the western continuous beach-barrier shoreline between Kennedy Bay-Hull Heads and Caldwell with wave energy decreasing to the north and south, with mud flats fronting the beach at Caldwell, and the sheltered steep rocky slopes and low mangrove-lined shores of Hinchinbrook Island. The northern barrier extends for 36 km, broken only by the Tully River and five creek mouths. It consists of inner Pleistocene barrier extending up to 5 km inland and an outer regressive Holocene between 1 and 1.5 km wide, made up of central beach ridge plain, with considerable reworking of the boundaries by inlet migration and the formation of multiple recurved spits. Forsyth et al. (2010) dated a 2 km wide series of beach ridges just south of the Tully River and found they dated between 5 ka and present, indicating they are still regressing. They inferred the formation and height of the ridges can be correlated with tropical cyclone frequency and magnitude. The orientation of the creek mouth and spits to the north and south suggest this is a sediment sink, with little if any longshore transport, though tidal currents may be bypassing sediment northwards around Tam O'Shanter Point. The eastern side of the compartment on Hinchinbrook Island is a major sink for fine sediment from the Herbert River which has been infilling in Missionary Bay and its 40 km^2 mangrove forest. The Port Hinchinbrook marina at Caldwell, which was developed in the late 1990s, contains two training walls that extend up to 0.7 km into the Hinchinbrook Channel. Mangroves have developed along the southern wall, with a sandy high tide beach along the northern wall, suggesting southerly sand transport into the channel.

14.8.10 SC:QLD03.07.06 Cape Richards–Lucinda

SC:QLD03.07.06 occupies the eastern shore of Hinchinbrook Island extending for 63 km from Cape Richards to Lucinda (Fig. 14.21b). The island's east coast is a rocky embayed shoreline containing the large Ramsay Bay barrier that links the island to Cape Richards and a series of smaller embayed beaches to the south, terminating at the large cuspate accumulation of sand at George Point the northern entrance to Hinchinbrook Channel and opposite the Herbert River mouth. The Ramsay Bay regressive barrier systems and backing large mangrove swamp have been investigated by Pye (1983a, b, c), Grindrod and Rhodes (1984) and Pye and Rhodes (1985). They found the barrier is underlain by a transgressive mangrove sequence that since the sea level still stand has regressed 4 km into Missionary Bay, the outer beach-dune system is presently transgressing over the mangroves as a series of well-developed blowouts and parabolics extending up to 0.5 km inland. The beach itself is a well-developed R + LTR containing up to 75 equally spaced rip channels along its 8.5 km length with an average spacing of 110 m. Grindrod and Rhodes focused on using the barrier-mangrove stratigraphy to reconstruct the late Holocene sea-level curve and found sea level reached its present level about 6.5 ka in general agreement with the Thom and Roy (1985) sea-level curve for southeast Australia. Pye and Rhodes focused more on the stratigraphy of the barrier-mangrove systems and found there had been two episodes of dune transgression, one as sea level was rising between 9.5 and 6 ka and the second during the past 0.9 ka. They attributed both episodes to rapid shoreline erosion. The island shoreline, in particular Ramsay and Zoe Bays and the southern George Point, appears to be a sink for sediments and a closed system.

14.8.11 SC:QLD03.07.07 Hinchinbrook Channel

SC:QLD03.07.07 occupies the 40 km long Hinchinbrook Channel that runs between the island and the mainland (Fig. 14.21b). The channel ranges in width from 4 km at its northern entrance at Caldwell to less than 1 km along its central section, both sides lined by mud flat and mangroves. On the mainland and the mouth of the Herbert River, the mangroves are up to 4–5 km wide. The entire channel is a sink for sediments delivered by the river and from the adjoining SC to the south, with a series of regressive sand spits extending up to 10 km along the southern side of the channel.

14.8.12 SC:QLD03.07.08-09 Lucinda–Eleanor Creek–Cape Pallarenda

The next two SCs (QLD03.07.08-09) form the northern and southern shores of Halifax Bay (Fig. 14.23), which has a total shoreline length of 113 km and faces east then northeast, with the Palm Islands lying off the northern SC. The northern half consists of a near continuous series of sandy beaches backed by narrow stable to regressive barriers, each bordered by dynamic inlets with migratory recurved spits (Fig. 14.24a and c). All the spits and creek mouth ebb tide deltas are deflected to the north with the Taylors Beach spit deflected 3.5 km northwards (Fig. 14.24b), all evidence of northerly longshore sand transport, with the ultimate sink between the Hinchinbrook Channel. The southern half of the bay faces northeast and is sheltered in the south by Magnetic Island and Cape Pallarenda. The lower energy is reflected in the nature of the shoreline, which consists of a near continuous series of sandy beaches, each bordered by protruding creek mouths and their extensive ebb tide deltas. All the creek and deltas are skewed to the north owing to the southerly waves and northerly sand transport. The beaches range from wide often ridged sand flats on the tidal deltas (Fig. 14.24b) to R + LTT on the more exposed sections between the deltas. As Townsville City is located at the base of the bay, there have been a number of coastal investigations of the region.

Fig. 14.23 SCs:QLD03.07.08-10 include the long Halifax Bay and Cleveland Bay. (Source: Google Earth)

The Townsville coastal plain was investigated by Hopley and Murtha (1975) and Hopley (1978) who found it's widened from 3 km in the north to 30 km in the south and contains both inactive early Holocene and active drainage channels, which drain across older (late Pleistocene) clays. Approximately 20 streams have deposited sediment at the shore which have been reworked northwards into a series of regressive beach-foredune ridges separated by mangrove-filled swales. They dated inner ridges at 6–5 ka, beachrock at Balgal and Shelly Beaches at 2.2 and 2.5 ka and an inner chenier at Bohle River at 2.3 ka. Pearce (1992) utilised aerial photographs to measure the migration of Bluewater and Althaus Creeks at Saunders and Toolakea Beaches (QLD 847 and 849) located towards the southern end of Halifax Bay and found that between 1941 and 1986 they migrated up to 3 km to the northwest at a rate of ~60 m year^{-1}.

GHD (2012) developed a coastal hazard strategy for the Townsville region. Owing to the low-lying nature of much of the coast and its exposure to erosion, storm surges and sea level rise, they recommended retreat as the highest ranked strategy. They concluded The Strand and Rowes Bay will be able to accommodate the hazards, with only the port-industrial area to be defended.

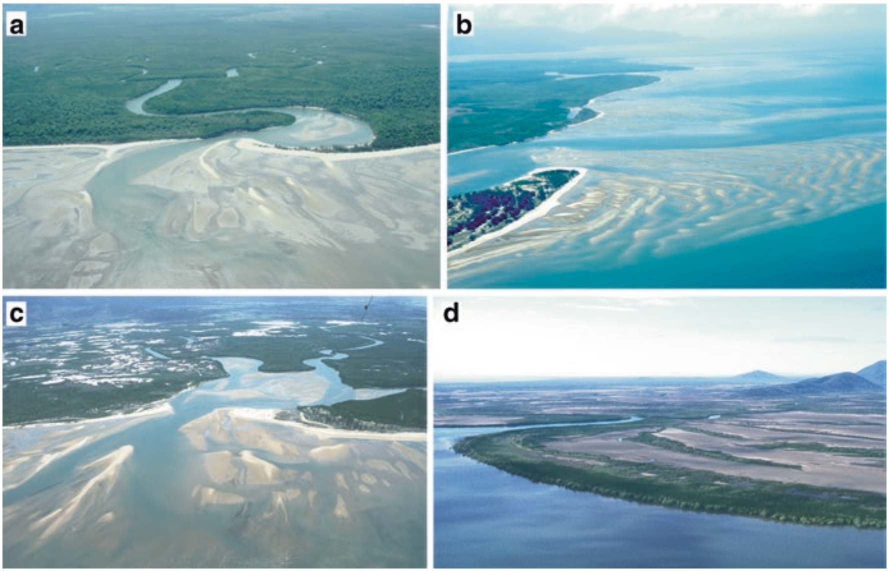

Fig. 14.24 PC:QLD03.07 coast: (**a**) 1 km wide tidal sand flats extending seawards of Dallachy Creek (QLD 791–792); (**b**) 1.5 km wide ridged sand flats off Taylors beach (QLD 832); (**c**) Cattle Creek (QLD 835–836) has extensive tidal sand flats and backing mangrove-lined salt flats; and (**d**) the wide supratidal flats and cheniers at the mouth of Crocodile Creek. (Photos: AD Short)

14.8.13 SC:QLD03.07.10 Cape Pallarenda–Cape Cleveland

The southern Cleveland Bay SC (SC:QLD03.07.10) is a 25 km wide north-facing U-shaped bay, with 45 km of shoreline that ranges from moderate energy in the west to very low energy in the south and east (Fig. 14.23). The energy distribution is reflected in the nature of the shoreline. Starting in the east, the eastern tip of the bay is occupied by the steep slopes of Cape Cleveland with mangroves fringing the base of some of the slopes, together with a few pockets of sand. Ten kilometres south of the cape, continuous mangrove-lined mud flats commence occupying the entire 20 km long southern shore, apart from a series of the TD funnel-shaped creek mouths (Fig. 14.24d). The mangroves are backed by supratidal flats extending up to 10 km inland and an outer 3 km wide chenier plain. The mangroves terminate in the west at the Ross River mouth which has deposited a 2 km wide series of widely spaced beach ridges that trend west. Townsville port dominates the next 2.5 km followed by the 2 km long The Strand a reconstructed and nourished beach (Riedel et al. 1999). Muller et al. (2006) investigated sediment transport on The Strand post its 1998 construction. They found while the four groynes had greatly reduced longshore transport, that muddy sediment was accumulating in the shelter southern section, while sand was being transported around the northern Kissing Point and into Rowes Bay. Wave energy increases northwards along Rowes Bay beach which has a R + LTT and evidence of northerly sand transport to and around Cape Pallarenda to supply the 5 km long Shelly Beach spit in the adjoining SC.

14.8.14 PC Overview

This is a reasonably long (485 km) PC that trends east–southeast with a generally east to northeast-facing shore, with the only major obstacles being Hinchinbrook Island and the southern Cape Cleveland. The southern cape appears to be a closed to longshore transport and the southern Cleveland bay (SC:QLD03.07.10) a sink for fine sediments. There is evidence of northerly longshore transport out of The Strand and into Rowes Bay on the order of 4000 m^3 $year^{-1}$ (Riedel et al. 1999) and from Rowes Bay around Cape Pallarenda to supply the migratory spits of Shelly Beach. This transport continues the length of the next two SCs (QLD03.07.8-09), with the Hinchinbrook Channel (SC:QLD03.07.07) being a sink for this sediment. Hinchinbrook Island (SC:QLD03.07.06) appears to be a sink for onshore sediment transport, with no transport around its northern boundaries at capes Sandwich and Richards. Rockingham Bay (SC:QLD03.05.05) has two sections, the southern Hinchinbrook-Missionary Bay, with the bay a major sink for fine sediment, probably derived from the Herbert River, while the sandy northern section, north of Caldwell, is broken into a series of embayment, each providing a sink for sediment, with little evidence of sediment throughput apart from a possibly leaky northern boundary at Tam O'Shanter Point. SC:QLD03.07.04 is a similar embayed east-facing SC containing three regressive barriers (Mission, Murdering and Cowley), but little evidence of sediment throughput, except at Double Point, now that the Cowley barrier has reached the tip of the point. The northern three SCs (QLD03.07-03-01) are largely backed by steeply rising slopes, with little accommodation space for barrier, except for a few now infilled embayments (Etty, Bramston, Mulgrave mouth, Oombunghi and King), with little apparent longshore transport, and the northern Cape Grafton closed.

14.9 PC:QLD03.08 Cape Cleveland–Cape Conway

PC:QLD03.08 is the longest PC in the northeast division and on the east Queensland coast extending for 533 km between capes Cleveland and Conway (Fig. 14.1) and containing seven SCs (Table 14.1). This PC is distinguished by the overall shift in the orientation of the coast to face the northeast, together with the large Burdekin and Don river deltas and in the south the rugged Whitsunday coast and islands. The geology is dominated by Carboniferous granite between capes Cleveland and Edgecumbe and Permian and Cretaceous volcanics along the Whitsunday coast and islands. The coast contains a number of prominent capes and bays including capes Bowling Green and Upstart, Abbott Point and capes Edgecumbe and Gloucester and their intervening bays, terminating at the prominent Cape Conway. It is also a moderately developed coast with the major towns of Ayr (8000), Home Hill (3000), Bowen (10,500), Proserpine (3500) and Airlie Beach (8000), together with about 60 smaller coastal communities and tourist destinations, both on the mainland and the Whitsunday Islands, with the broader Bowen and Whitsunday regions having populations of 15,000 and 22,000, respectively.

14.9.1 Rivers and Creeks

There are more than 50 rivers, streams and tidal creeks along this compartment, with one of Australia's largest rivers, the Burdekin (130,475 km^2), and its delta dominating the centre. Secondary rivers include the Haughton (2111 km^2), Elliot (478 km^2), Don (1230 km^2) and the Gregory (185 km^2).

14.9.2 Coastal Processes and Sediments

Beach sediments are predominately moderately sorted, coarse quartz sand, with carbonate averaging 28% ($\sigma = 30\%$) and ranging from 1 to 92% (Table 14.2), with areas of local enrichment around the rocky headlands including Cape Upstart and Cape Edgecumbe and along the Cape Gloucester-Whitsunday coast. Downdrift of the three deltas – the Burdekin, Elliot and the Don – quartz sediments dominate with carbonate usually <1–2%. These deltas are the main source of contemporary terrigenous sediment, with the remainder derived from the shelf and locally from smaller streams and carbonate production.

The coast has a tropical savanna climate (Aw, Fig. 1.8) and remains dominated by the southeast trade wind and waves and exposure to tropical cyclones. Wave height is highly variable along the coast owing to the number of capes and bays, with the shore ranging from exposed along the Burdekin coast to very sheltered in the bays. Riedel (1975) monitored wave conditions between Cape Cleveland and Cape Ferguson and found they ranged from 0.2 to 0.4 m in height and arrived predominately from the southeast (56%), east-southeast (27%) and east (24%). Tides are meso-tides and reach 2.7 m at Bowen.

14.9.3 Beaches

There are 163 beaches that have a mean length of 1.37 km and occupy 224 km (42%) of the coast, with the rocky shore, mangroves and river and creek mouths making up the remainder (Table 14.11). The beaches are a mixture of TM (55.3%) all located on the more exposed easterly facing sections of the coast including

Table 14.11 PC:QLD03.08 beach types and states

BS	BS	No.	%	Length (km)	%	Mean (km)	σ (km)
6	R	4	2.5	1.2	0.5	0.3	0.2
7	R + LTT	55	33.7	48.3	21.6	0.9	1.4
8	R + LTR	11	6.7	56.8	25.4	5.2	5.0
9	UD	4	2.5	18.5	8.3	4.6	2.2
10	B + RSR	14	8.6	27.2	12.2	1.9	0.8
11	B + SF	62	38.0	48.6	21.7	0.8	1.7
12	B + TSF	13	8.0	23.2	10.4	1.8	0.8
		163	100	223.7	100	1.4	–

Bowling Green Bay, Cape Bowling Green-Burdekin delta and Abbott Bay, while TD (44.3%) beaches and their sand and tidal flats are located in the more sheltered sections of these bays and the coast.

14.9.4 Barriers

There are 38 barriers that occupy 164 km (31%) of the PC (Table 14.4). The relatively small number and area is due to a combination of the extent of steep bedrock shore and low energy sheltered bay shorelines, both of which preclude significant barrier development. The largest system is the 6 km wide Big Beach (QLD 879) regressive system with 40 beach ridges. Most of the barriers are low (mean height 4.5 m) and range from 260 to 860 m in mean width. They have a total area of 15,173 ha, volume of 745 M m^3 and relatively small unit volume of 4550 m^3 m^{-1}. Note the barriers do not include the large delta plains, only the outer active spits and ridges.

This PC contains open, leaky and closed SCs, within which some have considerable longshore transport. The eight SCs are discussed below.

14.9.5 SC:QLD03.08.01 Cape Cleveland-Cape Bowling Green

Bowling Green Bay (SC:QLD03.08.01) is an open 35 km wide U-shaped north-facing bay bordered by capes Cleveland and Bowling Green (Fig. 14.25), with 90 km of generally low energy shoreline, arranged in four sectors: Cape Bowling Green, the southern bay mangroves shore, Big Beach and Cape Ferguson. While this is a largely sedimentary shoreline, the beaches occupy just 32 km (35%) most of the remainder mangrove-lined tidal flats, creek mouths and the rocky Cape Ferguson. Beginning in the east 15 km long, Cape Bowling Green forms the eastern boundary. The cape is the terminus from sands transported up to 40 km from the mouth of the Burdekin River, with the fines moving around the cape and into

Fig. 14.25 PCs:QLD03.08.01-02 extend from Cape Cleveland to Cape Upstart and include Bowling Green and Upstart bays and the large Burdekin River delta. (Source: Google Earth)

Bowling Green Bay. The cape is unstable and susceptible to overwashing and erosion and could be destroyed by both sea-level rise (Goh 1993) and decreasing sediment supply from the Burdekin River. The 40 km long southern bay shore is dominated by tidal flats, mangroves and several tidal creeks (including Barratta, Barramundi and Haughton), all of which are susceptible to inundation. They are separated by a series of widely spaced beach ridge-cheniers which, while generally migrating west, have east migrating spits at the creek mouths. The 15 km long Big Beach-Cungulla Beach and barrier dominate the western shoreline up to the rocks of Cape Ferguson. It has a south migrating spit at Cungulla with northerly transport along the central-northern end which appears to be terminated by Cape Ferguson. The 12 km long Cape Cleveland shore has three embayed beaches in the south with steep rocky shores dominating the northern cape.

Nott et al. (2015) examined the ~100 beach ridges in the 5 km wide Cungulla regressive barrier. They found the ridges are Holocene in age and associated with marine deposits formed during intense activity associated with the category 3–5 tropical cyclones. They also found gaps in the ridge building which they attributed to either river erosion or period of tropical cyclone quiescence. The small beach-front community of Cungulla is located along the southernmost outer ridge-spit in the mouth of the Haughton River. This is a low wave energy (B + SF to TSF) but highly dynamic environment with sand moving southwards along the spit and into the mouth. CES (2012) calculated that sand is moving southwards along the main beach ridge to the spit at the northern end of the community at a rate of 9000 m^3 $year^{-1}$. The accumulation of this sand is temporarily staving the downdrift Cungulla beach resulting in some erosion that resulted in the construction of several makeshift groynes in front of the houses. CES (2012) propose nourishing this section in order to protect the houses from both erosion and storm surges.

14.9.6 SC:QLD03.08.02 Cape Bowling Green–Cape Upstart

The Burdekin River delta-Upstart Bay compartment (SC:QLD03.08.02) contains 110 km of shoreline arranged in four sectors (Fig. 14.25): Cape Upstart, the south-east Nobbies Creek mangrove shore, RM beach and the Burdekin delta. Sandy beaches occupy 67 km (61%), the remainder the rocky Cape Upstart, the southern mangrove-lined Nobbies Creek and the creek and river mouths. In the south are the 15 km of high rocky shores and small pocket beaches of Cape Upstart and the mangrove-lined tidal flats of the funnel-shaped Nobbies Creek. Some sand is moving south along the rocky shore as indicated by near continuous sand beaches at the base of the steep slopes, some shore transverse sand waves, south-deflected creek mouths and the sink, a 0.5 km wide sand wave field (Fig. 14.26c) where the Nobbies Creek mangroves begin just off beach QLD 902. The creek connects to the east with the rear of the cape barrier (QLD 929) and the Elliot River, all of which links Cape Upstart to the mainland. The 25 km long southern shoreline commences at Nobbies Creek and grades west into 17 km of TD sandy beaches, including 14 km long RM beach, bordered and backed by tidal creeks, ebb tide deltas and sand and flats (Fig. 14.26b). Wave energy increases from the Burdekin River northwards. The 15 km wide Burdekin River mouth is highly dynamic responding to flood events, longshore (quartz-rich) sand transport and storm surges. North of the mouth is 40 km of highly dynamic tidal creeks (Branch, Plantation and Alva), sand beaches and migratory recurved spits (Fig. 14.26a) extending all the way to the tip of Cape Bowling Green. The five to six spits are migrating at between 100 and 200 m $year^{-1}$ (Hopley 1979; Pringle 1983, 1984). Goh (1993) found that the fluvial sand averages a coarse 0.82 mm at the Burdekin Bridge, fining to 0.3–0.5 mm along the coast, indicative of longshore transport and downdrift fining. This shore is prone to episodic erosion and accretion associated with the migratory sand spits, as well as flooding, overwashing and inundation. Damming of the Burdekin River is likely to substantially decrease sediment supply, which will impact the entire delta, with the lower and the upper deltaic plain becoming increasingly susceptible to both saltwater intrusion and inundation. By 2100 erosion is predicted to have removed the entire Cape Bowling Green spit, the river mouth to recede by up to 400 m and Alva Beach and the sand spits by up to 150 m. There have been a number of studies of the Burdekin, foremost of which is the work of Belperio (1978, 1983) together with Hopley (1970), Johnson et al. (1986) and Pringle (1983, 1984).

Fig. 14.26 PC03.08 coast: (**a**) Plantation Creek spit (QLD 892), part of the Burdekin River delta; (**b**) Molongle Creek and its spits and ebb tide delta (QLD 900–901); (**c**) the western shore of Cape Upstart with sand moving into the sand wave sink off Nobbies Creek (QLD 902); and (**d**) multiple recurved spits at the mouth of the Elliot River (QLD 930). (Photos: AD Short)

Fielding et al. (2005) in reviewing the Burdekin delta found it covers an area of 1260 km^2, with the active southern delta covering 782 km^2. It has an annual sediment discharge of between 2.7 and 9 M m^3 year^{-1}, with bedload between 0.45 and 19.7 M m^3 in major floods, the bedload composed of well-sorted, immature sediments. The delta front is exposed to relatively high southeast waves averaging 0.66 m (T = 4.6 s) at Cape Bowling Green which maintain a fair-weather wave base of 15 m and storm wave base of 35 m. These conditions drive the longshore transport northwards along the Burdekin coast. Bainbridge et al. (2012) investigated the extreme 2010–2012 flood events and found that they developed a sediment plume extending >50 km offshore and > 100 km to the north. Suspended clay and slit were deposited within 10 km of the river mouth, while sediment binding to organic particles was carried up to 100 km northwards.

14.9.7 SC:QLD03.08.03 Cape Upstart–Abbott Point

Abbott Bay (SC:QLD03.08.03) is a 40 km wide bay with 60 km of shoreline, consisting of three sectors as the bay curves round from the south to face east (Fig. 14.27). The sectors range from the sheltered southeast mangroves, central recurved spits and more exposed northern barrier and Cape Upstart. The shoreline

Fig. 14.27 SCs:QLD03.08.03-05 extend from Cape Upstart to Gloucester Island and include the Don River delta and city of Bowen. (Source: Google Earth)

is a mix of sandy beaches (61%), mangrove-lined sand flats, creek mouths and rocky shore. In the east is the low beachrock Abbott Point, containing the Abbot Point jetty and coal loader. The shore extends 7 km west of the point to Mount Bruce as steep rocky coast containing two embayed beaches. Sand sourced from the Don River may be moving around Abbott Point and along this shore. Between Mount Bruce and Mount Curlewis is 9 km of predominately low tidal flats and mangroves containing a series of west-trending sand spits at the mouths of the tidal creeks and the Elliot River mouth (Fig. 14.26d), all highly susceptible to change. From Mount Curlewis to the base of Cape Upstart are three longer beaches, separated by upland creeks (Elliott River and Saltwater, Splitters and Branch), each backed by extensive mangroves and exposed to northwesterly sand transport, as indicated by the multiple north-trending recurved spits. The longer Cape Beach (QLD 929) has a 2.5 km wide inner and outer barrier (Fig. 14.28a). The outer barrier regressed up to 1.5 km and is now unstable with minor dune transgression, and the backing creek is deflected to the northern end. North of Cape Beach is 15 km of steeply sloping rocky Cape Upstart shoreline, apart from several small embayed beaches along its base, including Kingfisher and Coconut bays (QLD 925 and 927). Sand appears to be entering the SC around Abbot Point, moving intermittently via the spits to Cape Beach, the moving northwards to at least the northern end of the beach, and possibly beyond and around Cape Upstart.

Fig. 14.28 PC:QLD03.08 coast: (**a**) the Cape barrier and lagoon (QLD 929), the largest in this PC and now unstable; (**b**) Abbott Point beach (QLD 944) is paralleled by a beachrock reef; (**c**) migratory spits heading north from the Don River delta (QLD 947); and (**d**) up to 20 ridged sand flats at Bowen (QLD 961). (Photos: AD Short)

14.9.8 SC:QLD03.08.04 Abbott Point–Cape Edgecumbe

The Don River delta occupies the centre of the 28 km long SC:QLD03.08.04 which extends from Abbot Point south to Cape Edgecumbe (Fig. 14.27). The river delivers periodic pulse of sand to the coast during floods, with Gourlay and Hacker (1986) estimating it delivered 1.1 M m^3 during the 1980 flood. The ongoing deposition has protruded the delta several kilometres into the bay and produced a largely sedimentary shoreline with sandy beaches and spits occupying 90% of the shore. The SC can be divided into three sectors. Between the base of Cape Edgecumbe and the river mouth is the 4 km long TM Queens Beach (QLD 954). The Don River delta and its west-trending multiple recurved spits occupy the central 14 km (Fig. 14.28c). The spits are backed by Euri Creek and extensive mangroves of the lower deltaic plain and then the rich farmland of the upper deltaic plain. This sector is susceptible to inundation from storm surge, flooding and sea-level rise, as well as saltwater intrusion into the upper deltaic plain. The northern sector is a relatively straight sandy beach, backed by a narrow regressive barrier, with minor dune transgression along its northern half, which extends up to Abbot Point (Fig. 14.28b) and the coal loading facilities. Sand is being transported from the delta mouth to Abbott Point, where there is a small groyne, and likely into the next SC.

14.9.9 SC:QLD03.08.05 Cape Edgecumbe–Cape Gloucester

Edgecumbe Bay (SC:QLD03.08.05) is a sheltered northeast-facing embayment, 18 km wide at its entrance, with 75 km of generally crenulate shoreline (Fig. 14.27). The large Gloucester Island and smaller bay islands, together with its orientation, shelter the shore for the southeast waves, with the shore receiving only smaller wind waves generated within the bay. The bay shore is a mixture of TD beaches, resilient bedrock and mangrove-lined tidal flats and about 10 tidal creeks (Fig. 14.29a) and shallow muddy bay floor (Frankel 1976) with 25 TD beaches occupying half the shoreline. They range from B + RSF at Bowen (Fig. 14.28d) to B + SF and TSF in the south, where they become increasingly fringed by mangroves. The shore is largely undeveloped apart from Bowen City and its port, salt ponds and a section of the Bruce Highway in the northern corner and fish farms in the southern corner between Eden Lassie Creek and the small Gregory River. There is very limited bed-load sediment entering the bay, with the main source of sediment being the bay floor and in situ carbonate production (sediments range 30–40% carbonate) making the bay a closed SC and sediment sink. Ryan et al. (2015) cored Bramston Reef in the bay in order to examine the impact of the mud-rich waters on reef growth. They found the reef was initiated ~5.4 ka and reached sea level by 4.2 ka and has since survived in this mud-rich environment.

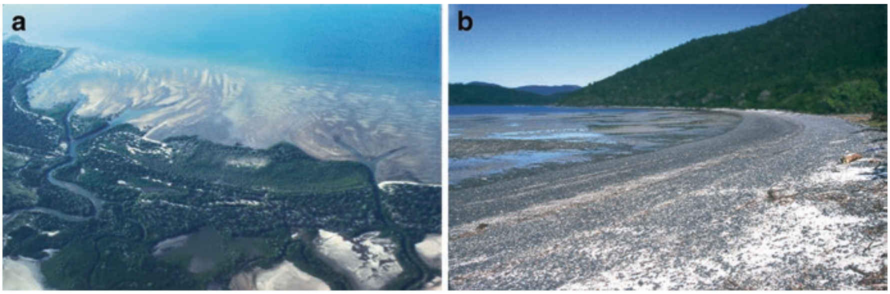

Fig. 14.29 (**a**) One kilometre wide sand flats in the centre of Edgecumbe Bay (QLD 969); and (**b**) cobble beach and flats (QLD 1011) in Woodwark Bay. (Photos: AD Short)

14.9.10 SC:QLD03.08.06 Cape Gloucester–Pioneer Point

The northern Whitsunday coast (SC:QLD03.08.06) consists of a highly indented series of approximately ten 2–5 km long, funnel-shaped bedrock bays extending from Cape Gloucester to Pioneer Point (Fig. 14.30) with a crenulation ratio of 2.8. They contain 116 km of predominately steep bedrock shoreline, with the bays generally increasing in size to the east, with 7 km wide Pioneer Bay the largest. Beaches occupy just 19 km (16%) of the predominately steep rocky shore. Small mangrove-lined creeks and tidal flats occupy the head of most of the bays, with the beaches located in indentations in the protruding points. Most of the shore is undeveloped apart from the northern Hideaway Bay-Dingo Beach and southern Cannonvale-Airlie Beach area. Wave energy is very low within the bays, with tides the dominant process. Sediments are very limited with coarse carbonate sand making up ~50% of the beach sand and a number of beaches composed of cobbles and boulders (Fig. 14.29b). Sediment transport is essentially non-existent within or between their deep embayments, the entire system being closed to external and internal transport and consisting of a number of closed TCs.

Fig. 14.30 SCs:QLD03.08.06-07: Whitsunday bays and islands – Cape Gloucester to Cape Conway. (Source: Google Earth)

14.9.11 SC:QLD03.08.06 Pioneer Point–Cape Conway

The Whitsunday coast and islands (SC:QLD03.08.07) is a highly indented 66 km long bedrock coast extending from Pioneer Point to Cape Conway and containing a series of small mainland bays, with the Whitsunday Islands group offshore, all with highly variable alignment (Fig. 14.30). It consists of predominately rocky volcanic shores apart from TD beaches at base of more exposed bays and mangroves at base of sheltered bays (Swamp, Roper Inlet, Trammel, Anderson and Woodcut). The 18 beaches make up just 10 km (15%) of the shoreline, with the rocky shore dominating, including mangrove-lined rocky shore in the sheltered bays. Some embayments (Puritan and Genesta) have small sand and cobble/boulder beach ridge barriers, while along the more exposed shore north of Cape Conway are six small TM beaches. A few beaches are fringed by coral reefs. Sediments are predominately carbonate (~60%) together with some scattered locally derived cobble-boulders. Whitehaven Beach on Whitsunday Islands is TM R + LTT and composed of 100% pure white quartz. Overall this a highly variable and irregular bedrock-dominated shore, with the only significant longshore transport occurring along Whitehaven Beach into the sand-choked Hill Inlet (one of Australia's most photogenic and well-publicised beach-inlets, with claims it is the whitest beach in Australia. See Sect. 34.7 and Table 34.5 to see which Australian beach is actually the whitest).

14.9.12 PC Overview

This long PC contains two major deltas which contribute substantial terrigenous sand together with a series of closed, leaky and open SCs. The northern Bowling Green Bay (SC:QLD03.08.01) is bordered by Cape Bowling Green, the low sandy terminus for the Burdekin River sand, with only the fines making it into the quiescent bay. Sand is moving clockwise within the bay at the creek mouths and along Big Beach, but does not appear to be moving out of the bay around capes Ferguson and Cleveland. The Burdekin-Upstart Bay (SC:QLD03.08.02) has another U-shaped bay at its base with spatially discontinuous clockwise sediment transport, that is initially southwards along the rocky western shore of Cape Upstart and then discontinuous between the creek and RM beach (QLD 901). The Burdekin River injects large volumes of sand during floods which are transported northwards initially via series of migratory spits all the way to the tip of Cape Bowling Green. Abbott Bay (SC:QLD03.08.03) has an open eastern boundary with Don River sand likely moving around Abbott Point and along the eastern shore. This transport is initially discontinuous, becoming more apparent and continuous by the Elliot River mouth and along the Cape Beach system, which has built out in line with the base of Cape Upstart. Where the sediment moves from here is unknown. The Don River delta system (SC:QLD03.08.04) is delivering substantial bedload to its delta which is being transported north, initially by a series of migratory spits then via the longer Abbott Point beach to the point and probably around it into the Abbott Bay compartment. Edgecumbe Bay (SC:QLD03.08.05) is a sheltered, low energy closed SC, with no external sources of sand and little internal sources and production. The southern two Whitsunday SCs (QLD03.08.07-08) are both highly irregular and deeply indented, with variable shoreline orientation and generally low wave energy. They contain a number of deeply embayed TCs. Longshore sand transport is essentially non-existent, apart from along Whitehaven Beach on Whitsunday Island.

14.9.13 Regional Overview

The eastern Cape York Peninsula region is both long and highly variable. It is unified by a tropical humid to savanna climate, the prevailing low to moderate southeast trade wind and waves, together with meso-tides, all located in lee of the GBR. The highly variable geology and its structure and alignment have produced numerous headland and several north-facing bays which result in major changes in shoreline orientation and exposure and which interrupt or prevent the overall northerly sediment transport, breaking the coast into a number of open, leaky and closed SCs and TCs. Half the coast consists of sandy beaches, the remainder a mix of mangrove-lined tidal flats and rocky shore in the many sheltered bays and rocky shore on the exposed headland, together with over 460 creek and river mouths.

Besides the spatial variation in coastal environments, the coast has undergone considerable temporal changes during the Quaternary. Pleistocene highstands have left a legacy of barrier deposits the length of the coast, including some of the northern massive transgressive dune systems. The Holocene brought the PMT which peaked ~1–2 m above present sea level ~6 ka (Hopley et al. 2007). At the same time, the GBR was in catch-up mode with a deeper than present reef surface which allowed more ocean waves to penetrate the reef and move shorewards across the lagoon. At the coast inshore-intertidal was deeper as the extensive tidal flats and inshore deposits were yet to form. The combination of the deeper reef, higher sea level and a deeper inshore allowed higher wave to reach the shore during this mid-Holocene 'high energy window'. The impacts would have been several including transporting large volumes of inner shelf sand in exposed locations, generating higher energy beach-barrier systems including active dune transgression and generating higher rates of longshore sand transport. The coast we see today is now sheltered by the outer GBR as well as mid-shelf and in places fringing reefs, all of which reduce deepwater wave energy, while the inshore and intertidal have been filled with sediments reducing inshore-intertidal gradients which further reduce breaker wave energy. The net result is a lower energy sediment-filled shoreline.

Because of the considerable variation in shoreline type and orientation, this region has a wide range of exposure to hazards and vulnerability. The major hazards are delivered with tropical cyclones and their associated strong winds, heavy rain, flooding, high waves, storm surges and coastal erosion and inundation. All of these will continue into the future, with the additional impact of sea-level rise and potential changes in the frequency, intensity and tracks of the cyclones (DERM 2011). In general, all the low-lying tidal-supratidal flats, creek and river mouths will be most vulnerable to sea-level rise, followed by the many low beach ridges, some of which have been developed for housing. QRMC (2003) investigated the risk to coastal flooding and storm surge in the Burdekin region and found that a category 5 storm surge would extend up 10 km inland and inundate all the lower deltaic plain. The higher energy TM beaches usually backed by higher foredunes grading into transgressive dunes will be the least vulnerable of the sedimentary shores, while the higher resilient rocky shore will have low vulnerability.

References

Bainbridge ZT, Wolanski E, Álvarez-Romero JG, Lewis SE, Brodie JE (2012) Fine sediment and nutrient dynamics related to particle size and floc formation in a Burdekin River flood plume, Australia. Mar Pollut Bull 65:236–248

Belperio AP (1978) An inner shelf sedimentation model for the Townsville region, Great Barrier Reef. Ph.D. thesis, James Cook University, Townsville, 209 p

Belperio AP (1983) Terrigenous sedimentation in the central Great Barrier Reef Lagoon: a model from the Burdekin region. BMR J Aust Geol Geophys 8:179–190

Bird ECF (1970) Coastal evolution in the Cairns district. Aust Geogr Stud 11:327–335

Brooke BP, Huang Z, Nicholas WA, Oliver TSN, Tamura T, Woodroffe CD, Nichol SL (2019) Relative sea-level records preserved in Holocene beachridge strandplains – an example from tropical northeastern Australia. Mar Geol, 411. https://doi.org/10.1016/j.margeo.2019.02.005

BPA (1984) Mulgrave Shire northern beaches. Beach Protection Authority Queensland, Brisbane, 366 p

CES (2012) Cungulla shoreline erosion management plan. Report for Townsville City Council prepared by Coastal Engineering Solutions, 88 p

Chappell J, Grindrod J (1984) Chenier plain formation in northern Australia. In: Thom BG (ed) Coastal geomorphology in Australia. Academic Press, Sydney, pp 197–231

DERM (2011) Queensland coastal processes and climate change. Department of Environment Resource Management, Brisbane, 49 p

Fielding CR, Trueman JD, Alexander J (2005) Sharp-based, flood-dominated mouth bars sands from the Burdekin River delta of northeastern Australia: extending the spectrum of mouth-bar facies, geometry, and stacking patterns. J Sediment Res 75:55–66

Forsyth AJ, Nott J, Bateman MD (2010) Beach ridge evidence of a variable late-Holocene tropical cyclone climate, North Queensland, Australia. Palaeogeogr Palaeoclimatol Palaeoecol 297:707–716

Forsyth AJ, Nott J, Bateman MD, Beaman RJ (2012) Juxtaposed beach ridges and foredunes within a ridge plain – Wonga Beach, northeast Australia. Mar Geol 307–310:111–116

Frankel E (1976) Guide to Edgecumbe Bay, excursion guide to the Great Barrier Reef: Sydney, International Geological Congress, pp 27–51

GHD (2012) Coastal hazard adaption strategy for Townsville City Council. Pilot project. GHD, Brisbane, 76 p

Goh S (1993) Estimates of shoreline retreat with rising sea-level, Cape Bowling Green, north Queensland, Australia. In: 11th Australasian conference on coastal and ocean engineering, Townsville, Institution of Engineers Australia, pp 723–724

Gourlay MR, Hacker JLF (1986) Pioneer River estuary sedimentation studies. University of Queensland Press, St Lucia, 207 p

Grindrod J, Rhodes EG (1984) Holocene sea-level history of a tropical estuary: Missionary Bay, north Queensland. In: Thom BG (ed) Coastal Geomorphology in Australia. Academic Press, Sydney, pp 151–178

Harris PT (1989) Sand wave movement under tidal and wind-driven currents in a shallow marine environment: Aolphus Channel, northeastern Australia. Cont Shelf Res 9:981–1002

Harris PT (1994) Comparison of tropical, carbonate and temperate, siliclastic tidally dominated sedimentary deposits: examples from the Australian Continental Shelf. Aust J Earth Sci 41:241–254

Heggie BJ, Wallis R (2001) Cairns Cityport – Marlin Marina redevelopment. In: 15th Australasian conference on coastal and ocean engineering, Gold Coast, Institution of Engineers Australia, pp 1–8

Hemer MA, Harris PT, Coleman R, Hunter J (2004) Sediment mobility due to currents and waves in the Torres Strait-Gulf of Papua region. Cont Shelf Res 24:2297–2316

Hopley D (1970) The geomorphology of the Burdekin Delta, North Queensland. Department of Geography, James Cook University, Townsville, 66 p

Hopley D (1978) An introduction to the geomorphology of the region (Townville). In: Hopley D (ed) Geographical studies of the Townsville area. Department of Geography, James Cook University, Townsville, pp 37–42

Hopley D (1979) Australian landform example no. 35, Deltaic Barrier Spit. Aust Geogr 14:248–251

Hopley D, Murtha GG (1975) The quaternary deposits of the Townsville coastal plain. Department of Geography, James Cook University, Townsville

Hopley D, Smithers SG, Parnell KE (2007) The geomorphology of the Great Barrier Reef: development, diversity and, change. Cambridge University Press, Cambridge, 532 p

Horne D, Lees B, Cupper M, Fitzsimmons K (2015) The development of the Princess Charlotte Bay chenier plain: new results and insights. Mar Geol 364:12–20. https://doi.org/10.1016/j.margeo.2015.03.004

Johnson, DP, Belperio, AP, Hopley D (1986) A field guide to mixed terrigenous-carbonate sedimentation in the Central Great Barrier Reef Province, Australia. Australian Sedimentologist Group field guide series no. 3, Geological Society of Australia, Sydney, 173 p

Jones MR, Stephens AW (1986) Evolutionary processes on a deltaic coast – evidence from the Barron delta, Trinity Bay, Queensland. In: Frankel E, Keene JB, Waltho AE (eds) Recent sediments in eastern Australia: marine through terrestrial. Publications Geological Society of Australia, NSW division no. 2, pp 117–129

Lees BG (1992) Geomorphological evidence form late Holocene climatic change in northern Australia. Aust Geogr 23:1–10

Lees BG, Yanchou L, Head J (1990) Reconnaissance thermoluminescence dating of Northern Australian coastal dune systems. Quat Res 34:169–185

Leonard S, Nott J (2015) Rapid cycles of episodic adjustment: understanding the Holocene fluvial archive of the Daintree River of northern Australia. The Holocene 25(8):1208–1219

Leonard S, Nott J (2016) A Holocene fluvial archive of the Mulgrave River, northeastern Australia: influence of tropical cyclones and sediment delivery to the Great Barrier Reef. Palaeogeogr Palaeoclimatol Palaeoecol 441:845–853

Muller J, Wüst RAJ, Hearty PJ (2006) Sediment transport along an artificial shoreline: "The Strand". Townsville NE-Queensland, Australia. Estuar Coast Shelf Sci 66:204–210

Murray RJ, Ford LR (1983) Problems in the analysis of data for the assessment of longshore sediment transport: an example from north Queensland. In: Sixth Australian conference on coastal and ocean engineering, Gold Coast, Institution of Engineers Australia, pp 21–26

Nott J (2003) The urban geology of Cairns, Queensland, Australia. Quat Int 103:750–782

Nott J (2006) Tropical cyclones and the evolution of the sedimentary coast of Australia. J Coast Res 22:49–62

Nott J, Smithers S, Walsh K, Rhodes E (2009) Sand beach ridges record 6000 year history of extreme tropical cyclone activity in northeastern Australia. Quat Sci Rev 28:1511–1520

Nott J, Chague-Goff C, Goff J, Sloss C, Riggs N (2013) Anatomy of sand beach ridges: evidence from severe Tropical Cyclone Yasi and its predecessors, northeast Queensland, Australia. J Geophys Res 118:1710–1719. https://doi.org/10.1002/jgrf.20122

Nott J, Forsyth A, Rhodes E, O'Grady D (2015) The origin of centennial- to millennial-scale chronological gaps in storm emplaced beach ridge plains. Mar Geol 367:83–93

Pearce CM (1992) Beach morphodynamics and shoreline change at Saunders Beach and Toolakea, Halifax Bay, North Queensland. B.Ed. Honours thesis. Department of Geography, James Cook University, Townsville, 95 p

Pringle AW (1983) Sand spit and bar development along the east Burdekin Delta coast, Queensland, Australia. Department of Geography, James Cook University, Townsville

Pringle AW (1984) Evolution of the east Burdekin Delta coast, Queensland, Australia 1940–1980. Z Geomorphol 28:129–154

Pye K (1982) Morphological development of coastal dunes in a humid tropical environment, Cape Bedford and Cape Flattery, North Queensland. Geogr Ann 64A:213–227

Pye K (1983a) Dune formation on the humid tropical sector of the north Queensland coast, Australia. Earth Surf Process Landf 8:213–222

Pye K (1983b) Formation and history of Queensland coastal dunes. Zeitschrift Fur Geomorphologie Supp 45

Pye K (1983c) Coastal dune formations of northern Cape York Peninsula, Queensland. Proc R Soc Queensland 94:33–39

Pye K, Bowman GM (1984) The Holocene marine transgression as a forcing function in episodic dune activity in eastern Australia. In: Thom BG (ed) Coastal geomorphology in Australia. Academic Press, Sydney, pp 179–196

Pye K, Rhodes EG (1985) Holocene development of an episodic transgressive dune barrier, Ramsay Bay, north Queensland, Australia. Mar Geol 64:189–202

Pye K, Switsur S (1981) Radiocarbon dates from the Cape Bedford and Cape Flattery dunefields. Search 12:225–226

QRMC (2003) Burdekin Shire Council natural disaster risk management study. Report parts A and B. QRMC Risk Management, Brisbane, 306 p

Riedel HP (1975) Design of a small boat harbour in a cyclone area – Townsville. In: 2nd Australian conference on coastal and ocean engineering, Gold Coast

Riedel P, O'Brien P, Smith R, Macfarlane B (1999) Beach Renourishment at The Strand, Townsville. In: 14th Australasian conference on coastal and ocean engineering, Perth, Institution of Engineers Australia, 8 p

Robinson DA, Cook DJ (1980) Barron River delta investigation. In: 17th International conference coastal engineering, Sydney, 16–17 (abstract)

Ryan EJ, Smithers SG, Lewis SE, Clark TR, Zhao JX (2015) Chronostratigraphy of Bramston Reef reveals a long-term record of fringing reef growth under muddy conditions in the central Great Barrier Reef. Palaeogeogr Palaeoclimatol Palaeoecol 441:734–747

Short AD (2000) Beaches of the Queensland Coast: Cooktown to Coolangatta. Sydney University Press, Sydney, 360 p

Short AD (2006) Beaches of the Northern Australia coast: the Kimberley, Northern Territory and Cape York. Sydney University Press, Sydney, 463 p

Tamura T, Nicholas WA, Oliver TSN, Brooke BP (2017) Coarse-sand beach ridges at Cowley Beach, north-eastern Australia: their formative processes and potential as records of tropical cyclone history. Sedimentology, 24 p. https://doi.org/10.1111/sed.12402

Thom BG, Roy P (1985) Relative sea levels and coastal sedimentation in southeast Australia in the Holocene. J Sediment Petrol 55:257–264

TSRA (2011) Torres Strait Climate Change Strategy 2010–2013. Report prepared by the Env Mgt Program, Torres Strait Reg Authority, 20 p

Wolanski E (1983) Non-tidal currents in Torres Strait. In: 6th Australian conference on coastal and ocean engineering, Brisbane, Institution of Engineers Australia, pp 90–91

Wolanski E, Thomson R (1984) Wind-driven circulation on the Northern Great Barrier Reef continental shelf in summer. Estuar Coast Shelf Sci 18:271–289

Wolanski E, Ridd P, Inoue M (1988) Currents through Torres Strait. J Phys Oceanogr 18:535–1545

Chapter 15
Central Queensland Region

Abstract The 1800 km central Queensland coastal region trends to the southeast and contains several large bays including the muddy mega-tidal Broad Sound. The coast is also sheltered by the southern Great Barrier Reef and in the south by Fraser Island. It is exposed to a humid sub-tropical climate with the trade winds blowing onshore and delivering low to moderate seas coupled with some low ocean swell in the south, together with seasonal tropical cyclones. A few large rivers and numerous smaller streams deliver terrigenous sediment to the coast and have built deltas, with their quartz-rich sediment transported northwards. Beaches range from tide-modified to tide-dominated, while extensive mangroves fringe the bay shorelines. Barriers range from regressive beach-foredune ridges to massive transgressive dunes. This chapter describes the geology, coastal processes, beaches, barriers and sediment compartments within a framework of sediment compartments.

Keywords Central Queensland · Great Barrier Reef · Fraser Island · Beaches · Barriers · Sediment transport · Sediment compartments

15.1 Introduction

The central Queensland region (QLD04) occupies the southern third of the north-east division (Fig. 13.1). It commences at the prominent Cape Conway and trends generally southeast for 1827 km to Sandy Cape at the northern tip of Fraser Island (Fig. 15.1). This is a sub-tropical coast that straddles the Tropic of Capricorn lying between 20.5 and 25.3°S. The climate ranges from tropical savanna (Aw) in the north to humid sub-tropical (Cwa then Cfa) in the central-south (Fig. 1.7). The southeast trade winds and waves remain dominant, while tides increase southward to mega reaching their maximum on the east coast in Broad Sound (8 m) and then decrease to meso further south. The region contains several large embayments including Repulse Bay, Broad Sound, Shoalwater Bay, Keppel Bay, Port Curtis and Hervey Bay, together with a number of smaller bays. Offshore lie the high islands of the Cumberland, Northumberland and Keppel groups and the Great Barrier Reef (GBR). The GBR broadens its cluster of outer reefs to up to 120 km in width, with

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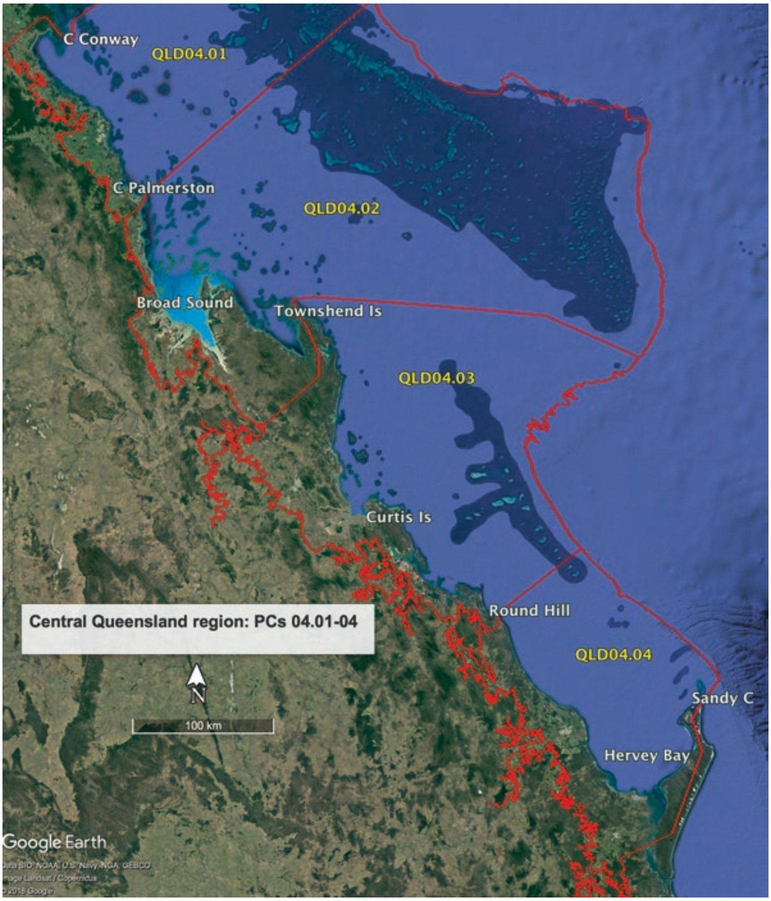

Fig. 15.1 The central Queensland region extends from Cape Conway to Hervey Bay-Fraser Island and contains four PCs:QLD04.01-04. (Source: Google Earth)

the outer edge lying between 150 km offshore in the north to 280 km off Gladstone, before terminating 50 km offshore in the small Capricorn-Bunker group, with the southern end of the GBR being the lone Lady Elliot Island at 24.1°S (Fig. 13.4). To accommodate this somewhat variable coastline, the region is divided into four PCs (Fig. 15.1, Table 15.1) and 21 SCs, each of which is discussed in the following sections.

The coast contains 497 sandy beaches and 183 barriers which occupy 45% and 37% of the coast respectively. The remainder of the shore a mix of bedrock and extensive mangroves in many of the bays, particularly in Broad Sound and Shoalwater Bay, and in the creek and river mouths.

Table 15.1 Central Queensland region PCs:QLD04.01-04

PC number[a]	Region: central Queensland	PC boundaries	Beach ID[b]	No. beaches	km[c]	Total km
QLD04.01		C Conway-C Palmerston	Q 1038-1170	133	3777–4113	336
QLD04.02		C Palmerston-Townshend Is	Q 1171-1299	129	4113–4647	534
QLD04.03		Townshend Is-Round Hill	Q 1300-1467	168	4647–5288	641
QLD04.04		Round Hill-Sandy C	Q 1468-1527	60	5288–5492	204
		+ W Fraser Is	FIs 11-17	7		112
		Region sub-total		497		1827

[a]NCCARF compartment number
[b]ABSAMP beach ID
[c]Distance from NT to QLD border

15.1.1 Coastal Geology

The coastal ranges occupy or lie close to much of the coast and account for the high proportion of rocky shore and embayed beaches. The Clarke-Connor-Broad Sound ranges parallel the coast between Proserpine and Broad Sound, followed by the Peninsula Range and generally moderate relief coast down to Round Hill, south of which the sediments of the Burrum-Burnett-Mary rivers dominate the shore. The bedrock begins with the Cretaceous granite of the Whitsundays, followed by a mix of sedimentary and metasedimentary rocks in Repulse Bay and along the Sarina coast, with Cretaceous granites in the Mackay region. Broad Sound has Permian volcanics on its west coast and sedimentary rocks along its south and east coasts which continue down the coast to Gladstone. Granite and volcanics occupy the Bustard Bay region, apart from the volcanics around Bundaberg, with Tertiary fluvial deposits extending from the Burnett River down into Hervey Bay and finally the Quaternary dune sands of Fraser Island. The roughly north-south trend of the coastal blocks and arches (Fig. 13.2) controls the alignment of the coastal ranges and many of the bays and headlands including the large north-trending Broad Sound, Shoalwater Bay and Curtis Island. The coast is dominated by the geology and its alignment, with most of the beaches bordered by rocks and headlands. The only substantial sedimentary shorelines are the mangroves and tidal flats of Broad Sound and Shoalwater Bay, the Fitzroy delta in Keppel Bay, north of the Burnett delta, and in the south sediments from the Kolan-Burnett-Burrum-Mary river deltas, together with Great Sandy Strait and Fraser Island.

This is a moderately developed section of the coast with the major cities and towns of Proserpine (3500), Mackay region (125,000), Sarina (6000), Rockhampton (80,000), Gladstone (70,000), Bundaberg region (100,000), Hervey Bay (65,000) and Maryborough (30,000), as well as dozens of smaller towns and communities. The Bruce Highway parallels the coast but only touches it at Clairview on Broad Sound.

15.1.2 Rivers and Creeks

There are over 160 rivers, streams and tidal creeks reaching the coast including 10 rivers ranging from the small O'Connell to the Fitzroy, which has the largest catchment in coastal Queensland. From north to south, the rivers are the Proserpine (1095 km^2), O'Connell (859 km^2), Pioneer (1580 km^2), Styx (1890 km^2), Fitzroy (142,733 km^2), Boyne (2484 km^2), Kolan (2823 km^2), Burnett (33,323 km^2), Burrum (2368 km^2) and Mary (9595 km^2). All have deltas at their mouths, and some are delivering substantial sediment, including bedload to the coast.

15.1.3 Coastal Processes and Sediments

Coastal processes along this region remain dominated by the southeast trade wind and waves, which are generated within the GBR lagoon. As the GBR trends further offshore, it provides a greater fetch for waves together with the northernmost penetration of southerly swell on the mainland coast south from Round Hill. Mean deepwater wave height off Mackay reaches 0.65 m (H_s = 1.4 m), Gladstone 0.7 m (H_s = 1.3 m) and Burnett Heads 0.85 m (H_s = 1.5 m), all the highest inside the GBR lagoon (Table 13.3). Breaker wave height as recorded by COPE observations varies considerable from zero in the sheltered bays to a maximum of 0.8 m at Baffle Creek. In general, it averages around 0.5 m, with periods 4–5 s for most of the coast, increasing to 8 s at Baffle Creek, which receives some southerly swell (Table 13.4).

Tides are meso in the north rising to macro at Mackay (spring range = 5.5 m) and mega in Broad Sound (8 m and the highest on the east coast). They then decrease southwards to 4.1 m at Port Clinton, 3.9 m at Gladstone and 2.5 m at Bundaberg (Fig. 13.9; Table 15.2). Middleton et al. (1984) monitored and modelled the Broad Sound and Shoalwater Bay tides and found the macro-tides are a result of the ocean tide negotiating the GBR and entering though gaps in the GBR and arriving as tidal flows from the north and south which amplify the tide by a factor of four and have a phase lag of 3 h (an observation first noted by Flinders in 1802) combined with amplification by 1.5 into the narrowing bays, resulting in a total amplification of between five and six. Bode and Stark (1983) also noted the large tides which they associated with some form of resonance and the associated strong tidal currents in the sound.

Table 15.2 Tidal characteristics of the central Queensland coast

Location	Spring tide range (m)	Max spring tide range (m)	Relative time of arrival 0 h = point danger + = after, add hours
Mackay	4.9	5.5	+2.5
Broad Sound	6.3	8.0	+4
Port Clinton	3.9	4.1	+2
Gladstone	3.2	3.9	+1.5
Bundaberg	1.7	2.5	+1.5
Brisbane Bar	1.8	2.1	+1
Pt Danger	1.1	1.5	0

Table 15.3 PCs:QLD04.01-04 beach sand characteristics

QLD04	QLD04.01	QLD04.02	QLD04.03	QLD04.04
n	36	17	85	31
Size (mm)	0.49	0.43	0.27	0.41
σ (mm)	0.5	0.34	0.28	0.28
Sorting	0.64	0.74	0.52	0.61
σ (sorting)	0.33	0.28	0.44	0.3
Carbonate %	18.1	34.3	9.7	5.2
σ (%)	19.6	22.8	14.3	8.5
Range (%)	1-65	4-75	1-83	1-34

Beach sediments along this region are predominately moderately well-sorted medium quartz sand (~0.3–0.5 mm), with carbonate averaging between 5 and 34%, but ranging locally from 1 to 83% (Table 15.3). Figure 15.2 shows the longshore trends in size and carbonate, and while there is an underlying trend of medium sand (0.2–0.4 mm) and low carbonate (<20%), there are patches of coarse to very coarse sand and/or carbonate up to 80%. The areas of higher carbonate are located between Midgeton and Seaforth, the Sarina coast down into Broad Sound and Shoalwater Bay, the Capricorn coast between Yeppoon and Zilzie beach and the Bargara coast.

15.1.4 Beaches

The region contains 497 beaches which occupy 827 km (45%) of the coast. They average 1.7 km in length and are predominately orientated to the southeast (114°), with moderate embaymentisation (0.72). They are either TM or TD, with an average upper beach width of 14 m, a moderate swash zone slope of 4.3°, fronted by inter-tidal sand flats that average 438 m in width (σ = 656 m) (Table 15.4). The beaches within each compartment are discussed in the following sections, with details on all beaches provided by Short (2000).

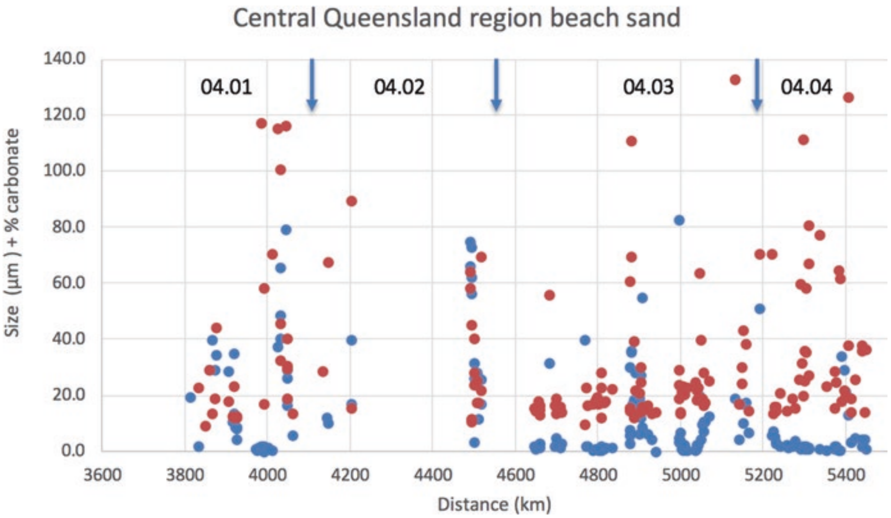

Fig. 15.2 Central Queensland region (PCs:QLD04.01-04) beach sand characteristics (size = red, µm; % carbonate = blue). While size is predominately fine to medium and carbonate <20% there are areas of both coarse sand and high carbonate, together with significant local variation. Distance from NT/QLD border, arrows indicate PC boundaries

Table 15.4 Region QLD04 beach characteristics

QLD 04		n	Mean (km)	σ (km)	Max (km)
Beach length (km)	827.1				
Mean length (km)		497	1.7	2.9	24.5
Orientation (deg)		497	114	102	-
Embaymentisation		497	0.7	0.4	-
Gradient (deg)		497	4.3	2.9	-
Beach width (m)		497	14.2	7.3	50
Sand ridges (m)		36	7.6	4.9	20
Intertidal (m)		497	438	656	4000

15.1.5 Barriers

There are a total of 183 barrier systems in the region, which extend along 673 km (37%) of the coast. They cover an area of 97,556 ha and are predominately vegetated and stable (99%). They have a total volume of 15,343 M m^3, with a unit volume of 53,310 m^3 m^{-1}, the highest in the division, due primarily to the large transgressive dunes and regressive barriers on the Capricorn coast (PC 04.03) (Table 15.5).

Table 15.5 Region QLD04 (PCs:QLD04.01-04) barrier dimensions

QLD:04	04.01	04.02	04.03	04.04	04
No.	51	62	48	22	183
Total length (km)	184.6	122	218	148.6	673.2
Mean min width	180	120	670	640	120
Mean max width	380	320	1670	1280	1670
Mean height (m)	5.1	5.2	15.4	7.5	8.3
Area (ha)	3766	2769	70,047	20,974	97,556
Unstable (ha)	0	47	1232	40	1319
Total volume (M m^3)	228	141	13,832	1142	15,343
Unit volume ($m^3\ m^{-1}$)	1237	1155	63,522	7686	22,791

15.2 PC:QLD04.01 Cape Conway–Cape Palmerston

PC:QLD04.01 is a 336 km long compartment that extends between Cape Conway and Cape Palmerston (Fig. 15.1). It begins in the north at the 30 km wide Repulse Bay and trends southeast including St Helens and Sand bays, the Mackay coast and the Pioneer River delta, and in the south Sandringham and Ince bays. Owing to the number of sheltered bays and prominent headlands, it has a crenulation ratio of 2.7, with the coast a mix of TM on the exposed sections and TD in the often mangrove-lined bays. Some sheltering is also provided by the series of high islands located 20–40 km offshore that extend south from the Lindeman Group off Cape Conway and includes the inner Repulse Islands and outer Cumberland Islands, Beverley Group and Guardfish Cluster, with the outer GBR located between 150 and 180 km offshore. Proserpine and Mackay are the two major towns in the region, together with a number of smaller coastal communities at Conway Beach, Midge Point, Seaforth-Ball Bay, Bucasia, McEwens Beach, the coal loading facility at Hay Point, the Sarina coast and Armstrong Beach. The PC contains five SCs (QLD04.01.01-05) listed in Table 15.6.

15.2.1 Rivers and Creeks

This PC has over 50 steams, creek and rivers reaching the coast including the larger Prosperine, O'Connell and Pioneer rivers. The Proserpine and O'Connell rivers flow into the northern end of Repulse Bay, and the Proserpine while facing southeast is sheltered by Cape Conway and the Repulse Islands and has a mangrove-lined funnel-shaped TD mouth. A regressive barrier extends south of the mouth for 10 km

Table 15.6 Central Queensland region QLD04 and its PC and SCs

Region/Comp. No.[a]	Region	Primary compartment boundaries	Beach ID[b]	No. beaches	km[c]	Total km
QLD 04	Central Queensland					
QLD04.01.01	Repulse Bay	C Conway-Proserpine R	QLD 1038-1047	10	3777–3816	39
QLD04.01.02		Proserpine R-C Hillsborough	QLD 1048-1097	50	3816–3931	115
QLD04.01.03	Mackay	C Hillsborough-Pioneer R	QLD 1098-1118	21	3931–3997	66
QLD04.01.04	Mackay	Pioneer R-Dudgeon Pt	QLD 1119-1128	10	3997–4024	27
QLD04.01.05		Dudgeon Pt-C Palmerston	QLD 1129-1170	42	4024–4113	89
PC:QLD 04.01		*C Conway-C Palmerston*		*133*	*3777–4113*	*336*
QLD04.02.01	Broad Sound (N)	C Palmerston-N Red Bluff	QLD 1171-1214	44	4114–4224	111
QLD04.02.02	Broad Sound	N Red Bluff-North Pt	QLD 1215-1222	8	4224–4451	227
QLD04.02.03	Shoalwater Bay	North Pt-Townshend Is	QLD 1223-1299	77	4451–4647	196
PC:QLD04.02		*C Palmerston-Townshend Is*	*QLD 1171-1299*	*129*	*4113–4647*	*534*
QLD04.03.01		Townshend Is-C Manifold	QLD 1300-1347	48	4647–4800	153
QLD04.03.02	Capricorn coast	C Manifold-Yeppoon	QLD 1348-1365	18	4800–4881	81
QLD04.03.03	Capricorn coast	Yeppoon-Zilzie Pt	QLD 1366-1380	15	4881–4906	25
QLD04.03.04	Keppel Bay	Zilzie Pt-Station Pt	QLD 1381-1394	14	4906–5000	94
QLD04.03.05	Curtis Island	Station Pt-C Capricorn	QLD 1395-1406	12	5000–5039	39
QLD04.03.06	Gladstone Hbr	The Narrows	–	–	–	66
QLD04.03.07	Curtis Island	C Capricorn-Gatcombe Pt	QLD 1407-1427	21	5039–5073	34
			Facing Is 1-7	7	0–18	18
QLD04.03.08	Port Curtis	Gatcombe Pt-Richards Pt	QLD 1428-1446	19	5139–5227	88
QLD04.03.09	Bustard Bay	Richards Pt-Round Hill	QLD 1447-1467	21	5227–5288	61
PC:QLD04.03		*Townshend Is-Round Hill*	*QLD 1300-1467*	*175*	*4647–5288*	*659*

(continued)

Table 15.6 (continued)

Region/Comp. No.[a]	Region	Primary compartment boundaries	Beach ID[b]	No. beaches	km[c]	Total km
QLD04.04.01		Round Hill-Burnett R	QLD 1468-1496	29	5288–5387	99
QLD04.04.02		Burnett R-Elliott R	QLD 1497-1511	15	5387–5412	25
QLD04.04.03	Hervey Bay	Elliott R-Sandy C	QLD1511-1527	17	5412–5492	80
		W Fraser Island	FIs 12-17	6		112
PC:QLD04.04		*Round Hill-Sandy C*	*QLD 1468-1527*	*60*	*5288–5492*	*204*
		+ W Fraser Island	*FIs- 12-17*	*7*		*112*
		Region (QLD04)		**497**		**1845**

[a]NCCARF compartment number
[b]ABSAMP beach ID
[c]Distance from NT/QLD border

down to the smaller O'Connell River, which is mangrove-lined with tidal sand flats extending 2 km into the bay (Fig. 15.3a). The Pioneer is the largest river in the PC and has built a substantial delta, now the site of Mackay City. There are many smaller mangrove-lined tidal creeks along this PC particularly in the sheltered north-facing funnel-shaped bays including Dempster Creek, St Helens Bay, Murray Creek, Sand Bay, Barker Creek, Sandringham Bay, Sarina Inlet and Llewellyn and Ince bays.

15.2.2 Coastal Processes and Sediments

Coastal processes are dominated by the southeast trade wind and waves, with waves higher on the open coast owing to the greater fetch in the GBR lagoon as the outer reef moves offshore. Tides increase southward reaching 5.5 m at Mackay. Beach sand along the compartment is typically moderately sorted, medium-coarse quartz sand, with 18% carbonate (Table 15.3). Sediment sources include the inner shelf, the three rivers (Proserpine, O'Connell and Pioneer), the smaller creeks and in situ carbonate production, including mangroves.

15.2.3 Beaches

There are 133 beaches along this PC that average 1.1 km in length and occupy 43% of the shore (Table 15.7). They are a mix of TM (49%) on the exposed sections (Fig. 15.3b) and TD (51%) in the many bays and sheltered sections (Fig. 15.3a, c

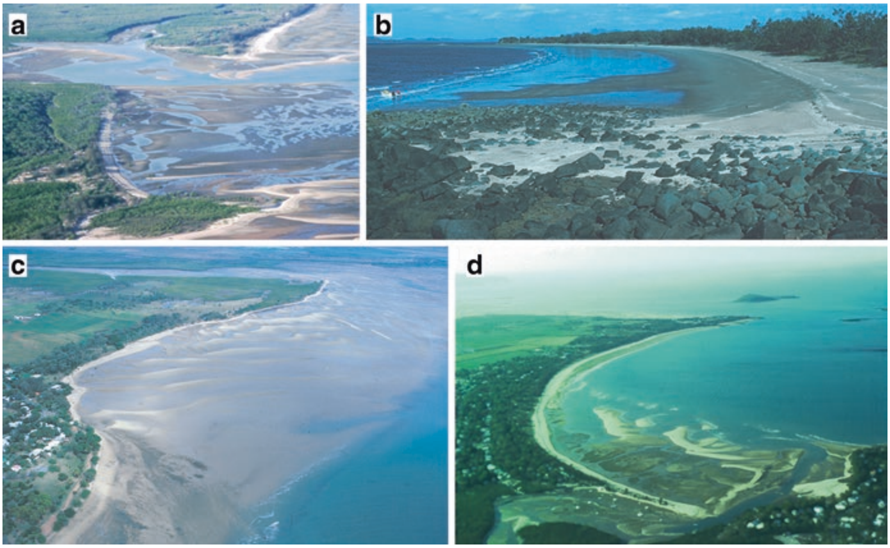

Fig. 15.3 PC:QLD04.01 coast: (**a**) tidal sand flats near the mouth of the O'Connell River (QLD 1053-4); (**b**) the wide UD Dewars beach (QLD 1079); (**c**) the Shoal Point spit with sand waves on the flats transporting sand into Sand Bay (QLD 1103); and (**d**) Bucasia beach which ranges from wide tidal flats in the south to UD in the more exposed north (QLD 1105). (Photos: AD Short)

Table 15.7 PC:QLD04.01 beach types and states

BS	BS	No.	%	Total length (km)	%	Mean (km)	σ (km)
7	R+LTT	46	34.6	24.8	17.0	0.5	0.7
9	UD	23	17.3	46.5	31.9	2.0	1.4
10	B+RSF	9	6.8	12.6	8.7	1.4	1.0
11	B+SF	49	36.8	55.5	38.1	1.1	1.0
12	B+TSF	6	4.5	6.4	4.4	1.1	1.0
		133	100	145.8	100	1.1	–

and d). The beaches are bordered by rocky points and headlands, as well as the many creek mouths and inlets. The remainder of the coast is predominately mangrove-lined tidal flats, rocky sections and creek and river mouths. The only prominent structure on the coast is the Mackay Harbour attached breakwaters and the Hay Point small boat harbour and its three coal loading jetties the longest extending 3.8 km seaward.

15.2.4 Barriers

There are 51 barriers along this compartment with a total length of 185 km occupying 55% of the shore. They range in mean width from 0.18 to 0.38 km, average 5.1 m in height, and cover an area of 3766 ha. Most of the barriers are low regressive beach-foredune ridges grading into recurved spits at many of the creek mouths. They have a relatively low total volume of 228 M m^3, with a very small unit volume of 1237 m^3 m^{-1}. The low volumes are a result of much of the river bedload being deposited in the bays and sand flats and with just a few small transgressive dunes in lee of the northern Mackay beaches where they extend only 100 m inland. Overall this is a lower energy, stable coast with river sediment accumulating in inter to subtidal sinks.

This PC has two major sources of terrestrial sand (Proserpine-O'Connell and Pioneer rivers) located in amongst a series of sheltered bay; consequently, longshore sand transport is restricted to the vicinity of the river mouths, together with several closed TCs. The sediments and transport in each of the five SCs are presented below.

15.2.5 SC:QLD04.01.01 Cape Conway–Proserpine River

SC:QLD04.01.01 occupies the sheltered northern bedrock-dominated corner of Repulse Bay (Fig. 15.4). It faces generally south between Cape Conway and Conway beach and includes the Lindeman Group of high islands. Roughly half of the 30 km of mainland coast consist of the steep, rugged, bedrock Cape Conway coast, with the northern corner containing two funnel-shaped TD tidal creeks – The Inlet and Repulse Creek, both infilled with mangroves and supratidal flats, while deep tidal channels and intertidal sand flats extend over 3 km into the bay. Immediately west are Repulse and Conway beaches, with a small regressive barrier backing Conway, and tidal flats grading from SF to RSF and extending 1.8 km into the bay. The sediment is derived from the Pioneer River, which discharges immediately west of the beach. The beaches, flats and very likely the inlets act as a sediment sink for Pioneer River sediments.

15.2.6 SC:QLD04.01.02 Proserpine River–Cape Hillsborough

Repulse Bay (SC:QLD04.01.02) is a 60 m long east to northeast-facing bay, bordered by Cape Conway and Cape Hillsborough (Fig. 15.4), with 115 km of generally crenulate shoreline consisting of a mix of drowned bedrock coast with several large tidal creeks, together with tidal flats and mangroves occupying the drowned valleys, with the creeks and bays increasing its size to the south. The Proserpine-O'Connell river delta occupies the northern 15 km of shore where they have deposited a ~5 km wide lower deltaic plain, with tidal flats extending up to 3 km into the bay (Fig. 15.5a). The Proserpine River is delivering fine quartz sand (<2% carbonate) to the northern bay, with the remainder of the bay containing a mix of fine to coarse carbonate-enriched sands (~20% carbonate). Sediments from the rivers appear to be accumulating in the northern bay and not moving around Cape Conway.

Fig. 15.4 SCs:QLD04.01.01-02 Repulse Bay and the irregular coast down to Cape Hillsborough. (Source: Google Earth)

Jones (1993) concluded that the major sources of sediment for the bay are the Prosperine and O'Connell rivers and the St Helens, Murray and Dempster creeks, with each having a localised impact and no external sources reaching the bay.

The remainder of the bay consists of a series of small bays and closed TCs occupied by funnel-shaped mangrove-lined tidal creeks, separated by bedrock headland with generally TD beaches and tidal flats. Dempster and Harvey creeks are deeply embayed, while the southern St Helens Bay down to Finlayson Point contains a massive area of tidal flats and mangroves in places up to 10 km wide. Between Seaforth and Cape Hillsborough are three more exposed embayed beaches which grade with increasing exposure from TD B+TF in the south to TM UD in the north (Fig. 15.7b).

Fig. 15.5 (**a**) New Beach and its wide sand flats (QLD 1151) at the mouth of the Proserpine River; (**b**) ultradissipative Cape Hillsborough Beach (QLD 1096); (**c**) Shoal Point (QLD 1103) is part of the sink for Pioneer River sand; and (**d**) Bucasia beach (QLD 1105) is part of the longshore sand transport system from the Pioneer River to Sand Bay. (Photos: AD Short)

15.2.7 SC:QLD04.01.03 Cape Hillsborough–Pioneer River

The Mackay coast compartment (SC:QLD04.01.03) extends for 68 km from its northern boundary at Cape Hillsborough to the Pioneer River (Fig. 15.6a) and consists of a series of three bedrock headlands (Slade (Fig. 15.7a), Eimeo and Shoal) each backed by mangrove-filled tidal creeks that flow out at the southern end of embayed beaches, the beaches grading northward from tidal flats to UD (Fig. 15.7d) and the larger northern Sand Bay, a sheltered terminal sediment sink. The Pioneer River enters the coast through a dynamic mouth at Mackay (Fig. 15.7b), and its medium to coarse quartz-rich sandy sediments (<2% carbonate) have been transported northward, assisted via pumping past Mackay port, with bypassing around Slade, Eimeo and Shoal points (Fig. 15.7b) and then along Williamsons Beach to be ultimately deposited in the 5 km wide aptly named Sand Bay (Fig. 15.8), a shallow sandy bay ringed by extensive tidal flats and mangroves. Longshore sand transport has been estimated at between 20,000 and 35,000 m^{3}year^{-1} (EPA 2004); however, it has been reduced by damming and gravel extraction on the Pioneer (Fryar 1999) and interrupted by the port breakwaters. Gourlay and Hacker (1986) undertook a

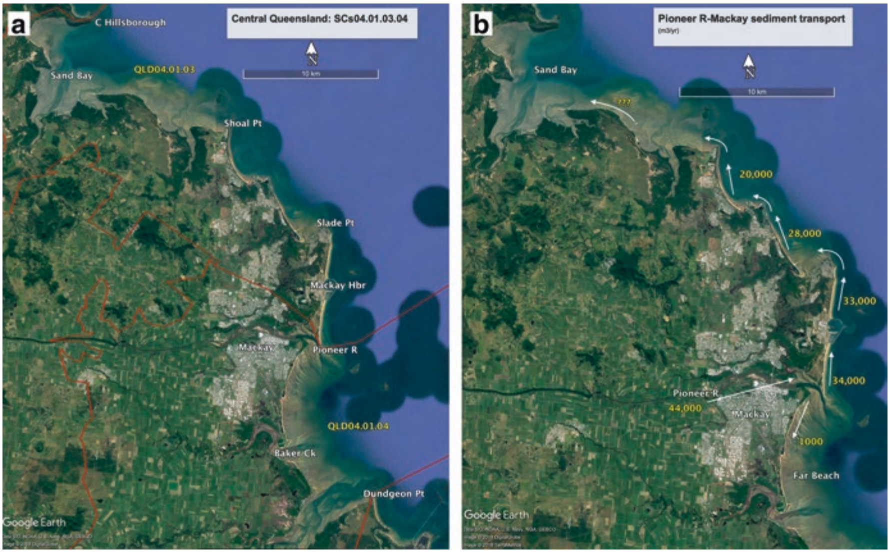

Fig. 15.6 (**a**) the Mackay coast (SCs:04.01.03-04) extends from Cape Hillsborough to Dudgeon Point; and (**b**) sediment is delivered by the Pioneer River and transported the Mackay coast to Sand Bay (transport rates (m^3 $year^{-1}$) based on EPA 2004; Thom et al. 2018). (Source: Google Earth)

major study of the Pioneer River and found that it drains a predominately granodiorite catchment and discharges between 0.07 and 1.35 M m^3 during floods, with an average flood delivery 0.49 M m^3, and major flood occurring every 40 years. The average annual bedload is ~50,000 m^3 $year^{-1}$, close to the BPA estimate of 44,000 m^3 $year^{-1}$ (Fig. 15.6b). They found that the river mouth switched from the southeast to the east following tropical cyclone Eline in 1898 and that since then 3.5 M m^3 (~40,000 m^3 $year^{-1}$) of sand has been deposited between the mouth and Flat Top Island with the shoreline prograding at a rate of 6 m $year^{-1}$ up to 1980.

15.2.8 SC:QLD04.01.04 Pioneer River–Dudgeon Point

SC:QLD04.01.04 extends south of the Pioneer River mouth along 27 km of predominately irregular low-energy shoreline to Dudgeon Point (Fig. 15.6a). Far Beach (QLD 1121-2) extends for 9 km south of the river mouth and receives limited sediment from the river which has accumulated in its 2 km tidal sand flats (Fig. 15.6b). It is bordered in the south by Bakers Creek and then the larger 3 km wide Sandringham Bay both mangrove-lined sand-choked TD funnel-shaped estuaries, with tidal flats extending 3–4 km offshore, all contained in an 11 km wide bay between the river mouth and Dudgeon Point. Sediments are predominately medium quartz-rich (<2% carbonate) indicating a terrigenous source. The Sandringham Bay ebb tide delta extends 2 km seaward of Dudgeon Point and may be supplying some sand to the beach on the southern side of the point.

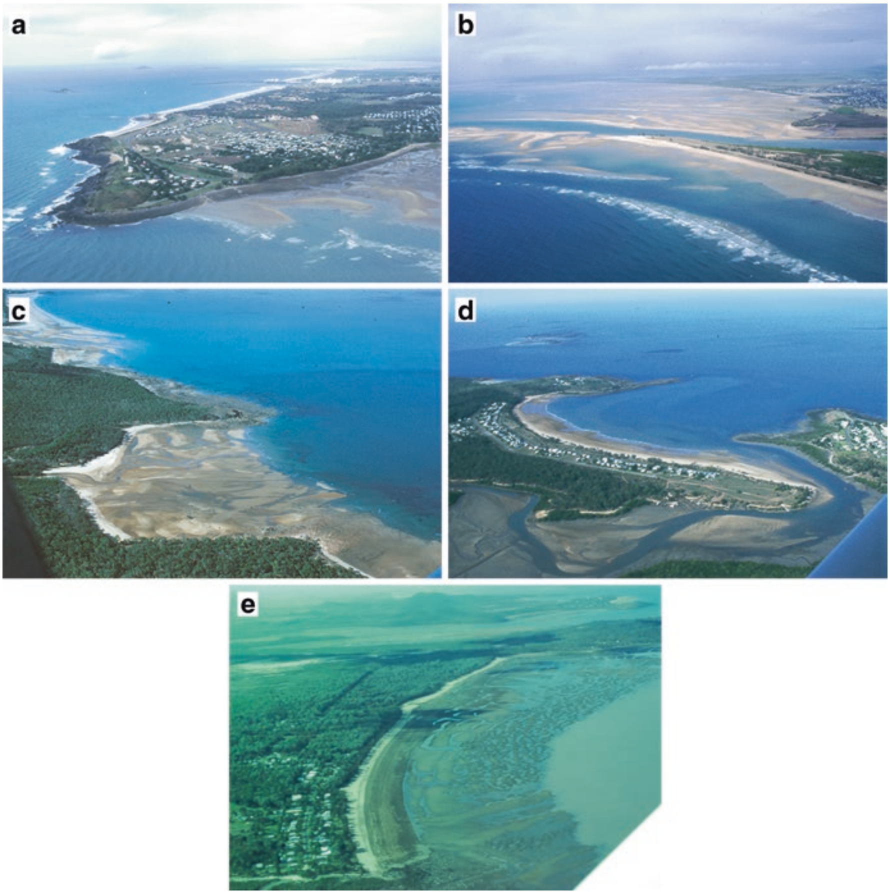

Fig. 15.7 PC:QLD04.01 coast, (**a**) sand moves from the Pioneer River north to Slade Point (left) which it bypasses into Slade Bay (right) (QLD 1112-3); (**b**) mouth of the Pioneer River and the extensive intertidal flats of Town beach (QLD 1119); (**c**) Mick Ready beach (QLD 1137) is typical of the many small sand-filled embayed beaches; (**d**) Grasstree beach has a narrow barrier backed by Cabbage Tree Creek (QLD 1139); and (**e**) Armstrong beach has tidal flats extending over 1 km offshore (QLD 1148). (Photos: AD Short)

15.2.9 SC:QLD04.01.05 Dudgeon Point–Cape Palmerston

The southern compartment (SC:QLD04.01.05) is an irregular 90 km long bedrock-controlled coast with a mix of protruding bedrock headlands (Fig. 15.8), containing TM sandy beaches on the exposed east-facing section south of Dudgeon and Hay points and at Sarina, with TD beaches grading into the sheltered bays (Fig. 15.7c) and estuaries containing tidal flats up to 2 km wide (Fig. 15.7e). There are also numerous small tidal creeks (Fig. 15.7d), together with mangroves and extensive supratidal flats. Beach sediments are predominately carbonate-rich (10–80%) medium sand, suggesting local sources. There are three large inlets (Sarina Inlet and

Fig. 15.8 SC:PC04.01.05 Sarina Coast extends from Dudgeon Point to Cape Palmerston. (Source: Google earth)

Llewellyn and Ince bays) and several smaller tidal creeks located between Dudgeon Point and Cape Palmerston. This SC appears to consist of a number of small closed TCs which include both embayed beaches and the larger bays and inlets, with little if any movement of sand between the TCs. The southern PC boundary at Cape Palmerston has sediment moving along its eastern shore which may be rounding the cape and moving into Ince Bay, while the northern boundary at Dudgeon Point may be receiving sand transported south from the Sandringham Bay ebb tide delta.

Lessa (1993), Masselink and Lessa (1995) and Lessa and Masselink (1996) investigated the dynamics, stratigraphy and evolution of two macro-tidal inlets in the Mackay region (Bucasia Creek in QLD04.01.02 and Louisa Creek in QLD04.01.05). They found the barriers have both transgressive and regressive units, which indicated sea level was 1.5–2 m higher 5.5–6.1 ka. They also concluded the barriers north of the Pioneer River (e.g., Bucasia) were supplied with Pioneer River sand, while those to the south (e.g., Louisa) were supplied with shelf sand.

15.2.10 PC Overview

PC:QLD04.01 is a generally lower energy compartment aligned parallel to the prevailing wind and waves, with sheltered shores in the bays and inlets. There are two major sources of terrestrial sediment in the Pioneer-O'Connell and Pioneer rivers, which have built deltas and supplied sediment to the adjoining coast and beaches, particularly the Pioneer whose sediments have been transported northwards for more than 35 km to be deposited in Sand Bay. Apart from these two, most of the PC consists of a series of small TCs, closed in the north at Cape Conway, but with possible limited sediment bypassing of the southern boundary at Cape Palmerston.

Beginning in the north at SC 04.01.01, the northern corner of Repulse Bay is a sink for sediment coming out of the Pioneer which has accumulated in the small regressive Conway beach barrier and possibly helped infill Repulse Creek and The Inlet. It is unlikely that any sediment is moving around Cape Conway. The larger Repulse Bay SC (QLD04.01.02) is also a sink for the Pioneer and O'Connell river sediments (Jones 1993) which have formed the 12 km long regressive barrier and its wide tidal flats that links the two river mouths and fills this northwestern corner of the bay. The remainder of the SC to the south consists of a series of discrete embayed beaches, bays and large tidal creeks which appear to have little connectivity forming a series of closed TCs. The northern Mackay coast (SC:QLD04.01.03) has the Pioneer River as its southern boundary delivering about 40,000 m^3 of bedload per year, which is then transported by longshore transport (including sand pumping) and headland bypassing for 35 km north to its final sink at Sand Bay. The southern Mackay coast (SC:QLD04.01.04) is receiving ~1000 m^3 $year^{-1}$ from the Pioneer that has led to the development of the Far Beach barrier and wide tidal flats and perhaps also contributed to the infilling of the sandy Baker Inlet and Sandringham Bay, with a possibility of some leakage to the south around Dudgeon Point. The Hay Point-Sarina coast (SC:QLD04.01.04) has a series of stable embayed TM beaches in the north, with no indication of longshore transport, and the large tidal inlets of Sarina Inlet, Llewellyn Bay, Dawson Creek and Ince Bay in the south, each discrete TCs largely occupied by wide mangrove-lined tidal flats. The entire SC seems closed with little internal interaction. Much of this PC is vulnerable to sea-level rise which will inundate the low gradient tidal flats and cause their tide-related ecosystems to shift landward. The deeper water across the flats and on the more exposed sections will also lead to an increase in breaker waves, shoreline recession and sediment transport.

15.3 PC:QLD04.02 Cape Palmerston–Cape Townshend

The Broad Sound-Shoalwater Bay PC (QLD04.02) is a long (534 km) and large compartment, containing three large SCs consisting of a more exposed east-facing section of coast extending south for 107 km from Cape Palmerston to Clairview and then the two large north-south trending funnel-shaped bays, Broad Sound and Shoalwater Bay (Fig. 15.1), with shorelines of 230 km and 197 km, respectively. This is a highly variable PC with four north-south trending shorelines ranging between exposed along the Cape Palmerston coast and western shore of Shoalwater Bay and very sheltered and tide-dominated within the bays and particularly along their eastern shores. The southeast trade wind and waves dominate, with tide rising from 5.5 m at Mackay to 8 m in Board Sound. There is very little development along this coast, with only the small communities of Camilla (400), Clairview (75) and St. Lawrence (400), the Bruce Highway and the small Plumtree-Stanage Bay community out at Arthurs Point on the tip of the central peninsula. Cattle stations occupy much of the surrounding country, together with the Defence Department's Shoalwater Bay Training Area. Apart from the western Bruce Highway section, there is limited access to most of the shore.

15.3.1 Rivers and Creeks

Fifty generally small to medium streams and tidal creeks drain the eastern slopes of the Conner Range, the central peninsula and the western slopes of the Peninsula Range, with just one small river, the Styx flowing into Broad Sound. However, the large tidal range amplifies flows in the tidal creeks in the sound and bay forming large funnel-shaped TD inlet, lined by mangrove forests up to several kilometres wide.

15.3.2 Coastal Processes and Sediments

Coastal processes within the PC are related to the degree of exposure to the southeast trade wind and waves, with limited fetch in both Broad Sound and Shoalwater Bay. Waves range from moderate on the east-facing sections (H_b~0.5 m) to zero deep within the bays and on west-facing shores. At the same time, the macro- to mega-tides dominate much of the shore, as indicated by the number of large funnel-shaped, mangrove-lined inlets and tidal creeks. Tidal currents are very strong within the bays and have eroded deep tidal channels down to bedrock in Broad Sound (Cook and Mayo 1978). Beach sediments are predominately well to moderately well-sorted medium quartz sand with an average of 34% carbonate (σ = 23%) but ranging from 4% to 75% (Table 15.5).

15.3.3 Beaches

The generally lower waves and in particular the high tide ranges have resulted in a dominance of TD beaches (64%), with TM (34%) located on the more exposed east-facing sections. The beaches occupy only 31% of the shore, with mangroves and tidal creeks making up much of the remainder (Table 15.8). The beaches average 1.3 km in length and are fronted by intertidal flats averaging 640 m (σ = 700 m), with the widest flats 3 km wide.

15.3.4 Barriers

There are 62 barrier systems occupying 122 km (23%) of the PC. They tend to be low (mean height = 5.2 m), either a single stable or a few regressive cheniers and beach ridges (Cook and Polach 1973) ranging from 120 to 320 m in width. They have a total area of 2769 ha, and volume of just 141 M m^3, with the smallest unit volume in the region of just 1155 m^3 m^{-1} (Table 15.5). The low occurrence and size of the barriers are a function of the general low level of wave energy and the dominance of tides, with most sediment deposited in the subtidal. There has been minor, now vegetated, dune transgression along the more exposed beaches south of Cape Palmerston.

There is only limited wave-driven longshore sand transport within this PC, with the coast consisting of either stable embayed beaches with limited headland bypassing on the more exposed sections, and the mangroves and tidal flats along the sheltered shores of Broad Sound and Shoalwater Bay.

15.3.5 SC:QLD04.02.01-03 Cape Palmerston–Townshend Island

The northern SC:QLD04.02.01 begins at Cape Palmerston (Fig. 15.9) as a series of embayed TM beaches (Fig. 15.10a) which as waves decrease and tides increase grade to southwards TD (Fig. 15.10b–d). While most of the beaches appear to be

Table 15.8 PC:QLD04.02 beach types and states

BS	BS	No.	%	length (km)	% (km)	Mean (km)	σ (km)
7	R+LTT	44	34.1	30.8	18.6	0.7	0.6
9	UD	19	14.7	28.9	17.5	1.5	1.9
10	B+RSF	6	4.7	22.0	13.3	3.7	1.1
11	B+SF	53	41.1	76.9	46.4	1.5	0.9
12	B+TSF	7	5.4	7.0	4.2	1.0	1.0
		129	100	165.7	100	1.3	-

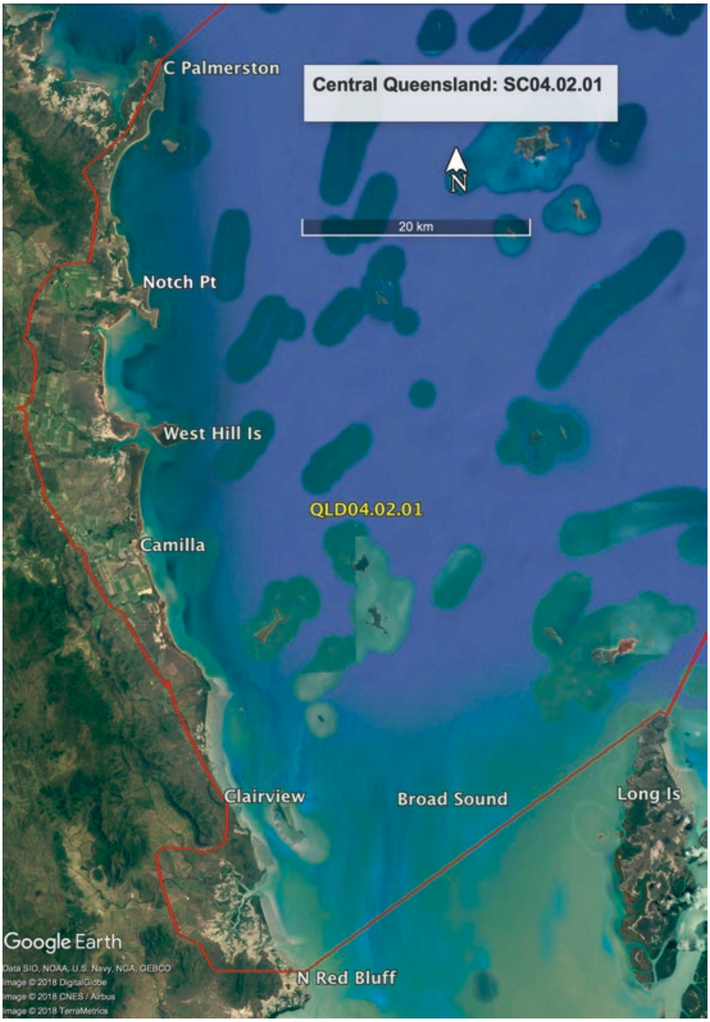

Fig. 15.9 SC:QLD04.02.01 Cape Palmerston to North Red Bluff. (Source: Google Earth)

stable with little evidence of longshore transport or headland bypassing, there does appear to be tidally driven headland bypassing between West Island and Cape Palmerston and into Ince Bay. SC:QLD04.02.02 commences just south of Clairview as mangroves replace the beaches and includes all of the tide-dominated Broad Sound (Fig. 15.11) with its many funnel-shaped tidal inlets, mangrove forest up to a few kilometres wide (Fig. 15.10e) and extensive tidal flats grading into deep tidal channels. The sound is tidally driven with strong flows though the channels and its 35 km wide entrance transporting turbid waters onto the inner shelf. Cook and Polach (1973) and Cook and Mayo (1978) investigated the cheniers at the mouth of the Styx River (Fig. 15.10d) and found they were deposited at 5, 3.5, 2.6, 1.6 and

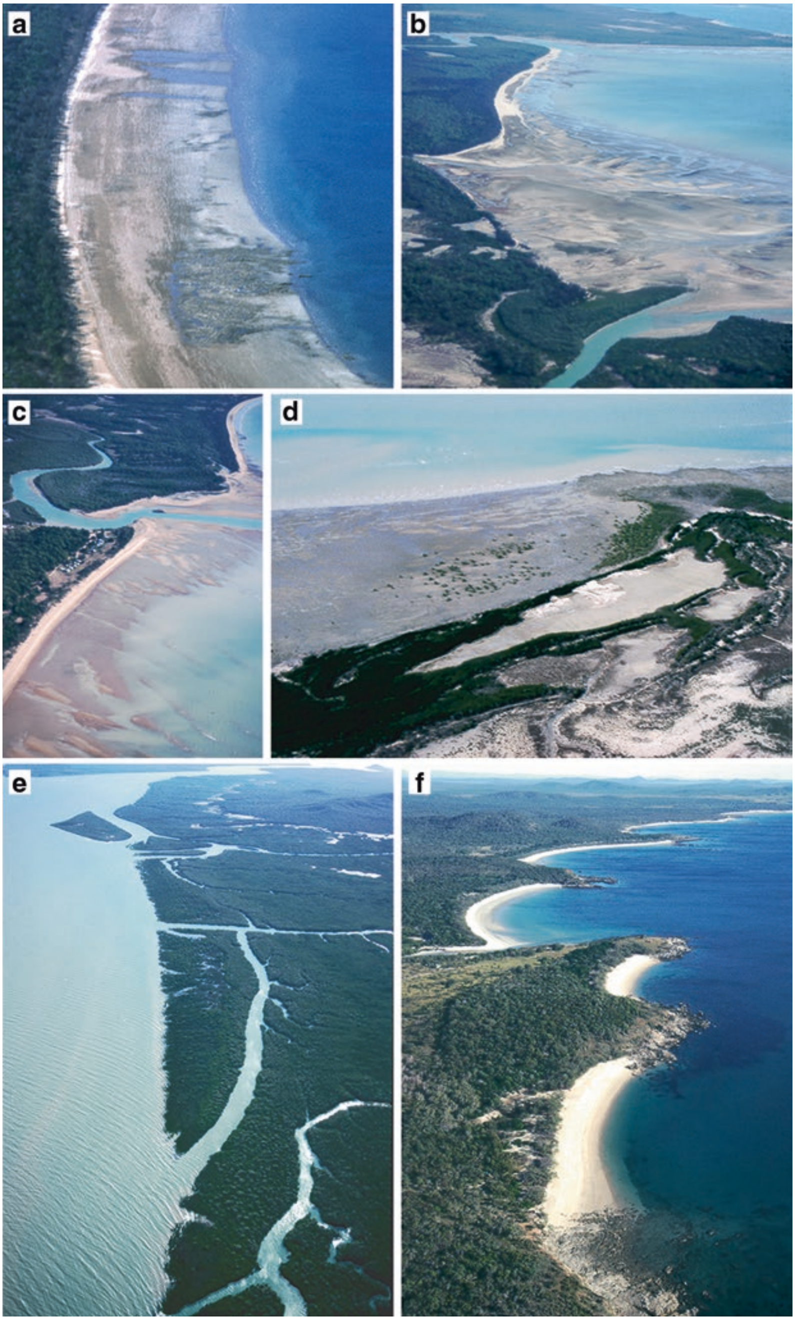

Fig 15.10 Broad Sound beaches: (**a**) UD beach south of Coconut Point (QLD 1177); (**b**) Marion Creek and tidal sand flats (QLD 1190); (**c**) Blind Creek at Camila with beach and tidal sand flats (QLD 1198); (**d**) cheniers at Charon Point (QLD 1216) which were dates by Cook and Polach (1973); (**e**) sheltered mangroves in Thirsty Sound; and (**f**) exposed TM beaches at Yenyardindle Huts in Shoalwater Bay (QLD 1268-71). (Photos: AD Short)

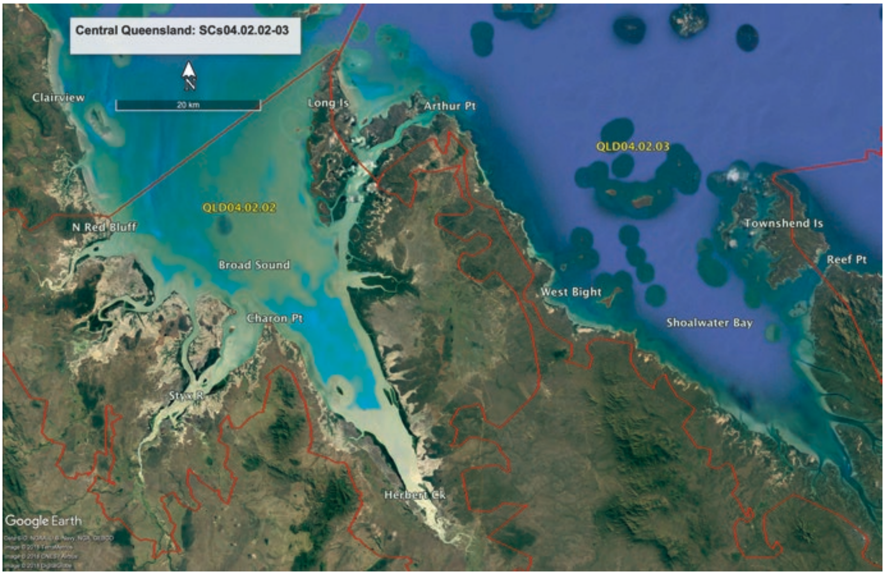

Fig. 15.11 SC:QLD04.02.02-03 Broad Sound and Shoalwater Bay. (Source: Google Earth)

0.7 ka. Based on this transect, they concluded there had been no change in the elevation of the cheniers which would indicate sea level reached its present level about 5 ka, and since then it had varied by no more than +/1 m. Shoalwater Bay (SC:QLD04.02.03, Fig. 15.11) is similar to the sound with its northwestern shore containing a series of more exposed embayed TM beaches (Fig. 15.10f) grading south to TD beaches as fetch and waves decrease to the south and then into mangroves in the southern corner, with tidal flats, creeks and wide belt of mangroves lining the rest of the bay shore. On the higher energy section, the beaches appear stable with no evidence of longshore transport or headland bypassing.

15.3.6 PC Overview

This is a relatively large PC containing three distinct SCs, with the southern two consisting of macro- to mega-tidal, north-facing mangrove-lined V-shaped bays. There is little input of terrigenous sediment, with carbonate sediments contributing on average 34% and locally up to 75% of the sediments. The small Styx River flows into Broad Sound, but its sediments are widely dispersed by the strong tidal currents, with the bedload forming subtidal sand ridges. There is little evidence for longshore sand transport, apart at West Island and Cape Palmerston on the more exposed northern SC. Tides dominate the inner bays and the many tidal creeks, with most of the more exposed beaches appearing stable. Rising sea level will generate greater inundation of the extensive low gradient tidal flats and their mangrove systems, while any change in tide range could have dramatic impacts and the extensive intertidal systems.

15.4 PC:QLD04.03: Townshend Island–Round Hill

PC:QLD04.03 commences at Cape Townshend the northern tip of Townshend Island and trends south then southeast for 614 km to Round Hill (Fig. 15.1), both prominent headlands named by Captain Cook in 1770, who also named Shoalwater Bay. The coastal orientation and topography are dominated by a series of shore parallel coastal ranges, which from the north are the Peninsula Range (maximum height 550 m), Coast Range (600 m), Mount Larcom Range (530 m), Curtis Island-Ramsay Range (160 m), Boyne Range (230 m), Many Peaks Range (740 m) and the Munro Range (490 m). The ranges are predominately composed of Devonian siltstones, sandstones and shales, together with Cretaceous volcanic north of Point Manifold, and Triassic volcanics forming the southern Munro Range in the Bustard Bay-Round Hill region as well as the Keppel Island group off Yeppoon. Their bedrock outcrops along much of the coast leading to numerous headlands and embayed beaches. The only major river to reach the coast is the Fitzroy, which flows into the wide, sheltered Keppel Bay. The outer GBR lies 120–240 km off the northern section, while the small Capricorn-Bunker Group, the southernmost group of reefs in the GBR, lies 60–80 km off the coast south of Gladstone.

This coast is a mix of reserves and major towns. In the north is the large Shoalwater Bay Defence Training Area (2897 km^2) which includes most of Shoalwater Bay and the open coast between Townshend Island and Five Rocks beach (QLD 1357) in all 290 km of coast together with a number of islands. This is followed by Byfield National Park (149 km^2) that extends down to Corio Bay and the start of the more developed Yeppoon-Keppel Bay coast with a population of around 20,000. South of the bay is the ~800 km^2 Curtis Island, with the Curtis Island National Park (103 km^2) occupying much of the eastern shore and in the south the large recently developed LNG facility (constructed since 2010) located opposite the large industrial city of Gladstone (70,000). There is little development in the southern Rodds and Bustard bays that includes the small Wild Cattle Island National Park (5.8 km^2), Rodds Peninsula and Eurimbula National Park (233 km^2) in Bustard Bay.

15.4.1 Rivers and Creeks

About 30 streams and creeks and two rivers reach the open coast along this compartment. Most are relatively small including the Boyne River (2484 m^2). However, the Fitzroy River, which has the largest catchment in coastal Queensland, flows into Keppel Bay forming an extensive floodplain and 500 km^2 Fitzroy River delta. The delta is a very sheltered TD system consisting mainly of extensive mangrove-lined tidal flats containing 275 km^2 of salt flats and 130 km^2 of mangroves, and wide TD funnel-shaped distributaries with 60 km^2 of open channels. The Fitzroy is supplying both bedload and fines to the bay, shelf and coast.

15.4.2 Coastal Processes and Sediments

Coastal processes along this compartment remain dominated by the southeast trade winds, which typically blow between 10 and 15 km h^{-1} for several days at a time (BPA 1979). Rainfall decreases to the south from a high of 1500 mm in the northern Peninsula Range to a low of 800 mm in Keppel Bay and northern Curtis Island. Rainfall then slowly picks up to 870 mm at Gladstone and 1170 mm at Round Hill. Tides decrease from 4.1 m at the northern Port Clinton to 3.9 m at the central Gladstone and 2.5 m at Bundaberg (Table 15.2). The waves remain dominated by the trades, with the wave climate controlled by the limited fetch within the GBR lagoon, which ranges from 160 km in the north to 300 km in the south. The longer southern fetch allows wave period to peak between 5 and 7 s and wave height between 0.4 and 0.6 m, with maximum waves reaching 3 m (Tables 13.3 and 13.4; BPA 1979). In addition, given the open-ended nature of the southern GBR, some southerly swell does penetrate up into this region contributing about 20% of the waves, with periods between 9 and 12 s and heights between 0.2 and 1 m. Southeast seas however remain dominant. At the shore the breaker wave climate ranges from fully exposed on east to southeast-facing beaches to zero in places like the southern shores of Keppel Bay. The beaches are composed of well-sorted fine to medium quartz sand, with an average of 10% carbonate but ranging locally from 1 to 83% (Table 15.3), with the areas of highest carbonate between Yeppoon and Zilzie beach and along the Bargara coast and the lowest <2% extending north of the Burnett River mouth (5380 km on Fig. 15.2).

15.4.3 Beaches

There are 168 beaches in the PC which occupy 258 km (40%) of the coast, with the remainder a mix of bedrock on the open coast and the extensive mangroves and tidal flats of the Fitzroy River delta and parts of Rodds Bay. The beaches are predominately TM (79%) with 69 km (27%) exposed rip-dominated beaches (R+LTR) and 72 km (28%) of the high energy but finer sand UD beaches (Table 15.9). TD beaches occupy just 21% of the coast, largely in the more sheltered Keppel Bay, Port Curtis and Rodds Bay.

Table 15.9 PC:QLD04.03 beach types and states

BS	BS	No.	%	length (km)	%	Mean (km)	σ (km)
7	R+LTT	84	50.0	63.9	24.8	0.8	1.2
8	R+LTR	23	13.7	68.8	26.7	3	3.9
9	UD	23	13.7	71.6	27.8	3.1	4.6
10	B+RSF	7	4.2	14.7	5.7	2.1	2.6
11	B+SF	29	17.3	37.2	14.5	1.3	1.16
12	B+TSF	2	1.2	1.4	0.5	0.7	-
		168	100	257.6	100	1.5	-

15.4.4 Barriers

There are 48 barriers spread along 218 km (34%) of the coast. They range in mean width from 0.67 to 1.67 km and have a relatively high average height of 15.4 m, a product of the abundant transgressive dunes. They occupy 70,047 ha, the largest in the region, and have a massive volume of 13,832 M m^3, which represents a massive 63,522 m^3 m^{-1}, the highest in the northeast division (Table 15.5). The largest barriers and highest volumes are all contained in the massive transgressive quartz-rich (98–99.5%) dune systems located in the north between Island Head and Water Park Point, 70 km to the south, with the largest extending south of Cape Manifold (Fig. 15.12) which contains 10,000 M m^3 and represents a massive 400,000 m^3 m^{-1}, equivalent to some of the largest southern Australian transgressive dune systems. The dunes extend up to 25 km inland with average height between 20 and 80 m. They consist entirely of imbricated long-walled parabolics, aligned to the trades (315º), and now largely stabilised by dense forest vegetation, with only 2% presently unstable. Smaller transgressive dunes occur along Farnborough Beach and on Curtis Island south of Cape Capricorn, and a small active area south of Bustard Head. The transgressive dunes in this region and their chronology remain to be investigated. There are also some extensive regressive barriers at Farnborough, in Keppel Bay, Port Curtis-Rodds Bay and Bustard Bay, the larger barriers containing 20–25 ridges, which are discussed below.

15.4.5 Sand Transport

The prevailing southerly wind and waves and the north-south orientation of the coast favour the northerly transport of sand. In addition, the massive transgressive dunes indicate that there has been an abundant supply of quartz-rich sand and sufficient wave energy to deliver it to and along the shore, combined with strong unidirectional southeast trade wind develop the longwalled parabolics up to 12 km long all oriented 315°. It is very likely the massive dunes received their sand from the inner shelf, with the ultimate source being the Fitzroy River, with Brooke et al. (2008) estimating 80% of the Fitzroy bedload accumulates on the coastal barriers.

Fig. 15.12 SCs:04.03.01-02 extend from Townshend Island to Yeppoon. (Source: Google Earth)

Ryan et al. (2006) investigated the geomorphology and sediment transport in Keppel Bay and found that fluvial sand accumulates in the south of Keppel Bay and is transported onshore by tidal currents. In addition, coarse carbonate-rich sand is moving into the bay by advection from the shelf to the south and from the east of Cape Keppel and is probably mixed with the modern river-derived sediments. BPA (1979) undertook a detailed examination of coastal processes, sediment and longshore transport from the Fitzroy River-Keppel Bay to the north. They found that while transport was predominately to the north, there were reversals under northerly waves and that net northerly transport out of Keppel Bay was 44,000 m^3 year^{-1}, decreasing to 19,000 m^3 year^{-1} by Lammermoor beach. The highest transport rates occurred at the northern tip of Farnborough Beach at Sandy Spit (95,000 m^3 year^{-1}), with the massive sink of Corio Bay at its northern end, and along the very exposed Nine Mile beach (304,000 m^3 year^{-1}), which is backed by the largest dune field. While all these figures are only estimates, the fact remains there is abundant evidence for northerly transport from the Fitzroy River north to the dune systems, with sand also being supplied from the sandy inner shelf (Fig. 15.13). Further south Hummock Hill Island at the southern end of Port Curtis contains evidence of sand ultimately derived from NSW (Veevers 2015) and represents the northern mainland terminus for this sand, as is discussed in Sect. 15.4.13.

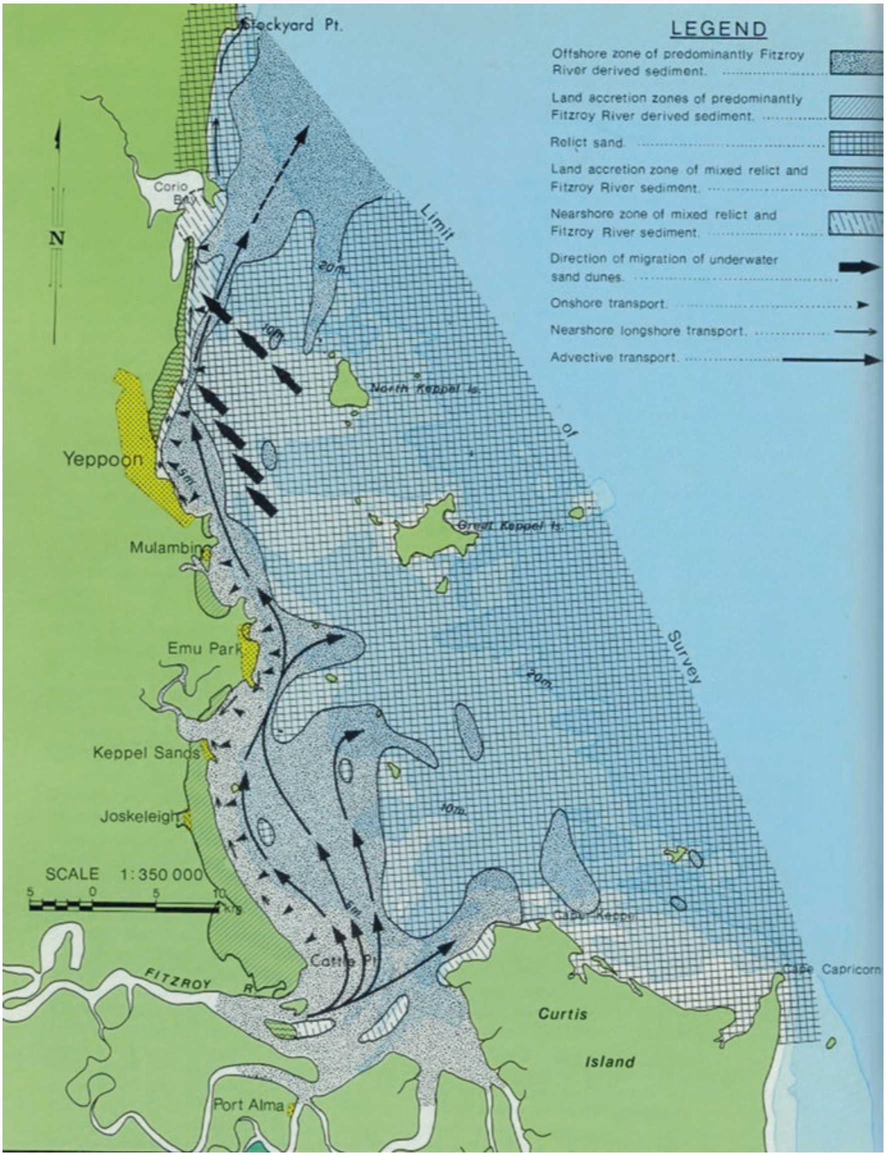

Fig. 15.13 Sediment distribution and transport routes in Keppel Bay. (Source: BPA 1979)

This PC contains nine SCs which will each be discussed below in terms of their geomorphology and potential for sediment transport.

15.4.6 SC:QLD04.03.01 Townshend Island–Cape Manifold

SC:QLD04.03.01 lies at the northern end of the PC between Cape Townshend and Cape Manifold and includes the 15 km long rugged eastern shore of the uninhabited Townshend Island (Fig. 15.12) which will not be considered in this discussion. South of the island between Reef Point and Island Head, the shore faces north-northeast and contains ten embayed beaches each backed by a foredune or small regressive barrier separated by rocky points and sloping headlands. It is possible that sand driven by waves and strong tidal currents is moving along this section and around Reef Point and into Strong Tide Passage and ultimately Shoalwater Bay, the adjoining PC. However, this would require field investigation to verify. Immediately south of Island Head is the large Island Head Creek which has been infilling with marine sand and acts as a sink for sand moving around the northern end of Pearl Bay and into the funnel-shaped TD creek. The coast to the south consists of the curving Pearl Bay, with North East Point separating it from the curving Port Clinton beach and its 50 km^2 sediment-filled bay (Fig. 15.14a), then a 10 km long east-facing beach between Cape Clinton and Cliff Point and finally the protruding Cape Manifold (Fig. 15.14b). This is an exposed east-facing coast that has received an abundance of sand that has either moved into Port Clinton and Island Head Creek as tidal deposits, or into the transgressive dune field in lee of Pearl Bay and Port Clinton beaches. The Port Clinton dunes extend up to 10 km inland, and are backed by a 2 km wide tidal creek, then an inner regressive Pleistocene barrier located on the western side of the port. This area represents the major northern sink for the Fitzroy-Keppel Bay sands, with the dunes alone estimated to contain 1275 M m^3 of fine to medium quartz sand.

15.4.7 SC:QLD04.03.02 Cape Manifold–Yeppoon

SC:QLD.04.03.02 extends due south from Cape Manifold for 50 km to Yeppoon (Fig. 15.12) and is the highest energy section of this PC and contains the largest sediment sink in the regressive and transgressive barriers and the sand-choked Corio Bay. As indicated by Fig. 15.13, sand is being transported north from the Fitzroy-Keppel Bay at rates estimates at up to 300,000 m^3 year^{-1} (Patterson and Ford 1980) to supply the exposed TM beaches, dunes and the ~20 km^2 of thick sandy tidal deposits in Corio Bay. The transgressive dune north of Corio Bay extends up to 12 km inland and to a maximum height of 220 m with an estimated volume of 10,000 M m^3, while the protruding regressive Farnborough barrier contains an estimated 1000 M m^3 in addition to the sand infilling much of Corio Bay. The Farnbrough's protrusion or subdued foreland (Fig. 15.14c) is aligned to wave refraction around North Keppel Island.

Fig. 15.14 (**a**) tidal flats and mangroves in Port Clinton; (**b**) view north from Cape Manifold showing the transgressive dunes (QLD 1354-56); (**c**) UD Flamborough Beach (QLD 1361); and (**d**) the UD embayed beaches between Zilize Point and Emu Park (QLD 1376-80). (Photos: AD Short)

15.4.8 SC:QLD04.03.03 Yeppoon–Zilzie Point

SC:QLD 04.03.03 is a protruding 28 km long bedrock-controlled coast located between Yeppoon and Zilzie Point (Fig. 15.15). It contains 17 embayed beaches ranging for more exposed UD to TD B+SF (Fig. 15.14d). As Fig. 15.13 indicates, sand is moving along this coast and bypassing the headlands with the coast acting as a conduit for sediment moving northwards from the Fitzroy-Keppel Bay SC to the large sinks to the north. Grigg et al. (1989) calculated rates along Kinka Beach between 10,000 and 12,000 m^3year^{-1}. There has been limited sediment accumulation with the small bays with the only barrier a 2 km regressive system at Kinka Beach, the remainder mainly single foredunes.

Fig. 15.15 SCs:QLD04.03.03-05 commence at Yeppoon and include Keppel Bay and the large Fitzroy River delta and Curtis Island in the east. (Source: Google Earth)

15.4.9 SC:QLD04.03.04 Zilzie Point–Station Point

SC:QLD.04.03.04 includes Keppel Bay and the Fitzroy River delta, and has a deeply embayed 95 km long shoreline located between Zilzie Point and Station Point on Curtis Island, providing a crenulation ratio of 3.4 (Fig. 15.15). On the southern side of Zilzie Point, a 3.5 km long 1.7 km wide series of recurved spits form the northern side of Cawarral Creek, with the small Keppel Sands community on the south side of the dynamic creek mouth. To protect the beachfront houses against inlet migration and beach erosion, a groyne was constructed in 1982 and extended to 200 m in 2001 (Piorewicz et al. 2003) and has successfully trapped sand on its southern side. To the south of Keppel Sands are two major depositional features, the 20 km long, up to 4 km wide Cattle Point regressive beach ridge plain (Fig. 15.16a), and the large Fitzroy River delta with its tidal flats, mangroves and funnel-shaped distributaries, totalling about 500 km^2 in area. The lower Fitzroy valley was flooded by the Holocene marine transgression by about 7 ka and has since filled with fluvial sand and estuarine mud to form the present floodplain and salt flats (Brooke et al. 2006). Most sediment delivered by the Fitzroy River is

Fig. 15.16 (**a**) Cattle Point and its low beach ridges (QLD 1389) and the mouth of the Fitzroy River and (**b**) dune overpassing at Cape Capricorn (QLD 1409). (Photos: AD Short)

accumulating in the lower deltaic plain and in Keppel Bay, which is sheltered by Curtis Island. Accommodation space is however limited, and sediment is transported around Cattle Point and northward to be reworked onto Long Beach and beyond (Fig. 15.13). Brooke et al. (2006) estimated that the Fitzroy is delivering 4575 kt year^{-1}, of which 315 kt year^{-1} is bedload, with 55% of the total load deposited on the Fitzroy floodplains and mangroves within Keppel Bay. Of the remainder, most is exported out of Keppel Bay with just 0.4% deposited as beaches and beach ridges. The exported sediment is subsequently remobilised and transported northward, some of this component no doubt supplying sand to the northern beach-barrier systems as indicated in Fig. 15.13. In addition, a limited amount of sand appears to be moving into Keppel Bay from the east, moving around Station Point on Curtis Island and along the northeastern side of the bay, where it forms a series of migratory barrier spits (QLD 1391-1392).

Brooke et al. (2006, 2008) surveyed the 2 km wide series of more than 20 beach ridges at the northern Long Beach (QLD 1389) end of the Cattle Point barrier in Keppel Bay and found it consisted of low 3-4m high beach ridges 3–4 m, with the inner ridges dating around 1.7 ka. They found there had been episodes of rapid ridge formation every 200–500 years associated with enhanced Fitzroy River sediment supply and fluctuating climate, with a gradual decline in river discharge and barrier accumulation over the past 1 ka, related to a decline in rainfall in the catchment. The most recent ridges, deposited in the past 100 years, contain trace elements evidence of large-scale clearing of native vegetation.

15.4.10 SC:QLD04.03.05 Station Point–Cape Capricorn

SC:QLD04.03.05 occupies the northern coast of Curtis Island extending for 47 km between Station Point and Cape Capricorn (Fig. 15.15), the northwest and northeastern tip of the island, respectively. The coast faces northeast and is moderately sheltered with the trades blowing offshore and refracted waves arriving obliquely along this drift-aligned shore. It contains a series six west-migrating barrier island-spits, all moving the sand northwest towards Station Point and ultimately into

Keppel Bay, with the beaches mainly B+SF and some UD. This is a sheltered but dynamic section of the shore, which, while it has regressed up to 4 km, the shoreline consists of a 15 km long series low migratory spits and inlets, with migratory tidal deltas and backed by low beach ridges which are all prone to erosion-accretion cycles and storm surge inundation.

15.4.11 SC:QLD04.03.07 Cape Capricorn–Gatcombe Point

SC:QLD04.03.07 continues down the 37 km long exposed east coast of Curtis Island and terminates at Gatcombe Point the southern tip of 18 km long Facing Island, the two islands separated by the 1.3 km wide North Entrance channel (Fig. 15.17). The compartment commences with the 3 km wide transgressive dunes in lee of the protruding 10 km long Cape Capricorn beach, the protrusion as result of wave refraction around Rundle Island, located 4 km offshore. Dune sand has overpassed Cape Capricorn in the past, with limited overpassing at present to

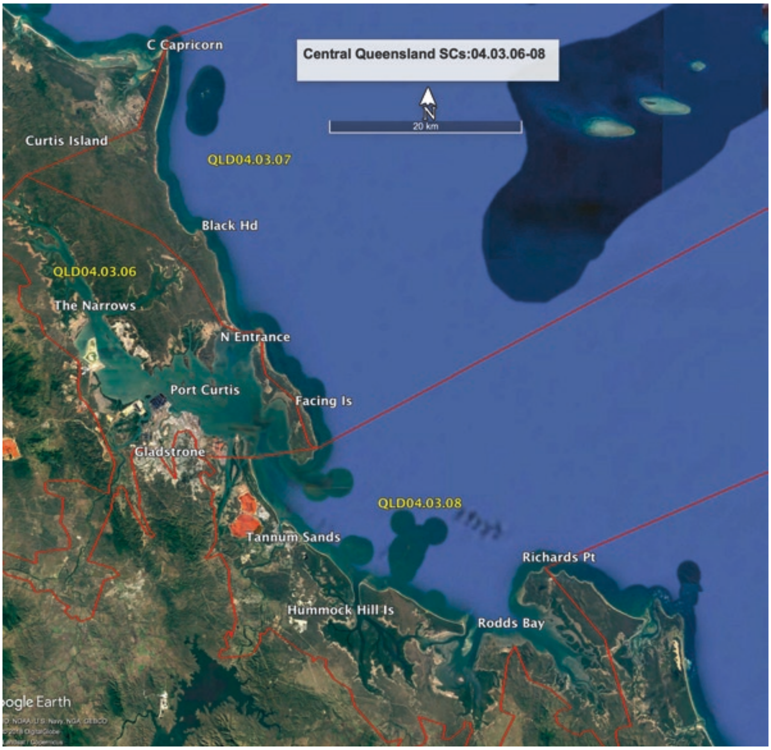

Fig. 15.17 SCs;QLD04.03.7-08 include Curtis Island, The Narrows and Port Curtis-Rodds Bay. (Source: Google Earth)

Red Beach (QLD 1402) (Fig. 15.16b) where flooding tidal currents have developed a 1.5 km long spit extending into the inlet, together with an earlier vegetated spit. This sand can be reworked though the tidal delta to supply the downdrift migratory spits in the adjoining SC and ultimately round Cape Keppel, Station Point and move into Keppel Bay. The red colour of the sand indicates it is reworked stabilised sand, probably early Holocene in age. It is also likely that sand is bypassing around Cape Capricorn and also supplying the tidal delta and migratory northern spits. At the southern end of the Cape beach, the dunes continue for another 6 km as largely clifftop dunes, some located behind a series of 16 small TM-embayed beaches (QLD 1410-25) that continue for another 6 km to Black Head. Steep cliffs 20–40 m high extends for 6 km south of the head, with embayed beaches and the rocky shore making up the remainder of the coast down to Southend. This southern bedrock-controlled section of the eastern shore of the island offers little room for sand accumulation and is questionable whether sand is moving northward along this coast. North Entrance separates Curtis and Facing islands and acts as a major sediment sink, possibly preventing any bypassing between the islands. There are limited onshore deposits along 17 km long Facing Island, mainly small transgressive dunes.

15.4.12 SC:QLD04.03.06 The Narrows

SC:QLD04.03.06 includes The Narrows, a 35 km long narrow (100–500 m wide) tidal channel that separates Curtis Island from the mainland, together with Gladstone Harbour-Port Curtis south as far as Gatcombe Head at the base of Facing Island. The Narrows shoreline is entirely TD and mainly lined with mangroves and tidal flats. The only beach in the SC is located at Gladstone's Barney Point (QLD 1428), a 300 m long B+SF. The entire compartment acts as a sediment trap for sediment moving south down the channel from Keppel Bay and into the harbour from the east via the North Entrance Channel and from the south via the 4 km wide channel between Gatcombe Head and Boyne Island. Much of the southern Narrows and Gladstone harbour shoreline has been heavily modified for port and industrial facilities, which include a major coal export facility, an aluminium smelter and a LPG export facility on Curtis Island.

15.4.13 SC:QLD04.03.08 Gatcombe Point–Richards Point

SC:QLD04.03.08 extends south of Gatcombe Head into Rodds Bay. This is another lower energy sheltered largely north-facing shore, mainly contained within Port Curtis-Rodds Bay (Fig. 15.17). It extends for 88 km between the northern tip of Gatcombe Point-Boyne Island and Richards Point. The Boyne Island, Tannum Sands, Wild Cattle Island and Hummock Hill Island beaches are predominately moderately exposed TM beaches (R+LTT and UD), with some B+SF in more sheltered locations, with the remainder of the bay mangrove-lined tidal flats particularly in very sheltered waters of the TD funnel-shaped Rodds Harbour. Sand appears to be bypassing the southern Richards Point and moving down along the western shore of Rodds Peninsula as a series of south-trending sand waves and spits, terminating at Spit End a 2 km^2 regressive foreland. Any sand moving beyond the spit would be deposited in Rodds Harbour. The three islands (Boyne, Wild Cattle, Hummock Hill) form the western shore of the bay, and each consists of regressive beach-foredune ridge barriers and north-trending spits at the boundary tidal channels, all evidence of interrupted north-trending sand transport by waves and tidal currents, terminating at the northern spit on Boyne Island which consist of a 5 km long series of regressive recurved spits. The end of this spit feeds an ebb tide delta with any sand transported beyond this point moving into Gladstone Harbour. This SC therefore has limited amounts of sand moving around Richards Point and accumulating at Spit End and transported into Rodds Harbour and the second cell of sand moving between the western islands to the tip of Boyne Island and probably beyond into Gladstone Harbour. Veevers (2015) found that heavy minerals on Hummock Hill Island have a provenance in the NSW eastern highlands, indicating that the sand has been transported northwards to Rainbow Bay and then via Great Sandy Strait to Hervey Bay and north to Port Curtis. This implies sand has been transported from the NSW along the entire southeast Queensland coast at least as far as Rodds Bay.

The generally low wave energy nature of the Port Curtis coast has led to the development of property and infrastructure close to the shore. However, as discussed above, the shoreline is dynamic and prone to shoreline oscillation which has placed these assets at risk, which in turn has led to the construction of makeshift protection. Gladstone Regional Council (2014) addressed the management of these issues on Boyne Island, Tannum Sands and Wild Cattle Island and proposed a range of soft management initiative including retreat from Colosseum Inlet on Wild Cattle Island.

15.4.14 SC:QLD04.03.08 Richards Point–Round Hill

The southern SC:QLD 04.03.09 is a more exposed northeast-facing sandy shore tied between the prominent headlands of Richards Point, Bustard Head and Round Hill (Fig. 15.18), with a shoreline length of 59 km. The compartment is primarily made up of the embayed northern shore of Rodds Peninsula and two curving beaches south of Pancake Point and in Bustard Bay. Most of the coast is located in the Rodds Peninsula and Eurimbula national parks and is uninhabited apart from the Round Hill community. The 22 km long curving Bustard Bay beaches are backed by a 2 km wide regressive to transgressive outer Holocene barrier and an inner, probably, Pleistocene barrier, with a total width of 5 km, while Pancake Point has shorter 2 km wide regressive barrier. The beaches are moderately exposed TM predominately R+LTT. Sand is moving clockwise along the Bustard Bay shore, being feed by headland bypassing of the eastern boundary at Round Hill. Some of this sand is lost into Round Hill Creek and then moves along the southern beach to the

Fig. 15.18 SC:QLD04.03.09 is an undeveloped section of coast between Richards Point and Round Hill. (Source: Google Earth)

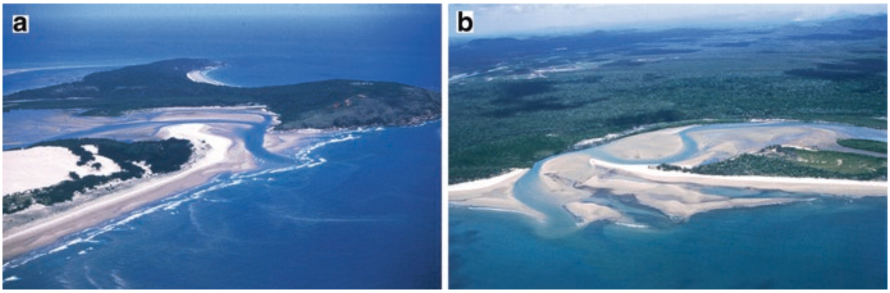

Fig. 15.19 (**a**) recurved spit and dune transgression at Jenny Lind Creek (QLD 1461) and (**b**) Eurimbula Creek and ebb tide delta (QLD 1462-63). (Photos: AD Short)

2 km long spit that forms the southern entrance to Middle Creek. Sand then moves along the northern beach to the recurved spits forming the southern entrance to Jenny Lind Creek (Fig. 15.19a), with the steep slopes of 80 m high Bustard Head forming the northern boundary. Sand may be bypassing Clews Point and moving into the 1.2 km wide Pancake Creek mouth and tidal shoals. Sand is apparently

moving along the northern embayed shore to Richards Point and beyond into SC:QLD04.03.08. In summary, this entire SC appears to be receiving sand around Round Hill, which then moves in a clockwise direction around the shores of the bay, with interruption and sinks at each of the creek mouths (Fig. 15.19b) and bypassing of the northern headland, to leak into the northern SC and Rodds Bay.

15.4.15 PC Overview

This long PC has a variety of SCs ranging from some of the largest transgressive dune systems on the east coast to low regressive beach-foredune ridges to salt flats lined by mangroves in the Fitzroy River delta. The Fitzroy River is a major source of sediment for its delta, Keppel Bay and northern downdrift coast, with other sediment derived from the inner shelf and longshore transport. Beginning in the south sand is bypassing Round Hill and moving into Bustard Bay (SC:QLD04.04.09) where it moves in a clockwise, but interrupted, direction to the northern boundary at Richards Point, which it is also bypassing moving along the shore and into Rodds Harbour (SC:QLD04.04.08). While the harbour is a major sink, sand moves along the western island shores of Rodds Bay-Port Curtis, with interruptions at the creek mouths to its terminus at the northern tip of Boyne Island where it is likely moving into the Gladstone Harbour sediment sink. The Narrows and Port Curtis (SC:QLD04.04.06) are a TD sediment sink with largely mangrove-lined shores, parts of which have been developed for port and industrial facilities. Facing and Curtis islands (SC:QLD04.04.07) have more exposed eastern shores and show evidence of northerly bypassing and longshore transport, to and around Cape Capricorn and then along the northern island shore (SC:QLD04.04.05) to and beyond Station Point and into Keppel Bay (SC:QLD03.04.04). Keppel Bay is dominated by the Fitzroy River, a major source of sediment, about half of which is accumulating on the floodplain-delta. The remainder being transported into the bay and northward, with much of the bedload being moved alongshore to form the regressive Cattle Point barrier and transported northwards to bypass the largely rock-controlled and small embayed beaches of (SC:QLD04.04.03). Wave energy increases along (SC:QLD04.04.02) with sand continuing north to the Farnborough barrier and the Corio Bay tidal sand flats, with some no doubt bypassing across Corio bay mouth and Water Park Point and onto Nine Mile beach and its massive transgressive dune system, a major sediment sink. Exposed TM beaches backed by the large transgressive dunes extend to the northern boundary at Cape Manifold. The northern SC (QLD04.04.01) is similar with two extensive dune systems, together with rocky points and two large tide-dominated creeks, all major sinks for the longshore and inner shelf sands. This PC terminates on the mainland at Reef Point where there is evidence that some sand is moving around the point and into Strong Tide Passage and Shoalwater Bay. In summary, sand is moving northwards throughout this PC, with much most likely derived from the inner shelf, but with a large ongoing source from the Fitzroy River, together with sand ultimately derived from NSW which arrived from the south and has been transported at least as far as Rodds Bay.

The sand has been deposited in a number of tidal creeks, bays and regressive barriers and in the massive northern transgressive dunes, with some leaking into the next PC and Shoalwater Bay at the northern boundary.

15.5 PC:QLD04.04 Round Hill–Sandy Cape

Round Hill and Sandy Cape are two major promontories, both named by Captain Cook in 1770, with Cook climbing Round Hill to view the surrounding coast. The two mark the boundaries of this 316 km long, reverse J-shaped PC:QLD04.04 (Fig. 15.1). The compartment consists of a 204 km long northeast-facing mainland section that curves round in the southern Hervey Bay to face north and link with the western shores of Fraser Island, which forms the eastern side of the compartment. The PC contains three SCs (Table 15.6) which are discussed below.

This PC is predominately a low-lying coast plain containing bedrock of low to moderate relief in the north between Round Hill (54 m) and Wreck Rock (20 m), in the centre between Burnett and Elliott heads (10 m) and in the south around Point Vernon (30 m). The geology begins with Triassic volcanics forming the Round Hill coast, grading southwards along the mainland coast into Triassic sedimentary and then Cretaceous sedimentary rocks between Round Hill and Burnett Heads (SC:QLD04.04.01), with Quaternary deltaic sediments of the Burnett River delta extending north of the low Burnett Heads. SC:QLD04.04.02 extends south of the heads has a series of low basaltic points (Triassic volcanics) to the low Elliott Heads, south of which Quaternary fluvial and marine sediments dominate most of Hervey Bay (SC:QLD04.04.03), with Cretaceous sedimentary rocks outcropping around the low protruding Point Vernon. Apart from the Point Vernon, most of the Hervey Bay shore is marine sediments, including the eastern Fraser Island shore which consists of marine-derived fine Quaternary dune sands.

This is a moderately developed section of coast with a number of satellite communities including the growing Agnes Waters-Round Hill (2000) in the north, then smaller coastal communities at Rules Point and Moore Park (2000), in the centre, with the coastal suburbs of Bundaberg (70,000) spread along the coast between Burnett Heads (2500), Bargara (7000) and Elliott Heads (1000); then the small communities of Burrum Heads (2000) and Woodgate (1000); and in the south the rapidly growing city of Hervey Bay (50,000). The eastern Fraser Island shore is a national park and essentially uninhabited apart from visitors and campers.

15.5.1 Rivers and Creeks

The Burnett River (33,323 km^2) is the largest river system in the PC and dominates the centre of the compartment, protruding 10 km seaward. It is flanked by the smaller Kolan River (2823 km^2) to the north and the Elliott (293 km^2) and Burrum

(2368 km^2) to the south. In addition, there are approximately 20 smaller streams and tidal creeks most with substantial ebb tide deltas.

15.5.2 Coastal Processes and Sediments

The wave climate is a mix of both sea and swell, as the northern section between Round Hill and Burnett Heads is the northernmost SC on the central-east Queensland coast to receive southerly ocean swell that moves through the 100 km wide gap between bottom of the GBR (Bunker Group) and Sandy Cape on Fraser Island. Carter and Pattearson (1987) investigated the Hervey Bay wave climate and found it received both seas from the northeast though southeast with periods of 3 s and refracted swell from the north though northeast with periods of 12 s. A waverider buoy located off Burnett Heads recorded a mean H_o of 0.85 m and H_{max} of 1.5 m, with a T = 5 s arriving predominately from the southeast (Table 13.3). As Burnett Heads is moderately sheltered in lee of Fraser Island, it is expected that wave height and period would increase slightly northwards reaching a maximum at Round Hill and decrease southwards into Hervey Bay as more shelter is afforded by Fraser Island. The southward decrease is confirmed by BPA (1993) which visually recorded daily wave characteristics at Pialba beach at the base of Point Vernon in Hervey Bay. Mean breaker wave height was 0.16 m (σ = 0.06 m), T = 4.3 s (σ = 1 s), with waves primarily from the east and then southeast to south. Likewise, Table 13.4 confirms the decrease in breaker wave height between Baffle Creek (0.8 m) and Urangan (0.15 m). Spring tide range is 2.5 m at Bundaberg (Table 15.2) and Point Vernon, resulting in WD beaches in the north switching to TM to TD in the south.

Beach sediments are predominately moderately well-sorted medium quartz sand with 5% carbonate (σ = 8.5%), apart from higher carbonate (10–34%) along the Bargara coast (Table 15.3).

15.5.3 Beaches

Sixty-seven generally longer beaches occupy 259 km (82%) of this predominately sedimentary coast, with an average length of 3.9 km (Table 15.10). The low to moderate waves and meso-tides result in WD beaches in the north (Fig. 15.20b), grading to TM and in places TD in the south. The mainland beaches are predominately TM R+LTT (36%) and R+LTR (21%), with 180 beach rips located between Agnes Waters and Rules Point, with an average spacing of 150 m. TD beaches prevail from Woodgate south, the beaches initially B+RSF (10%) with an average of 14 ridges, grading as waves continue to fall to B+SF (26%) particularly in Hervey Bay where the sands flats and tidal sand shoals extend up to 3 km into the bay. On Fraser Island, the low waves and fine sand maintain predominately B+SF along its western shore (FIs 12-16), grading to R along the more exposed northern-most western beach (FIs 17).

Table 15.10 PC:QLD04.04 beach types and states

BS	BS	No.	%	length (km)	%	Mean (km)	σ (km)
6	R	1	1.5	20.5	7.9	20.5	–
7	R+LTT	25	37.3	92.2	35.7	3.7	6.4
8	R+LTR	21	31.3	53.9	20.9	2.6	4.4
10	B+RSF	4	6.0	25.1	9.7	6.3	3.9
11	B+SF	16	23.9	66.3	25.7	4.1	5.7
		67	100	258.0	100	3.9	–

15.5.4 Barriers

The compartment contains 22 mainland barriers with an average length of 7 km which occupy 149 km (73%) of the coast, together with the 112 km western shore of the large Fraser Island barrier-sand island. The barriers, excluding Fraser Island (considered in PC:QLD05.01, Chap. 18), have a total volume of 1142 M m^3, which represents 7686 m^3 m^{-1}, typical of a low to moderately exposed shoreline. The barriers reflect the north to south decrease in wave energy, with higher energy now stable transgressive barriers in the north and wide regressive barriers to the south. The northern barriers between Round Hill and Rules beach are the most exposed with the highest energy beaches. All consist of now stable and well-vegetated Holocene transgressive dunes trending northwest (305°) and up to 1.5 km wide, the largest at Rules Beach. From Broadwater Creek, south to Elliott Heads the barriers are primarily a single to a multiple foredune ridges, the largest associated with the Kolan and Burnett river deltas. The Burnett has a 9 km wide regressive plain that extends for 20 km and contains 300 M m^3 of sediment, while the Kolan contains 150 M m^3. The southern SC:QLD04.04.03 contains the largest barriers. Beginning at Coonarr, the regressive barrier widens to the south reaching a width of 6 km at Woodgate and 4.5 km at Burrum Heads. These low regressive barriers fronted by wide sand flats contain both inner Pleistocene and outer Holocene beach-foredune ridge plains, all bordered by TD creeks with substantial ebb tide deltas. The mainland systems terminate at along the Hervey Bay shore (Pialba-Urangan) where a regressive ridge plain has been deposited, terminating at the northern entrance to Great Sandy Strait.

This PC grades from a sediment source and sinks in the southern Hervey Bay-Great Sandy Strait to sediment bypassing around Round Hill Head at its northern boundary (Fig. 15.20a), with small to moderate-sized barriers in between. Its three SCs are discussed below.

15.5.5 SC:QLD04.04.01 Round Hill–Burnett River

Starting in the north at Round Hill, the SC (QLD04.04.01, Fig. 15.21) curves gently to the southeast for 99 km to the Burnett River mouth as a near continuous sandy shore, with the 29 beaches occupying 90 km (91%) of the shore. Wave-driven

Fig. 15.20 (**a**) Round Hill and sand chocked Round Hill inlet (QLD 1463); (**b**) view south along the cusped and reflective Seventy-Seventy beach (QLD 1464); (**c**) the Baffle Creek inlet and ebb tide delta (QLD 1489-90); and (**d**) the 5 km long Barubbra Island spit extending north from the Burnett River (QLD 1495). (Photos: AD Short)

longshore transport begins at the river mouth with the 5 km long Barubba Island spit extending north from the mouth, together with north-trending spits at the mouths of the Kolan River and Baffle Creek. Transport would be expected to be on the order of 10,000's m^3 $year^{-1}$. Pattearson and Carter (1987) examined the Burnett River sand supply and its impacts and found that the beaches between the Burnett and the Kolan rivers have undergone several progradational phases related to major changes in Burnett distributary channels which cause periodic releases of large volumes of sand. They suggest the cycles are on the order of 2000 years and that the present accretionary phase commenced 0.8 ka and in now entering a period of stability-erosion, though harbour works in the Burnett may interrupt this process.

15.5.6 SC:QLD04.04.02 Burnett River–Elliott River

The Bargara coast between Burnett River and Elliott River (SC:QLD04.04.02, Fig. 15.22) is a predominately low basalt shore (<10 m) containing a series of 15 small beaches (mean length = 0.4 km) occupying 6 km (24%) of the shore, the remainder basalt rocks and boulders. Elliott Heads has a sand-choked river mouth and ebb tide delta (Fig. 15.23a) with sand likely being delivered by the river and longshore transport from the south. The rocky coast to the north however limits

Fig. 15.21 SC:QLD04.04.01 between Round Hill and the Burnett River mouth is a near continuous wave-dominated sandy shore interrupted by subdued points and the creek and river mouths. (Source: Google Earth)

deposition to the few beaches, and it is expected that sand is moving in the subtidal along this SC driven by wave and tidal currents. There has been a proposal for a groyne linking the southern Elliott River entrance to Dr Mays Island to improve navigation (GCCM 2010), though it is unlikely this would stop the subtidal northwards movement of sand.

15.5.7 SC:QLD04.04.03 Elliott River–Sandy Cape

The larger southern SC (QLD04.04.03) includes the 80 km long mainland shore down to Urangan and then the entire 112 km western side of Fraser Island (Fig. 15.22). This is a predominately sedimentary shore with 17 beaches occupying 74 km (93%)

Fig 15.22 SCs:QLD04.04.02-03 contains the rocky Bargara shore and the predominately sandy Hervey Bay-western Fraser Island coast. (Source: Google Earth)

of the mainland and the entire sandy Fraser Island coast. On the mainland the coast consists of regressive barriers separated by tidal inlets with well-developed ebb tide deltas (Fig. 15.23a, b). Sand appears to be moving northwards from around Woodgate towards Elliott Heads and probably beyond. South of Woodgate, while wind and sea are predominately southeasterly, the south swell refracting around Sandy Cape-Breaksea Spit arrives from the northeast and is moving sand south into the Burrum River, as indicated by a 5 km wide series of south-trending spits that recurve into the river mouth. Beelbi and Eli creeks also have southeast-trending spits at their mouths, all indicating that sediment is being transport into the southern Hervey Bay, where at the end of the system, the Urangan barrier ridges-spits recurve eastward into Great Sandy Strait, both indicating south to easterly transport.

The western Fraser Island shore also shows substantial evidence of southerly sand transport with the large Wathumba creek spit extending 3 km southward, and the smaller Woralie, Bowarrady, Awinya, Bowal and Towoi creeks all deflected southward. In addition, there are south-skewed sand bars, and finally the terminal recurved Moon Point spit at the base of its western shore where it enters Great Sandy Strait (Fig. 15.23d). This transport is presumably driven by refracted ocean swell in the north and northerly wind waves and would be expected to be on the order of a few 1000 m^3 $year^{-1}$.

Gontz et al. (2016) examined the barrier stratigraphy just to the north of Moon Point (Fig. 15.23d) at the eastern entrance to Great Sandy Strait and found it con-

Fig. 15.23 (**a**) Elliott Heads and the Elliott River mouth (QLD 1509-11); (**b**) Coonarr Creek (QLD 1513-4) and its extensive ebb tide delta; (**c**) Point Vernon is surrounded by a narrow HT beach and intertidal rock flats (QLD 1533-3); and (**d**) Fraser Island's Moon Point (FR 12) a 1 km long recurved spits at the entrance to Great Sandy Strait. (Photos: AD Short)

tained a sequence of lower Pleistocene regressive units overlain by coffee rock, buried wetlands, an early to mid-Holocene transgressive unit, followed by a mid- to late Holocene regressive unit and finally the modern transgressive beach system, all indicative of the Holocene sea-level transgression and shoreline response.

BPA (1989) conducted a major study of the Hervey Bay region which is summarised in Pattearson and Carter (1987). They investigated the evolution and sediment transport in Hervey Bay and found that the Moore Park barrier has a higher inner Pleistocene barrier and outer Holocene which has prograded 1 km since 2.5 ka, the outer ridges dating modern. The southern 1 km wide Torquay barrier has experienced four phases of evolution, the latter two dating 3.3 and 2.7–1.9 ka. They proposed a model where the Burnett River is supplying sand in the north which is supplemented by shelf supply. Between Burnett and Burrum heads shelf sand is supplying the beaches, while in the south the Mary River is delivering sand to the Great Sandy Strait, which is then transported by tidal currents 20 km north into Hervey Bay where it combines with shelf sand and is transported onto the Urangan and Piabla beaches. Also as Veevers (2015) found sand as far north as Rodds Bay contains heavy minerals derived from the NSW hinterland, indicating that NSW sand has move up this coast via Hervey Bay and to the north. Using the Bijker formulae, Pattearson and Carter predicted longshore sand transport in the bay area. The found sand is moving in both directions, with a net northerly transport of 14,800 m^3 year^{-1} at Moore Park (QLD 1492), south of which the transport is more balanced with 1300 m^3 year^{-1} to the south at Palm-Coonarr beach (QLD 1512), and a balanced 50 m^3 $year^{-1}$ at Woodgate (QLD 1514), south of which the southerly bias increases to 2400 m^3 $year^{-1}$ at Dundowran (QLD 1519), dropping to 300 m^3 $year^{-1}$ at the low energy Scarness (QLD 1525). This supply of sand has been responsible for the extensive regressive south-trending barriers along the southern bay shore.

15.5.8 PC Overview

This is the southernmost PC in the central Queensland region, the southernmost affected by the GBR and the first to receive limited southern ocean swell. As such it represents a transition for the meso-megatidal, low to moderate wave energy, GBR-protected, northeast-central Queensland coast, to the high energy micro-tidal WD coast of southeast Queensland and southern Australia. The high energy waves and wind have built the world's largest sand island to form the eastern side of the southern SC in Hervey Bay. As with all the coast to the north, sand transport is predominately to the north, with reversals in the southern sections of Rodds Bay and Hervey Bay and a major sink for Fitzroy River sediment in Keppel Bay. In SC:QLD04.04.03, northerly sand transport commences from around Woodgate with waves transporting sand north, bypassing Elliott Heads and the Bargara coast (SC:QLD04.04.2) and then moving along the near continuous beaches of SC:QLD04.04.01 between Burnett Heads and Round Hill, where it bypasses the point and moves into Bustard Bay and PC:QLD04.03. South of Woodgate on the sand is moving south in Hervey Bay down to Urangan and the entrance to the Great Sandy Strait, where sand is also arriving via Great Sandy Strait from the Mary River and along the western shore of Fraser Island. Southern Hervey Bay is therefore a major sediment sink for shelf, fluvial and Fraser Island sand, which is in part manifest in the number of active regressive barriers and predominately sedimentary shores.

As wave energy decreases to the south into Hervey Bay, beaches range from low energy WD R to TM and TD with extensive sand flats. Likewise, the barriers range from now stable transgressive dunes in the higher energy north to extensive low beach-foredune ridge regressive barriers in the south, most bordered by tidal creeks with substantial ebb tide deltas.

15.6 Regional Overview

The central Queensland region (QLD04) is an 1845 km long southeast-trending coast located to the lee of the GBR. It is dominated by low to moderate southeast trade wind and waves and meso- through macro-tides, with predominately TM and TD conditions. The trend of the coast is interrupted by major sheltered bays at Repulse Bay, Broad Sound and Shoalwater Bay, Keppel Bay, Port Curtis-Rodds Bay and finally the southern Hervey Bay, together with numerous smaller bays, all of which have low to very low energy shores most lined by wide tidal flats and mangroves. The southerly winds and waves assisted by flooding tidal currents tend to transport sediment northwards with the numerous headland and bays interrupting the transport and most of the bays acting as sediment sinks, with local transport reversals. On the open coast, most of the sand is deposited as beaches and regressive barriers, apart from the major dune transgression between Port Clinton and Waterpark Point on the Capricorn coast.

Change climate will have a range of impacts along this region. DERM (2011) reports that sea level may rise between 0.26 and 0.79 m by 2100, combined with a 20% increase in rainfall associated with tropical cyclones as well as changes in the frequency and intensity of tropical cyclones. The rising sea level will deepen water over the GBR allowing more ocean wave energy to penetrate the lagoon and possibly make it to shore increasing breaker wave energy. At the same time the higher sea level will deepen the inshore-intertidal waters along TD coasts allowing more wave energy to reach the shore. Combined, this will lead to higher waves and more energy to transport sand predominately northwards. It may also lead in combination with the higher sea level to beach recession and possibly reactivation of presently stable dune fields, particularly if accompanied by higher velocity winds. In the sheltered bays and tidal inlets including the large Fitzroy River delta, the rising sea will inundate the intertidal and supratidal flats and initiate a landward shift and expansion in mangroves and all tide-related ecosystems, together with saline intrusion into the presently freshwater floodplains. An increase cyclonic rainfall would increase flooding as well as river and sediment discharge, which could add to adjacent sediment budgets. Major cities like Mackay and Hervey Bay built on deltas and low beach ridge plains will become increasingly exposed to flooding and storm surge inundation.

Sandy Cape at the tip of Fraser Island is the boundary between the northern tropical province and the southern temperate province. At this tip begins a total transformation in the nature and morphodynamics of the coast, as is presented in the following chapters about the temperate southern province.

References

Bode K, Stark KP (1983) Simulation of tides and currents in the Mackay region. In: 6th Australian conference on coastal and ocean engineering, Brisbane, Institution of Engineers Australia, pp 85–89

BPA (1979) Capricorn coast beaches. Beach Protection Authority, Brisbane, 238 p

BPA (1989) Hervey Bay beaches. Beach Protection Authority, Brisbane, 323 p

BPA (1993) Point Vernon – City of Hervey Bay 1977–1988. Coastal Observation Program Engineering, Beach Protection Authority, Brisbane

Brooke B, Bostock H, Smith J, Ryan D (2006) Geomorphology and sediments of the Fitzroy River coastal sedimentary systems – summary and overview. Cooperative Centre Coastal Zone, Estuary Waterways, Indooroopilly, Tech Report 47, 25 p

Brooke B, Ryan D, Pietsch T, Olley J, Douglas G, Packett R, Radke L, Flood P (2008) Influence of climate fluctuations and changes in catchment land use on Late Holocene and modern beach-ridge sedimentation on a tropical macrotidal coast: Keppel Bay, Queensland, Australia. Mar Geol 251:195–208

Carter TB, Pattearson CC (1987) Wave climate determination for coastal processes study in the Hervey Bay region, south east Queensland. In: 8th Australasian conference on coastal and ocean engineering, Lauceston, Institution of Engineers Australia, pp 134–139

Cook PJ, Mayo W (1978) Sedimentology and Holocene history of a tropical estuary, Broad Sound. Queensland Bureau Mineral Resources, Geol Geophys Bull, 170, 206 p

Cook PJ, Polach HA (1973) A chenier sequence at broad sound, Queensland and evidence against a Holocene high sea level. Mar Geol 14:253–268

DERM (2011) Queensland coastal processes and climate change. Queensland Climate Change Centre of Excellence, Department of Environment Resource Management, Brisbane, 49 p

EPA (2004) Mackay coast study. Environment Protection Agency, Brisbane, 113 p

Fryar R (1999) Pioneer river sand and gravel extraction study. In: 14th Australasian conference on coastal and ocean engineering, Perth, Institution of Engineers Australia, 8 p

GCCM (2010) Elliott heads study. Griffiths Centre Coastal Management Research Report 107, Griffith University, 64 p

Gladstone Regional Council (2014) Boyne Island and Tannum Sands shoreline erosion management plan. Final Report, Gladstone Regional Council, Gladstone, 80 p plus appendices

Gontz AM, McCallum AB, Moss PT, Shulmeister J (2016) Ground penetrating radar observations of present and former coastal environments, Great Sandy National Park, Queensland, Australia – Focus on Moon Point, Fraser Island. J Coast Res 75:730–734

Gourlay MR, Hacker JLF (1986) Pioneer River estuary sedimentation studies. University of Queensland Press, St Lucia, 207 p

Grigg WL, Piorewicz J, Evans PA (1989) A study of a beach-estuary interaction problem: Kinka Beach/Causeway Lake case study. In: 9th Australasian conference on coastal and ocean engineering, Adelaide, pp 224–228

Jones MR (1993) Nearshore sediments, Cape Hillsborough to Gloucester Island: Department of Minerals and Energy (Qld), Project Rept MA66-1, 59 p

Lessa G (1993) Tidal currents, tidal inlets and sediment dynamics on central Queensland coast; a preliminary anaylsis In: Thoms M (ed) Catchments and coasts in eastern Australia. Dept Geography, University of Sydney, Monograph

Lessa G, Masselink G (1996) Morphodynamic evolution of a macrotidal barrier estuary. Mar Geol 129:25–46

Masselink G, Lessa G (1995) Barrier stratigraphy on the macrotidal central Queensland coastline, Australia. J Coast Res 11:454–477

Middleton JH, Buchwald VT, Huthnance JM (1984) The anomalous tides near Broad Sound. Cont Shelf Res 3:359–381

Pattearson DC, Carter TB (1987) Coastal process studies for the Hervey Bay region, south east Queensland. In: 8th Australasian conference on coastal and ocean engineering, Launceston, Institution of Engineers Australia, pp 128–133

Patterson DC, Ford, LR (1980) Capricorn coast beaches – a detailed study of coastal behaviour. In: 17th international conference on coastal engineering, Sydney, pp 109–110 (abstract)

Piorewicz J, Szmytkiewicz JM, Ostrowski R, Skaja S (2003) Keppel Sands shoreline changes due to engineering structures. – monitoring and modelling. Australasian Coast and Ports Conference, Auckland, 8 p

Ryan DA, Brooke BP, Bostock H, Collins LB, Buchanan C, Siwabessy J, Margvelashvili M, Radke L, Skene D, Hamilton L (2006) Geomorphology and sediment transport in Keppel Bay, central Queensland, Australia. Cooperative Research Centre for Coastal Zone, Estuary and Waterway Management, Indooroopilly, 35 p

Short AD (2000) Beaches of the Queensland coast: Cooktown to Coolangatta. Sydney University Press, Sydney, 360 p

Thom BG, Eliot I, Eliot M, Harvey N, Rissik C, Sharples C, Short AD, Woodroffe CD (2018) National sediment compartment framework for Australian coastal management. Ocean Coast Manag 154:103–120

Veevers JJ (2015) Beach sand of SE Australia traced by zircon ages through Ordovician turbidites and S-type granites of the Lachlan Orogen to Africa/Antarctica: a review. Aust J Earth Sci 62:385–408

Chapter 16
Temperate Southern Province

Abstract The temperate southern province occupies the entire southern coast of Australia with a 15,300 km long coastline. While much of the climate is dominated by the sub-tropical high, midlatitude cyclones bring frontal rain and humid conditions to the southeast and southwest coasts, with a more arid central Bight and central west coast regions. The open coast is dominated by micro-tides and exposed to persistent moderate to high southerly swell which drives both substantial onshore and longshore transport. Moderate-sized rivers and numerous streams flow to estuaries along the humid coasts where shelf-derived sediments are predominately quartz. However, across most of the south coast shelf carbonate dominates the beach material. This chapter reviews the physical and biological processes that operate across the shelf and coast.

Keywords Southern Australia · Micro-tides · South swell · Coastal processes · Biological processes · Shelf carbonate

16.1 Introduction

In this book the Australian coast has been divided into two provinces, the tropical northern province (Chaps. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14 and 15) and the temperate southern province (This chapter and Chaps. 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33 and 34), which includes essentially all the southern Australian coast below the Tropic of Capricorn. It extends clockwise from Sandy Cape on Fraser Island at 24.7°S, right around the southeast, southern and south and central west coasts to Giralia Bay at the base of Exmouth Gulf (22.4°S) and includes Tasmania which extends to 43.6°S together with several major islands and bays (Table 16.1). It has 15,311 km of shoreline containing 6647 beaches which occupy 8743 km or 57% of the coast (Table 16.1). While this half is termed 'temperate' owing to its overall climate, it is also distinguished from the northern 'tropical' half by its dominant coastal processes. The southern half is not only a little cooler with sub-tropical to temperate climates but is also exposed to the Southern Ocean, the source of the world's highest and more persistent waves, generated by midlatitude

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Table 16.1 The shoreline length and beach number and length of the temperate southern province and its divisions and regions

Division	Region	Mainland (km)	Island/ bays (km)	Total (km)	Beaches No.	Beaches (km)	Beaches %
Southeast	Central East	1033	266	1299	309	800	64
	Southeast NSW	1032	202	1234	640	627	51
	Gippsland	449	0	449	106	362	81
	East Tasmania	1097	407	1504	706	542	36
Great Southern	West Tasmania	701	100	801	434	248	31
	North Tasmania	439	222	661	455	401	61
	Central Victoria	797	260	1057	588	634	60
	Southeast SA	488	269	757	285	487	64
	SA Gulfs	1422	190	1612	734	1028	64
	Eyre Peninsula	1143	0	1143	638	654	57
	Nullarbor	844	0	844	65	484	57
	Southeast WA	1180	0	1180	565	773	65
Southwest	Southwest WA	916	0	916	516	815	56
	Central west WA	1659	195	1854	606	888	48
	Province Total	**13,200**	**2111**	**15,311**	**6647**	**8743**	**57**

The islands include Fraser, Moreton, Flinders, Maria, Bruny, King, Kangaroo, Rottnest and Dirk Hartog Islands and the bays Port Stephens, Broken Bay, Sydney Harbor, Botany Bay, Port Hacking and Port Phillip

cyclones that also bring strong south though westerly winds. On the open coast, the waves and wind combine to transport massive volumes of shelf-derived sand to and along the shore and into estuaries, beaches and barriers and supply massive coastal dune fields. Along the humid southeast and southwest coasts, most of the sand is ultimately derived from the hinterland and delivered to the shelf primarily at low sea levels, while across the arid south and central west coasts, it is predominately carbonate in origin derived from shelf and inshore marine organisms.

Figure 16.1 illustrates the southern province's 14 regions which are also listed together with the 3 divisions in Table 16.1. The following chapters examine this entire southern coast, including several major islands and bays. It starts with an overview of the geology, climate and coastal and biological processes (Chap. 16). The southern province including its 3 divisions, 14 regions, 59 PCs and 228 SCs are all described in the following 18 chapters. Chapters 17, 22 and 31 provide

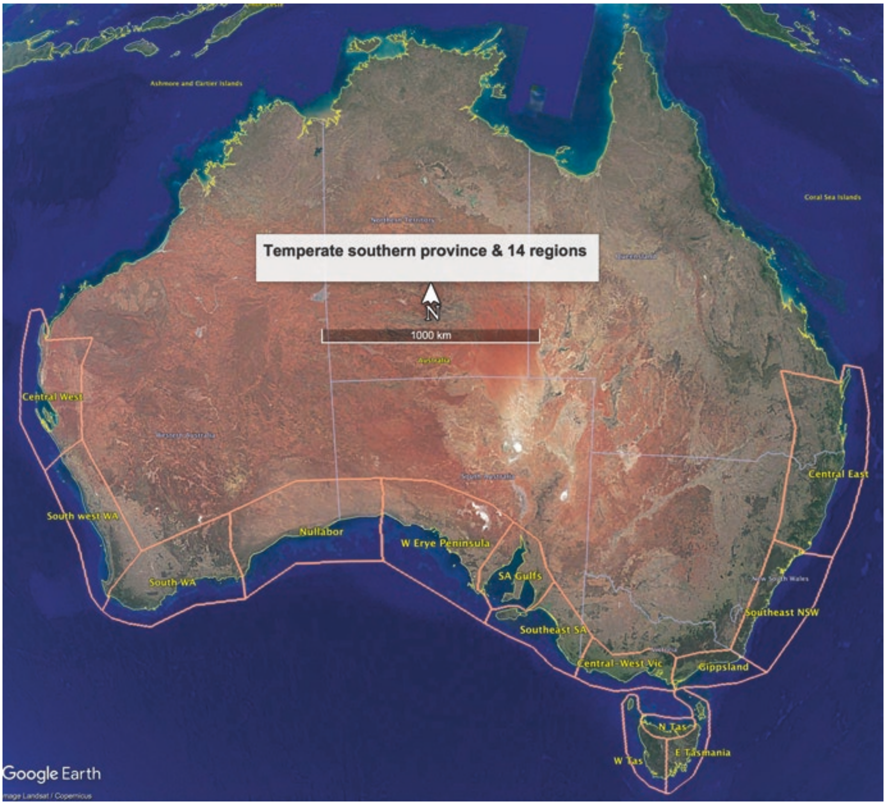

Fig. 16.1 The southern Australian temperate province and its 14 regions. (Source: Google Earth)

background information on each of the divisions, while Chapters 18, 19, 20, 21, 23, 24, 25, 26, 27, 28, 29, 30, 32, and 33 provide information on each of the regions including descriptions of each of the PCs and SCs. It finishes with a final review and overview of the Australian coast in Chap. 34.

16.2 Geology

Australia's geological evolution and general geology are described in Chap. 1. A brief summary is provided below, with some regional and local details provided in the relevant following chapters. In the west, the ancient Yilgarn Craton dominates the southern half of Western Australia (WA) though it only reaches the coast in the south between Albany and Augusta (Fig. 1.2). The coast is largely occupied by a series of younger sedimentary basins, beginning with the Carnarvon Basin in the central west, the Perth Basin south of Kalbarri down to Augusta, the Bremer Basin east of Albany, and the uplifted limestone Eucla Basin extending from Point Malcolm to Head of Bight in South Australia (SA). (Fig. 1.3) The South Australian coast is a mix of basins, with the Eucla in the west and marine-filled Murray Basin that extends east into western NSW and Victoria, and ancient the more resilient Gawler Craton dominating the Eyre Peninsula and the Adelaide Geosyncline forming the Yorke and Fleurieu peninsulas. East of the Adelaide Geosyncline and the Tasman Line are the younger (<500 Ma) accretionary fold belts that extend to the east coast, bordered along the coast by younger sedimentary basins including the Murray. In Victoria (VIC), the Otway Basin occupies the western coast and the Gippsland Basin much of the east coast, with bedrock highs occurring along the Mornington Peninsula and from Cape Liptrap though to Wilsons Promontory, while north of Marlo, the rugged Lachlan Fold Belt occupies the coast. The Lachlan Fold Belt dominates the southeast coast up to Durras, then the resilient horizontal sedimentary rocks of the Sydney Basin north to Port Stephens, north of which the rugged New England Fold Belt occupies the coast north to Yamba. The low Clarence-Moreton Basin occupies the coast between Yamba and Ballina, with sedimentary rocks dominating north to Brisbane, north of which is the small Nambour and larger Maryborough basins, which are occupied by the coastal lowlands and the sand islands, separated by sedimentary rocks along the Sunshine Coast. In total the geology is a mix of cratons, fold belts and basins. The basins however range from fully lithified bedrock (Sydney and Eucla), to partially lithified calcarenite (Murray, Otway, Bremer, Perth and Carnarvon) to unlithified (Gippsland, Bass).

Tasmania (TAS) is separated from the mainland by the submerged Bass Basin. The island consists of a rugged and resilient western Tasmania Terrane that has been joined by an extension of the Lachlan Fold Belt that comprises the eastern Tasmania Terrane. Much of the eastern terrane was covered by thick dolerite sheets during the Jurassic, and the dolerite now dominates much of the east and south coast, while Tertiary volcanics deposited basalt in many of the north coast river valleys.

As a result, rocky shore dominates much of the southern coast and is the main reason the beaches average just 1.3 km in length, with rocks, reefs, islets, forelands and headlands forming the boundaries. The only two beaches >200 km in length are both located in basin regions, namely, the Coorong (Murray Basin) and Ninety Mile (Gippsland Basin).

As will be seen in the following chapters, the geology has a profound impact on the southern coast. In the interior, it has been eroded to supply sediment to the coast, with the sand-sized quartz grains comprising most of the east and some south coast beaches. The geology also influences the general coastal orientation; the size and morphology of the coastal valleys and their estuaries; size and configuration of the beaches, including their morphodynamics (Short 2010); and the nature and extent of rocky shore.

16.3 Climate

This province spans 21° of latitude (22.4°–43.6°S) and 15,000 km of coast and consequently contains a range of climate types, from humid sub-tropical along the central east coast to hot desert on the central west coast. A general climate overview is provided in Chap. 1, with the following proving a summary of the southern climate. Beginning in the east, the humid sub-tropical (Cwa) extends from southern Queensland down to the central NSW coast, where it grades into oceanic (Cfb) with warm summers and year-round rainfall (Fig. 1.8). Cfb continues around the southern NSW and eastern-central Victorian coast to Cape Otway and includes all of TAS. West from Cape Otway, the coastal fringe has a Mediterranean climate (Csb) with warm summers and cool moist winters, which extends along the coast through western VIC and SA as far as Streaky Bay on the western Eyre Peninsula. The Great Australian Bight-Nullarbor coast is cool semi-arid (BSk), with Csb extending along the southwest WA coast from Israelite Bay to Busselton. North of Busselton, increasing summer temperatures produce hot summer Mediterranean (Csa) as far north as Kalbarri, with hot semi-arid (BSh) to Shark Bay and then hot desert (BWh) to Exmouth Gulf and into the Pilbara (Figs. 1.5 and 1.7). The southeast QLD, Pilbara and Exmouth coasts are also being exposed to summer tropical cyclones.

The southern climate is controlled by two major pressure systems – the sub-tropical high that resides over the continent year-round, shifting a few degrees north and south (30–36°S) with the seasons and delivers dry stable conditions, and the midlatitude cyclonic lows that continuously track rapidly around the Southern Ocean between 50 and 60°S. The lows occasionally penetrate north between the slower-moving highs and when they reach the continent bring cooler conditions and at times frontal precipitation to the southwest and southeast coasts, particularly during winter (Fig. 1.4). The humid east coast is also influenced by summer tropical cyclones that can reach as far south as Brisbane and east coast cyclones that can impact the entire southeast coast bringing heavy rain, high seas and strong winds. The net result is year-round rainfall along the east coast with summer rainfall becoming increasingly dominant north of Merimbula (Fig. 1.5a, b; Table 16.2). Across the south and southwest winter rains dominate, while in the west summer rains dominate north of Exmouth. The amount of rainfall reflects the dominance of the high which maintains dry desert conditions along the Bight and central west coast and the lows which bring more humid conditions to the southwest and southeast and central east coasts.

Temperatures are latitudinally controlled and tend to be warm to hot during summer ranging from mean maximum of 18 °C in Tasmania to 24 °C in southeast Queensland and up to 27 °C in Exmouth Gulf, while winter mean maximums range from 8°S in Tasmania to 18 °C in southeast Queensland and Exmouth (Fig. 1.5c, d).

Table 16.2 Southern Australia seasonal temperatures and precipitation from selected stations (data from Bureau of Meteorology)

Location	Latitude (°S)	Summer max (°C)	Winter max (°C)	Summer (mm)	Winter (mm)	Total (mm)
Southeast						
Brisbane	27.3	30	22	687	333	1020
Coffs Harbour	30.3	28	19	955	526	1481
Sydney	33.8	26	16	641	574	1215
Merimbula	37.0	25	16	449	323	772
Hobart	42.9	23	13	248	247	495
South						
Melbourne	37.8	26	14	323	386	709
Adelaide	34.8	29	15	166	364	530
Ceduna	32.1	29	17	102	194	296
Esperance	33.8	26	17	179	438	617
Albany	35.0	23	16	231	698	929
Southwest						
Perth	32.0	32	18	119	608	727
Kalbarri	27.7	34	22	58	289	347
Carnarvon	24.8	33	22	74	151	225
Exmouth	21.9	38	24	137	123	260

16.4 Coastal Processes and Systems

The southern Australian coast is for the most part an exposed and energetic coast and also one that has experienced a long period of geological stability. This has allowed the coastal processes to act on the present coast at present and past high stands of the sea producing a coast that has experienced multiple phases of evolution during the Quaternary and in places back into the Pliocene and even Tertiary. The remnants of these multiple phases of both erosion and deposition can be found around much of the coast and are in places a very important component of the modern coast.

16.4.1 Waves

The southern coast has a persistent moderate to high energy wave climate receiving waves predominately from the mid latitude cyclones and regionally from several other sources. On the southeast coast (Fraser Island to southeast Tasmania), waves are derived from five sources (Fig. 16.2; Short and Trenaman 1992, Shand et al. 2010). The midlatitude cyclones deliver the dominant southerly swell year-round, with a winter peak when the lows move closer to the southern coast. The predominately south to southwest swell has to refract to reach the east coast and in doing so

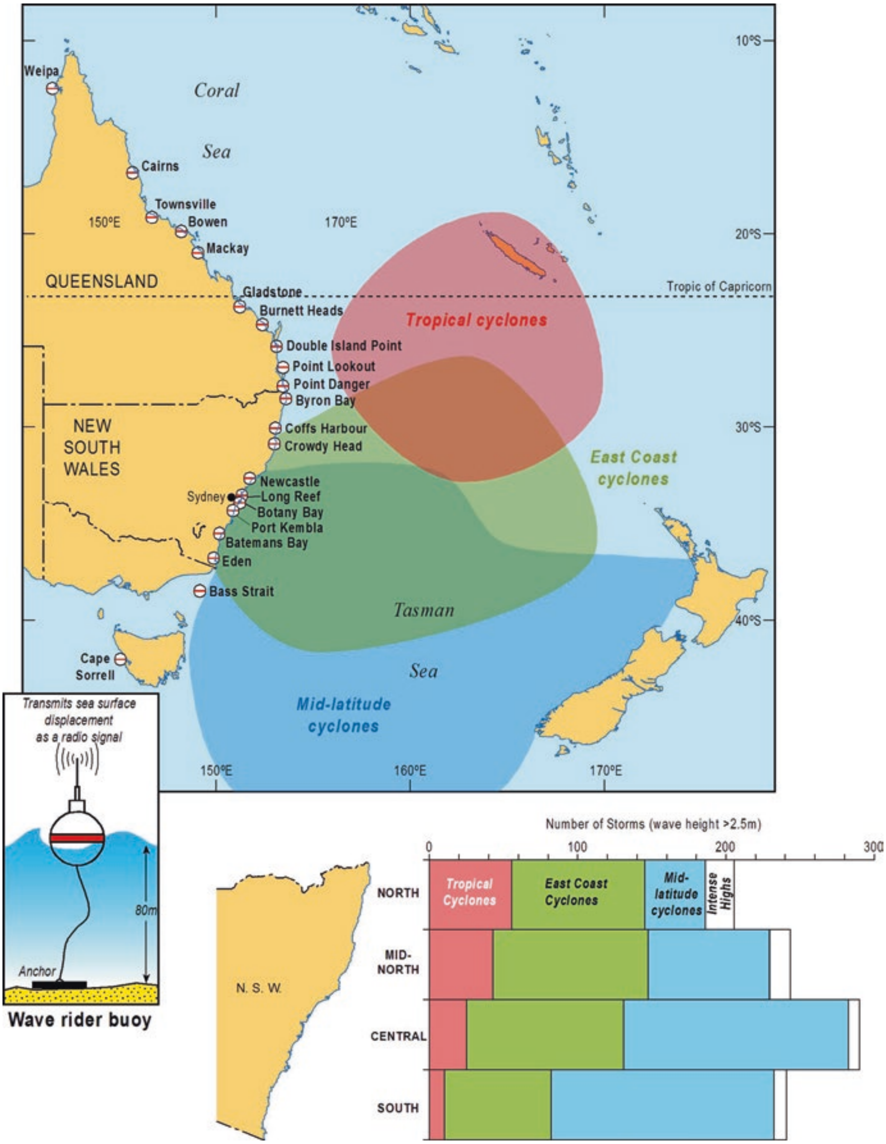

Fig. 16.2 Location of waverider buoys along the east Australian coast and the areas where tropical, east coast and midlatitude cyclones are located when their waves arrive at Sydney. Lower: sources and frequency of wave greater than 2.5 m. (Source: Short and Woodroffe 2009)

decreases in wave height and energy. Deepwater waves average 1.6 m at Sydney with a period of 10 s and generally decreases in height slightly to the north (1.2 m at Point Lookout) and south (1.5 m at Eden). Other wave sources include the east coast cyclones that can occur year-round with a late summer-winter peak. They

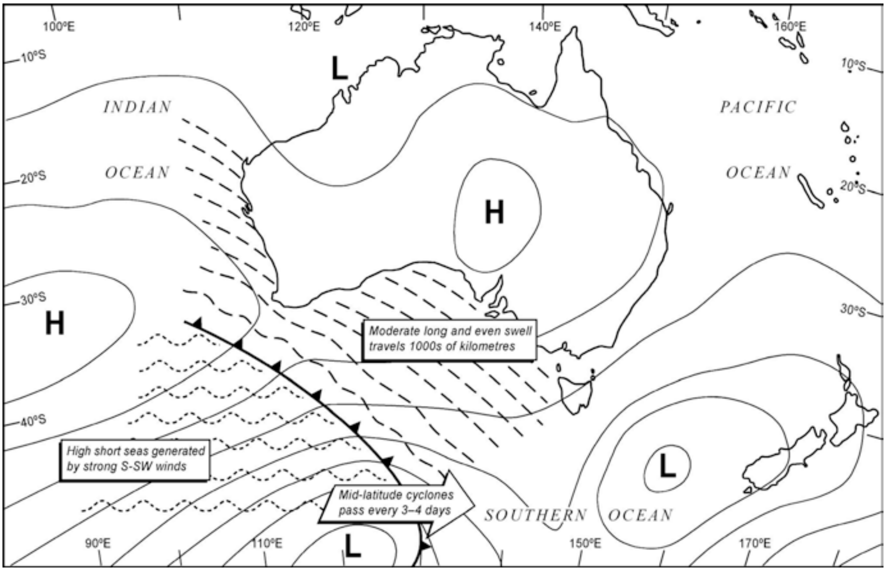

Fig. 16.3 Schematic example of a midlatitude cyclone (sub-polar low) tracking south of Australia and generating high seas and swell which impact the entire southwest, southern and southeast coasts. (Source: Short 2005)

produce the highest and most damaging waves on the southeast coast usually arriving from the east. Tropical cyclones tend to occur in late summer and can generate moderate to high east to northeast swell down the coast. High pressure easterly winds dominate the onshore winds but only occasionally produce waves greater than 3 m during that are called ‘black noreasters’. During warm summer days, the northeast sea breezes blow from late morning bringing short choppy northeast seas.

The long southern coast is entirely dominated by the persistent southwest swell generated by the year-round midlatitude cyclones as they track south of Australia (Fig. 16.3). The waves average > 2 m (Fig. 1.11) with a late winter maximum. Figure 16.4 shows the monthly average wave height at Cape Sorrel (west Tasmania), Cape du Couedic on Kangaroo Island and offshore Perth. Waves are highest averaging 3 m year-round at Cape Sorrel which at 42°S it is closest to the lows. They decrease slightly (2.7 m) by Cape de Couedic at 36°S and average 2.1 m off Perth at 32°S, reflecting the northward decrease in wave height as they move from the southern source. Wave period is long (12–14 s), decreasing to 8–10 s at Perth where it is combined with the short southwest sea breeze waves. The other wave sources across the south and southwest coast are wind wave associated with the passage of winter westerly fronts and the onshore summer sea breeze, both of which generate short seas. The southerly sea breeze is particularly important along the southwest-central west WA coast, owing to its strength and persistence, together with the fact that much ocean swell is precluded from the coast by inshore calcarenite reefs.

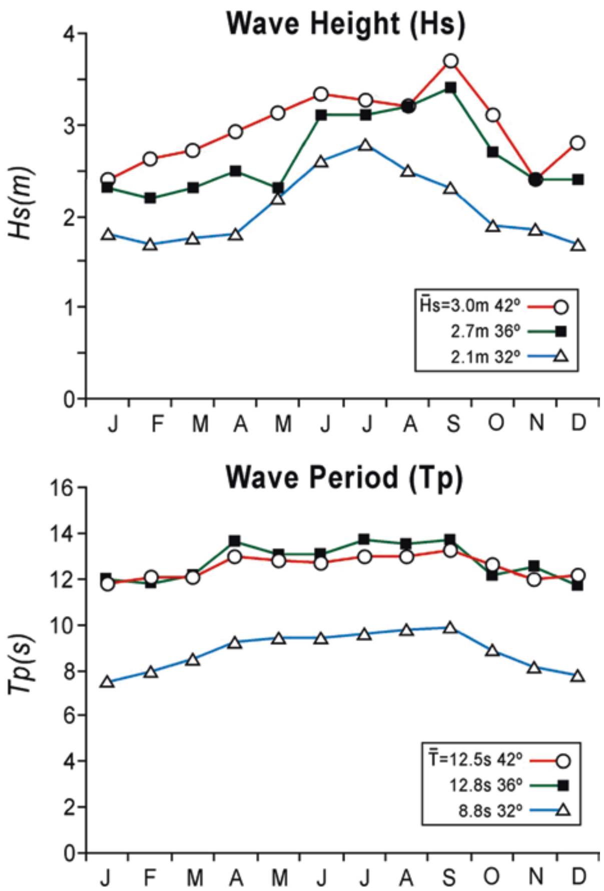

Fig. 16.4 Monthly significant wave height (H_s) and peak period (T_p) recorded by waverider buoys at Cape Sorrel (42°S), Cape Du Couedic (36°S) and off Perth (32°S). Note the year-round persistent high waves peaking in late winter, together with the decrease in wave height to the north. (Source: Short and Woodroffe 2009)

Figure 1.12a illustrates the wave energy flux around Australia. It clearly highlights the high level of deepwater wave energy (>60 kW^{-1}) across the southern and southwest coast, the lower wave energy (<30 kW^{-1}) along the southeast coast, the northward decrease in wave energy on both coasts, and the very low energy (<10 kW^{-1}) across the northern coast. Figure 1.12b illustrates the monthly variability in wave energy, with most of the southern coast experiencing minimal variability, indicating the moderate to high waves arrive year-round with little difference between the seasons, though as Fig. 16.4 indicates there is a slight winter maximum. The high level of wave energy around the southern coast and its generally southerly direction has had a profound impact on the entire exposed southern coast, transporting masses of sand onshore to build beaches, barriers and flood tide deltas and moving its northwards particularly along the east and west coasts to major sediment sinks in the southeast QLD sand islands and the Zuytdorp-Shark Bay region on the west coast.

16.4.2 Storm Surges

Storm surges are elevations in sea level generated by strong wind, low barometric pressure and locally enhanced by the Coriolis force and low shelf gradient. Around southern Australia, they occur when midlatitude and east coast cyclones impinge upon the coast. Owing to the generally steep southern continental shelf, they are usually <1 m, only reaching higher elevations (~2 m) in the shallow Bass Strait and SA gulfs (Fig. 1.14). However, as they are generated by cyclones close to shore, they are usually accompanied by high waves and strong winds and can result in the generation of extreme water levels leading to shoreline erosion and coastal inundation.

16.4.3 Tides

Tides around the south coast are predominately micro, apart from some meso-tides in southeast QLD, Bass Strait and the SA gulfs. Figure 1.15 illustrates the spring tide range around Australia, and Table 16.3 lists the spring tide range for selected southern Australian tide stations. As indicated tides are <2 m down the entire

Table 16.3 Mean spring tide range at selected southern Australian locations

Location	Mean spring tide range (m)
Brisbane	1.8
Sydney	1.6
Hobart	1.5
Georgetown	2.4
Western Port	2.3
Port Phillip Heads	1.1
Port MacDonnell	1.1
Adelaide	2.4
Port Augusta	3.2
Thevenard	1.7
Eucla	1.3
Albany	1.0
Fremantle	1.0
Carnarvon	0.9
Learmonth	2.1

southeast coast, and close to 1 m across the south coast, except where amplified in Bass Strait and the SA gulfs. They are ~1 m up the southwest coast and just begin to increase (~2 m) at Learmonth. More details on regional tides will be provided in the following chapters.

16.4.4 Shelf Waves

Shelf waves are periodic oscillations in sea level that occur along a coast. There are two types that occur along the southern Australian coast: one a progressive wave and the other a standing wave (Provis and Radok 1979). The progressive wave is driven by the passage of midlatitude cyclones crossing south of the continent. The waves arrive on WA coast and move from west to east across the southern coast and on to southeastern coast, with a period between waves of 5 and 20 days, but peaking at 4–5 days, and can raise sea level for a few days at a time. On the south coast, they commonly reach 0.5 m in height and can reach 1.5 m. These waves can move up the NSW coast as a coastal trapped waves where they are usually <0.2 m but can reach up to 0.5 m in height (Wyllie et al. 1993).

The second type is more seasonal, with periods of several months and which affect the entire coast simultaneously, that is, they stand against the coast. These are driven by the seasonal latitudinal shift in pressure systems and can also result in sea-level oscillations as much as 0.5 m with periods between 20 and 365 days, particularly along the southern coast. As tides on the open southern Australian coast are normally of the order of a few decimetres, these waves exert significant control on the actual sea level at any time and depending on when they occur can cause abnormally high or low tides. They also make it difficult for the casual observer to determine the actual state and height of the tide.

16.4.5 Ocean Currents

Figure 1.18 illustrates the generalized ocean currents around the Australian coast. On the east coast, the warm East Australian Current (EAC) flows south along the QLD and northern NSW coast before breaking into a series of clockwise spiralling eddies off the NSW central-south coast. This current brings warm water (Fig. 1.17) and contributes to the warmer, humid conditions along the southeast coast. It also contributes to the formation of east coast cyclones which deliver heavy rain, strong winds and high seas to the coast. In the south the great Antarctic Circumpolar Current runs well south of the continent at relatively high speed (2–6 km h^{-1}), driven by the strong westerly wind stream. It flows continuously around the southern oceans, centred between 50 and 60°S. Between the main current and the southern Australian coast, the currents, while still predominantly westerly, decrease in velocity owing to increasing distance from the main westerly wind stream, more variable wind direction and the impact of the relatively shallow continental shelf. Closer to the coast, the currents become increasingly dependent on local winds, which still however are predominantly westerly. Along the southeast SA coast, a seasonal reversal in the coastal current can occur, with a westerly flow of water from Bass Strait flowing up along the southeast SA coast during summer.

On the west coast, warm water pools in the northeastern Indian Ocean and moves down the WA coast as the warm, narrow Leeuwin Current. It brings warmer tropical waters south along the coast and is partly responsible for the world's most poleward fringing coral reefs at Ningaloo (24°S) and oceanic coral reefs at Houtman Abrolhos (29°S). The current reaches as far south as Cape Leeuwin and periodically moves around the cape and as eddies and then east into the Great Australian Bight and beyond.

16.4.6 Tsunami

Tsunamis can impact the entire Australian coast; however, their height and impact at the coast vary considerably (Fig. 1.16). The northwest coast is directly exposed to tsunamis generated in the Indonesian archipelago, and recent tsunamis have inundated the coast to elevations of a few meters. As Fig. 1.16 illustrated, the predicted exceedance for 1 1:1000 year tsunami around the southern coast ranges from a maximum of 4 m on the Exmouth Peninsula and Gulf, decreasing down the west coast to ~1 m at Cape Leeuwin, and then remains low <1 m across the south coast, increasing to 1–2 m up the southeast coast. While the lower values can disrupt ports and moored ships, they tend to have little physical impact on the coast. Reports of mega-tsunami evidence on the southeast coast was examined by Courtney et al. (2012) who concluded they are based on 'erroneous interpretations of evidence' and 'that there is little reliable evidence to support the hypothesis that repeated large scale (mega) tsunami have occurred' on the NSW/southeast coast. The use of similar types of evidence to suggest mega-tsunamis have occurred on the central to northwest WA coast is likewise flawed in its interpretation.

Clarke et al. (2014) examined five historic landslides on the east Australian continental slope between Noosa and Yamba. Based on these they modelled potential tsunami hazard assuming a certain slide velocity and predicted such landslides could generate flows depth to between 5 and 10 m at the coast which could extend 1 km inland. Power et al. (2018) expanded on this investigation to include southern NSW and suggested that major earthquakes could trigger the landslides which may have an ARI of between 1500 and 15,000 years. While the above suggests that large tsunami could occur on the southeast coast, no evidence has been found to show they have occurred.

16.4.7 Rivers

Around the southern province, the rivers are confined to the humid east and southwest coasts, with all the Bight coast devoid of rivers and even streams. In total there are just over 1000 rivers and streams reaching the coast including several larger river systems (Fig. 1.9); however, most are small and ephemeral, with many flowing into ICOLs and few delivering bedload to the coast. Because the Great Dividing Range is located close to the east coast, most of the southeastern rivers have relatively small catchments and consequently, combined with climate, have relatively small and episodic discharges. Where they are larger as in the case of the Murray-Darling, it is located in a semi-arid region, also resulting in low discharge. Only a handful have managed to infill their estuaries or build a delta at the coast. In the central and southeast regions, the largest river in NSW is the Clarence, with a catchment of 22,200 km^2, compared to 142,000 km^2 for the Fitzroy in QLD. In eastern VIC the largest is the Snowy (15,096 km^2), the remainder all relatively small, while in Tasmania the Derwent (9718 km^2) is the largest of the island's generally small river systems. Most flow into drowned river valleys and are still infilling their estuaries and do not deliver bedload sediment to the coast. The only river of note on the south coast is the Murray-Darling with a massive, though largely semi-arid, catchment of 1.06 M km^2. Despite its size, its low rainfall and now substantial damming and water extraction, result is in it being unable to maintain an open mouth, while its bedload is deposited in Lake Alexandria. Between the Murray and the Blackwood River at Augusta, is 3256 km of coast without a significant river (Fig. 1.9) or even permanently open stream, a reflection of the aridity, with the central Nullarbor limestone having no surface drainage. The humid southwest rivers are also relatively small, the largest being the Blackwood (22,550 km^2) and the Swan (18,440 km^2), which flows into the Swan estuary. Further north in the central west are the larger Murchison (89,184 km^2), Woonamel (40,500 km^2) and Gascoyne (78,548 km^2) rivers. However, all have increasingly drier catchments and usually only flow following cyclone rainfall events. The Gascoyne has however built a substantial delta at Carnarvon and is a major source of sand for the downdrift beaches, barriers and dunes, as will be discussed in Chap. 33.

16.4.8 Sediments

The southern coast has two distinct sediment provinces. Along the humid southeast coast including eastern TAS and in WA's humid southwest, the sediments are quartz-rich, being delivered to the coast at low sea levels by the rivers mentioned above. These sediments have then been reworked and transported onshore by waves during and subsequent to the PMT to build the beach, barrier and estuarine systems. As Fig. 1.10 illustrates the entire east coast and southwest tip is dominated by low carbonate (<20–30%) quartz-rich beach sands, while the remainder of the coast is dominated by carbonate-rich beach sands (60–80%). The carbonate sediments are derived from three main sources: the shelf, seagrass meadows and coral reefs. The inner shelf is a major source of carbonate material, as is discussed in Sect. 16.5. In low energy seagrass meadows, shells and detritus from molluscs and other epifauna are transported shoreward across the tidal flats to be deposits on the flats and at the shore as coarse carbonate detritus. On the northern central west Ningaloo coast, fringing coral reefs are eroded and their detritus delivered to the shore as coarse coral and algal detritus. Most of the carbonate-rich areas also coincide with arid to semi-arid regions where there is little or no supply of terrigenous (quartz) sediment to the coast, further enhancing the predominance of the local carbonate material. The regional nature of the coastal sediments and their sources will be discussed in more detail in the following chapters.

16.4.9 Estuaries and Deltas

The humid areas of the southern province, namely, the entire southeast coast, the Tasmanian and Victorian coasts and the southwest of WA, have numerous streams and small- to moderate-sized rivers, most of which flow into WD barrier estuaries and coastal lagoons (ICOLs) and a few of which have developed WD deltas (Table 1.4). The nature of these estuaries and deltas is discussed in Sect. 1.6.3. The estuaries act as sinks for fluvial bedload material which is deposited as bayhead deltas, with some of the finer sediments being deposited in the central estuarine mud basin or exported offshore. At the seaward end marine sands fill the entrance as flood tide delta and barrier deposits. While all estuaries have these basic components, their dimensions are pre-determine by the size and morphology drowned river valleys and/or blocking barriers, and their degree of infilling or maturity a function of their size/accommodation space and receipt of sediments. Consequently, their size, morphology and maturity vary considerably around the southern coast. The generalised distribution of these systems and their evolutionary sequence is shown in Figs. 1.33 and 1.34 respectively.

16.4.10 Sediment Transport

The moderate to high southerly wave energy around southern Australia is responsible for massive rates and volumes of sediment transport to and along the open coast. In general sediment moves northwards up the southeast and southwest coasts at rates up to 500,000 m^3 $year^{-1}$ to ultimate sinks at Fraser Island and the Zuytdorp Cliffs/Shark Bay, respectively (Fig. 1.28). Across the long southern coast sediment is predominately moved onshore (northwards) to fill the massive Murravian Gulf and supply sand to the thousands of beach-barrier systems, including the largest transgressive dunes in Australia. Sediment supply and transport within each of the regions, PCs and SCs, will be discussed in the following chapters.

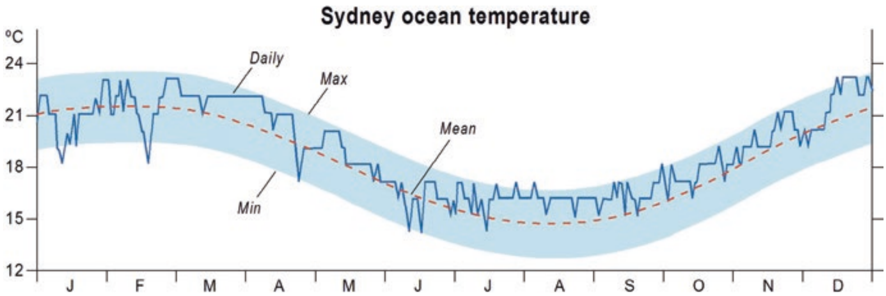

Fig. 16.5 Sea surface temperature at Sydney showing the seasonal and daily variation. (Source: Short and Woodroffe 2009)

16.4.11 Sea Temperature

Sea surface temperature around the southern coast is controlled primarily by latitude, with influence from the major ocean boundary currents. Figure 1.17 illustrates the latitudinal gradation in temperature and its seasonal variation. During summer, the southern temperatures range from high of 22–24 °C off southeast Queensland and Exmouth to a low of 14–16 °C in southern Tasmania. During winter these drop to 20–22 °C in the north and 10–12 °C in the south. On both the east and west coast, the impact of the warm EAC and Leeuwin currents is apparent from the poleward dip in water temperature extending down both coasts. Regionally there is warmer water during summer in the shallow SA gulfs (up to 24 °C), while they have cooler water during winter (down to 12 °C).

In addition to the regional and seasonal temperature variations, local winds can induce upwelling and downwelling that can result in the temperate varying by a few degrees in a matter of hours. Figure 16.5 shows the monthly, seasonal and daily variation in sea surface temperature at Sydney. The cooler spikes in the records are due to upwelling events when cooler bottom water upwells at the coast, while the warmer spikes reflect downwelling events, when warmer surface water flows towards the coast. Similar events can occur around much of the coast as local winds drive the surface waters offshore or onshore.

16.5 Biological Processes

Coastal biota is a major contributor to the southern Australian coast, with the main coastal ecosystems associated with the coastal dune vegetation, mangroves, seagrass and shelf biota, each of which is briefly discussed below.

16.5.1 Coastal Dune Vegetation

Australian coastal dune systems have by global standards robust vegetation that has adapted to the harsh marine impacted environment and thrived. As a consequence, Australian dunes are largely well vegetated and stable, particularly compared to similar coastal environments, at similar latitudes and climates elsewhere, which lack robust vegetation. Figure 16.6 illustrates a typical NSW coastal dune sequence from the bare beach, though the low grassy incipient foredune, to the higher shrub-covered foredune and backing well-vegetated and forested hind dune. All the species are endemic to the sand dunes and thrive in this generally harsh (swash, wind

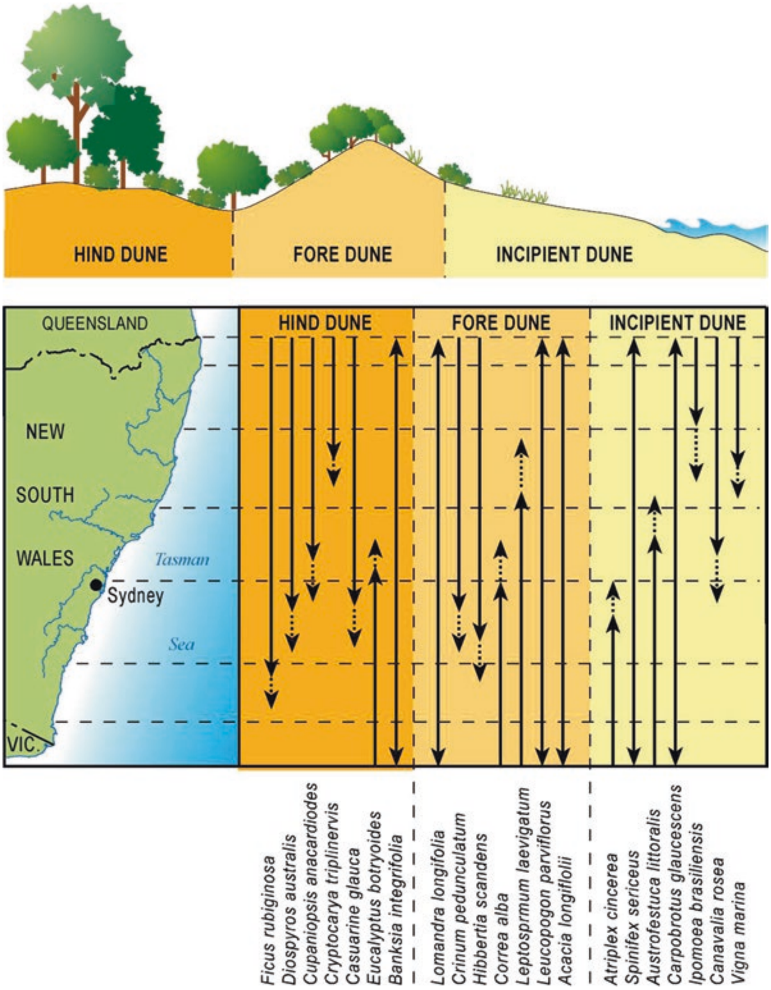

Fig. 16.6 Dominant species on NSW coastal dunes, showing both the landward transition and latitudinal extent of some species. (Source: Short and Woodroffe 2009)

and salt) and unfertile environment. This NSW example is representative of the structure of southeast coastal dunes including TAS and the humid southwest of WA, though as indicated the actual species will change with latitude and region.

Dunes across the more arid southern and western coasts have adapted to the drier environment, and while in general similar to the NSW example, they tend to have hardier plants, particularly on the foredune where saltbushes dominate, while the only tree to grow on the hind dune is the desert mallee species. However even in the most arid parts of the coast, including the hot desert environments along the Exmouth coast, the dunes remain relatively well vegetated and generally stable, with spinifex dominating the primary species.

The high level of stability allows the gradual formation of dune soils (pedogenesis) which further assists in the stabilization of the dunes. Along the humid southeast coast, rainwater leaching through the dunes over many thousands of years forms podzolic soils. These consist of a thin organic-rich A horizon and deep leached B horizon where the humid acids slowly dissolve and remove carbonate material and iron staining from the quartz sand, leaving near pure white quartz grains, a process that takes 10,000's years. The leached material is deposited at the water table and impregnates the sand with the dark organic material, commonly called 'coffeerock' (Figs. 1.31 and 16.7a; Thom et al. 1992, p 88). Lord and Burgess (1987) investigated the erodibility of indurated sand and found it was extremely variable in nature, making it difficult to define its engineering strength and properties. Along the more arid south and west coasts where the dunes are carbonate-rich and the climate semi-arid, the combination of porous carbonate sand and low rainfall leads over many thousands of years to the formation of calcrete soils (Arakel 1982). These have a hard (~1 m) thick cap of massive calcrete, with nodular calcrete below which grades into partly lithified dune sand (Fig. 16.7b) leading to the formation of aeolian calcarenite, commonly known as dunerock. Once formed these hard dune surfaces when exposed can form reefs, island, islets, cliffs and hard surfaces within the dune fields, all of which have major ongoing impacts on the entire suite of coastal morphodynamics (Short 2002, 2013). Calcrete formation is discussed by Arakel (1982, and the global distribution of dune calcarenite (eolianite) is presented by Brooke (2001).

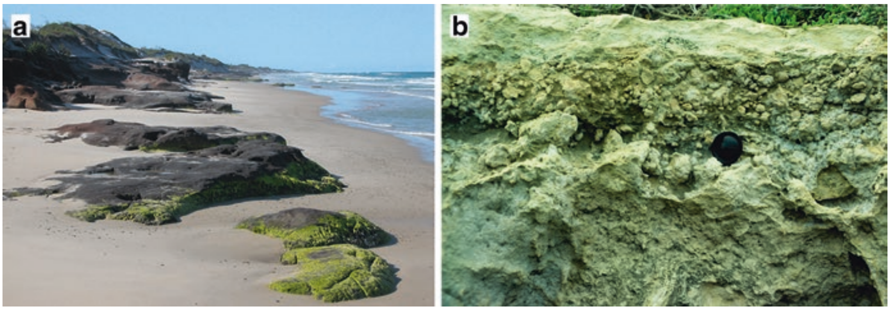

Fig. 16.7 (**a**) Massive coffeerock 2 m thick on the NSW north coast (NSW 35); and (**b**) an upper calcrete surface showing the massive then nodular calcrete over root casts. Lens cap for scale. (Photos: AD Short)

16.5.2 Mangroves

Mangroves are found in estuaries around much of the southern mainland coast but are absent along 2500 km of the coast between Davenport Creek in SA and Bunbury in WA and all of TAS. The number of species and their biomass is latitudinally controlled, with *Avicennia* the only species in south WA, SA and VIC. Species numbers increase northwards reaching two in southern NSW and eight in Moreton Bay on the east coast but only two in the central west of WA (Table 2.10). While small in area and representation (2640 km^2 and 12%; Table 2.9), compared to northern Australia, they still play a major role in estuarine ecology as well as helping to stabilize the estuarine shores.

16.5.3 Seagrass Meadows

Temperate seagrass meadows occur in sheltered open coast locations and in all estuaries right around the southern coast (Tables 2.11 and 2.12; Larkum et al. 2018). On the energetic southeast coast, they are largely restricted to estuaries; however, across the southern coast, they proliferate in the sheltered SA gulfs and bays, along much of the reef-sheltered western Nullarbor coast and right up the reef-sheltered south-central WA coast, reaching their pinnacle in the massive Shark Bay meadows, which at 4800 km^2 in area are the world's largest.

Seagrass meadows play three roles at the coast. They provide a rich coastal ecosystem; they help stabilize the sandy seabed, thereby decreasing sediment transport and locking sediment on the bed; and their ecosystem maintains a range of epifauna which supplies carbonate detritus to the coastal sediment budget (Fig. 16.8). All sand flats and beaches adjacent to meadows are supplied with epibiota detritus material produced in situ and reworked onshore by waves and tides. The seagrass meadows are the major source of sand for the low energy seagrass-fringed systems right around the southern and western coast and responsible for extensive carbonate banks-sand flats and associated regressive shell-rich beach ridge systems.

16.5.4 Shelf Biota

The exposed southern Australian continental shelf is a high energy wave swept shelf. It is also host to a range of epifauna that grow across the shelf including molluscs, red algae, bryozoans, sponges, benthic forams and echinoids (Fig. 16.9a). These organisms are eroded by waves, particularly during high wave events out to depths of 130 m (Fig. 16.9b). The detritus is eroded, abraded, sorted and transported landward from about 70 m depth. It arrives at the shore as usually fine to medium sand grains, ranging in size from fine to coarse and colour from white to brown

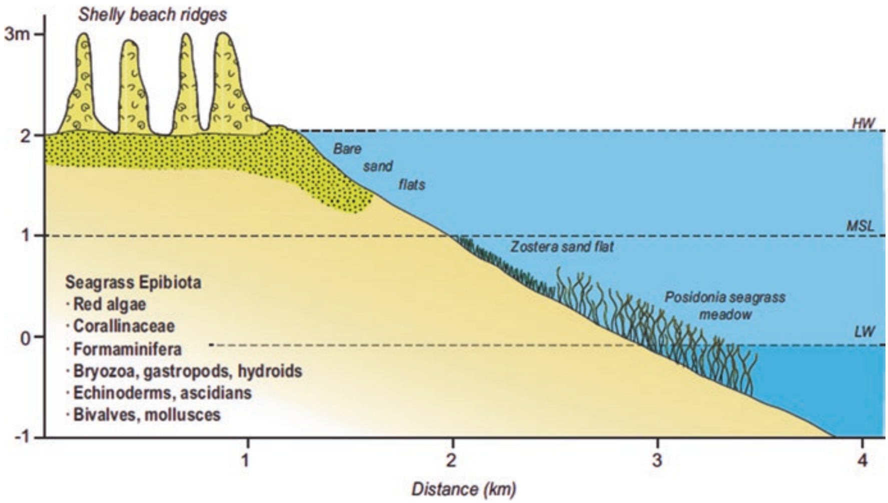

Fig. 16.8 Schematic cross-section of a typical low energy southern Australian coast seagrass temperate meadow dominated by Zostera and Posidonia seagrasses. The seagrasses grow inter to subtidally and here are backed by ~1 km wide sand flats, then shelly beach ridges. Hard detritus from the meadows supplies sand and gravel to the flats and ridges. (From: Short 2002)

(Fig. 16.10), illustrating both the range in source material and the selective sorting, transport and deposition that takes place across the shoreface. This material has supplied the bulk of the sediment to the thousands of beach and massive barrier and dune systems that typify the exposed energetic sections of the southern and western coast.

16.5.5 Coral Reefs

Coral reefs occur in three restricted locations on and off the southern coast. Off the east coast, the reef on Lord Howe Island at 31°S is the most poleward fringing reef in the world and its neighbouring Balls Pyramid (31.7°S) with the most poleward submerged reef (Linklater et al. 2016), due in part to the warm water it receives from the EAC (Fig. 1.18). On the central WA coast, Ningaloo Reef is the most poleward continental fringing reef in the world extending to 24°S, while offshore the Houtman Abrolhos is one of the most poleward ocean reefs extending to 29°S. The western reefs owe their origin in part to the warm Leeuwin Current which brings warm tropical waters down the west coast (Fig. 1.18). The Ningaloo reef is also assisted by the total lack of runoff which allows the reef to grow right to the shore on this hot arid desert coast, unlike the GBR reefs which are located 10's to 100's km offshore of the humid QLD coast. The Ningaloo Reef fringes the coast for 300 km as a near continuous reef located between 0.1 and 6 km offshore, with a shallow lagoon in between. This system will be discussed in Chap. 33.

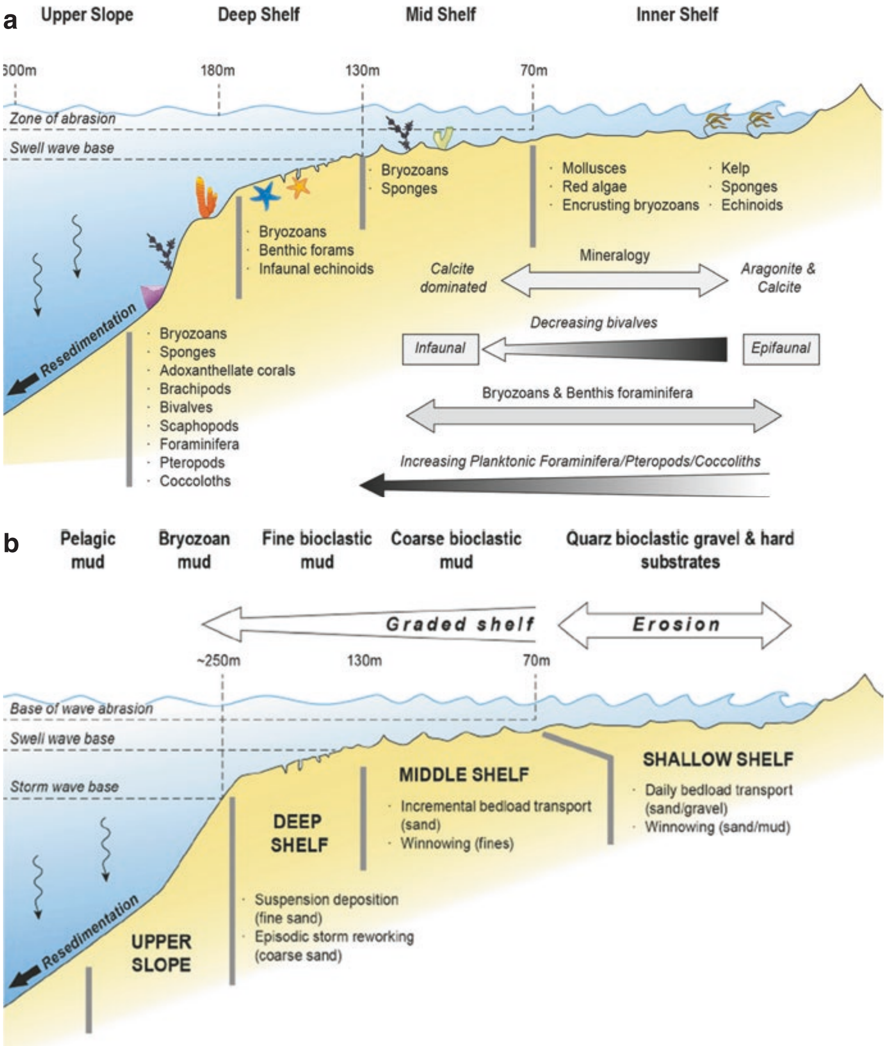

Fig. 16.9 (**a**) typical species types and zonation across the southern Australian shelf; and (**b**) hydrodynamic zonation and sediment type, grading and transport on the southern Australian shelf. (From: Short 2013, based on Boreen et al. 1993)

16.6 Summary

The great temperate southern province is both great in its extent (15,311 km) and its exposure to the world's highest energy and most persistent wave environment. The high waves have combined with the considerable shelf supply of sediment to build not only thousands of beaches, but also in combination with strong onshore wind

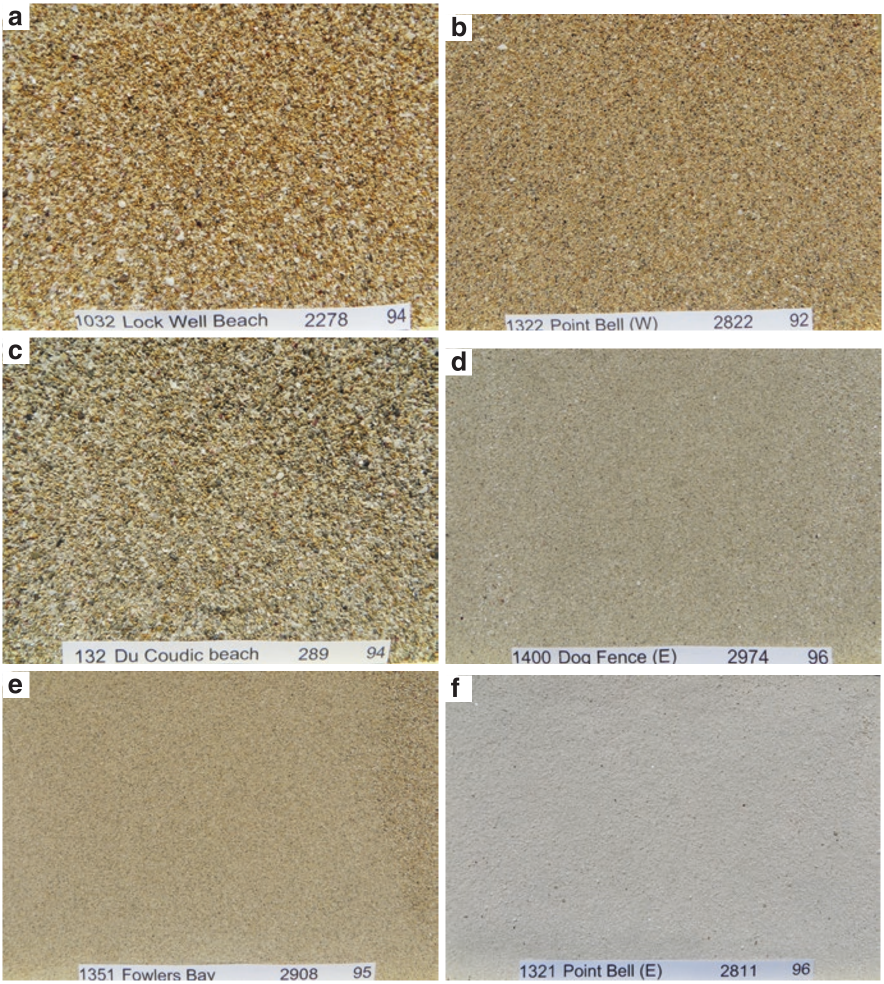

Fig. 16.10 Six beach sand samples from SA's western Eyre Peninsula (SA03), ranging from 92% to 96% carbonate and illustrating the range in size (0.15–0.45 mm) and colour of the carbonate-rich sands. Tags indicates SA beach number, name, km distance and percent carbonate. (Photos: AD Short)

the thousands of barrier systems including some of the world's largest deposits of marine sand. The long coast also has a variable geology and is exposed to a range of climate regimes, wave-tide regimes and sediment sources, all of which combine to generate considerable local and regional variability in beach and barrier type and extent. The following chapters will explore in more detail the nature of these systems that make up the southern regions, PCs and SCs.

References

Arakel AV (1982) Genesis of calcrete in quaternary soil profiles, Hutt and Leeman Lagoons, Western Australia. J Sediment Petrol 52:9–125

Boreen T, James N, Wilson C, Heggie D (1993) Surficial cool-water carbonate sediments on the Otway continental margin, southeastern Australia. Mar Geol 112:35–56

Brooke B (2001) The distribution of carbonate eolianite. Earth Sci Rev 55:135–164

Clarke S, Hubble T, Airey D, Yu P, Boyd R, Keene J, Exon N, Gardner J, Ward S (2014) Morphology of Australia's eastern continental slope and related tsunami hazard. In: Krastel S et al (eds) Submarine mass movements and their consequences, Advances in natural technological hazards research 37. Springer, Dordrecht, pp 529–538. https://doi.org/10.1007/978-3-319-00972-8

Courtney C, Dominey-Howes D, Goff J, Chagué-Goff C, Switzer AD, McFadgen B (2012) A synthesis and review of geological evidence of palaeotsunamis along the coast of southeast Australia: the evidence, issues and potential way forward. Quat Sci Rev 54:99–125

Larkum AWD, Kendrick GA, Ralph PJ (eds) (2018) Seagrasses of Australia: structure, ecology and conservation. Springer, Cham, 797 p

Linklater M, Carroll AG, Hamylton SM, Jordan AR, Brooke BP, Nichol S, Woodroff CD (2016) High coral cover on a mesophotic, subtropical island platform at the limits of coral reef growth. Cont Shelf Res 130:34–46

Lord DB, Burgess AL (1987) The erodibility of indurated sand. In: 8th Australasian conference on coastal and ocean engineering, Launceston, Institution of Engineers Australia, pp 160–164

Power HE, Wilson KM, Helfensdörfer, Mollison KC, Clarke SL, Hubble TCT (2018) Understanding submarine hazards to NSW. New South Wales (NSW) State Emergency Management Project (SEMP) 2017–2018, Sydney, Final Report, 144 p plus appendices

Provis DG, Radok R (1979) Sea-level oscillations along the Australian coast. Aust J Mar Freshwat Res 30:295–301

Shand TD, Goodwin ID, Mole MA, Carley JT, Browning S, Coghlan IR, Harley MD, Pierson WL, Kulmar MA (2010) NSW coastal storms and extreme waves. In: 19th NSW coastal conference, Batemans Bay, 14 p. http://www.coastalconference.com/2010/papers2010/Tom%20Shand%20full%20paper.pdf

Short AD (2002) The distribution and impacts of carbonate sands on southern Australia beach-dune systems. In: Magoon OT, Robbins LL, Ewing L (eds) Carbonate Beaches 2000. American Society of Civil Engineers, Reston, pp 236–250

Short AD (2005) Beaches of the Western Australian Coast: Eucla to Roebuck Bay. Sydney University Press, Sydney, 433 p

Short AD (2010) Role of geological inheritance in Australian beach morphodynamics. Coast Engr 57:92–97. https://doi.org/10.1016/j.coastaleng.2009.09.005

Short AD (2013) Australia's temperate carbonate coast: sources, depositional environments and implications. In: Martini P, Wanless HR (eds) Sedimentary coastal zones from high to low latitudes: similarities and differences. Geological Society London, London. https://doi.org/10.1144/SP388.5

Short AD, Trenaman N (1992) Wave climate of the Sydney region: an energetic and highly variable ocean wave regime. Aust J Mar Freshwat Res 43:765–791

Short AD, Woodroffe CD (2009) The coast of Australia. Cambridge University Press, Melbourne, p 288

Thom BG, Shepherd M, Ly CK, Roy PS, Bowman GM, Hesp PA (1992) Coastal geomorphology and quaternary geology of the Port Stephens-Myall Lakes area. In: Department of Biogeography and Geomorphology, Monograph 6, Australian National University Canberra, 407 p

Wyllie SJ, Gorham DJ, Davidson PJ (1993) Understanding tidal anomalies along the NSW coast. In: 11th Australasian conference on coastal and ocean engineering, Townsville, Institution of Engineers Australia, pp 421–425

Chapter 17
Southeast Division

Abstract The southeast division commences at Fraser Island and extends down the southeast coast to Wilsons Promontory, across eastern Bass Strait and along the east Tasmanian coast down to South East Cape, a total shoreline distance of 4446 km. In doing so it shifts from a humid sub-tropical to a humid temperate climate, while the coast remains dominated by moderate to occasionally high southerly swell and micro-tides, resulting in predominately WD beaches. The Eastern Highlands parallel the mainland coast, and numerous small rivers and streams flow to the coast into estuaries building bayhead deltas with very limited modern bedload supply to the coast. Longer beaches in southeast Queensland and northern NSW give way to shorter embayed beaches in the south and Tasmania, apart from Gippsland's Ninety Mile Beach. Sediment transport is to the north, interrupted and contained in the south while bypassing headlands in the north to its ultimate sink at Fraser Island and beyond. This chapter reviews the physical and biological processes operating along the coast together with the beach and barrier systems.

Keywords Southeast Australia · Tasmania · Southerly swell · Micro-tides · Longshore transport · Beaches · Barriers

17.1 Introduction

The southeast division extends from Sandy Cape on Fraser Island (24.5°S) to South East Cape (43.6°S), the southern tip of Tasmania. On the mainland, it covers 2514 km of open coast between Fraser Island at South Point (39°S) on Wilsons Promontory (the southern tip of the mainland) and another 1097 km between Cape Portland (40.5°S), the northeast tip of Tasmania, and South East Cape at its southern tip. In addition, in Queensland it includes Fraser and Moreton islands and their 226 km of shore, five NSW bays (Port Stephens, Broken Bay, Sydney Harbour, Botany Bay and Port Hacking) with 202 km of shore, and 407 km of shore around the three east coast Tasmanian islands (Flinders, Maria, Bruny), in total 4446 km of shore containing 1645 beach systems (Table 17.1).

A. D. Short, *Australian Coastal Systems*, Coastal Research Library 32,
https://doi.org/10.1007/978-3-030-14294-0_17

Table 17.1 The southeast division and regions

Region/No.[a]	Region boundaries	Beach ID[b]	No. beaches	km[c]	Total km
Central east	Sandy Cape-Cape Hawke				
QLD05 and NSW01		Fraser and Moreton	25	226	226
		QLD 1528-1601	74	5618–6091	473
		NSW 1-200	200	0–560	560
	Region sub-total		*299*		*1259*
Southeast	Cape Hawke-Cape Howe				
NSW02		NSW 201-721	521	560–1592	1032
		NSW bays	119	202	202
	Region sub-total		*640*		*1234*
Gippsland	Cape Howe-South Point				
VIC01	*Region sub-total*	*VIC 1-106*	*106*	*0–449*	*449*
East Tasmania	Stanley Pt-South East Cape				
TAS01		TAS 1-565	565	0–1097	1097
		Tas islands	141	407	407
	Region sub-total		*706*		*1504*
Southeast division	Division total		1645		4446

[a]NCCARF compartment number
[b]ABSAMP beach ID
[c]Distances clockwise from state borders and from Cape Portland TAS

This is the most populated division containing the capital cities of Brisbane (2.4 M), Sydney (5 M) and Hobart (0.23 M), as well as the dozens of regional cities, towns, villages and communities spread along much of the coast, with a total population of several million people. As a consequence, it is also the most intensively developed and heavily managed section of the Australian coast. The coastal management is divided between the populated areas that are managed to ensure safe and sustainable coastal development and the vast reserve areas (national and marine parks and reserves) that are managed to maintain the natural coastal environments. In total while much of the coast is occupied and developed to varying degrees, approximately 1700 km (38%) including 44% of the NSW coast is held in reserves, together with several large marine parks.

The division contains four regions (Table 17.1): the central east region which includes the southeast Queensland coast and islands and northern NSW south to Cape Hawke; the southern NSW region covers the central-south NSW coast down to the border at Cape Howe; the Gippsland region includes the entire east Victorian coast down to South Point; and the east Tasmania region includes the east coast of Tasmania down to the southern tip at South East Cape including eastern Flinders, Maria and Bruny islands (Fig. 17.1). These four regions are unified in this division by their location on the southeast of the continent, extensive geological control, east

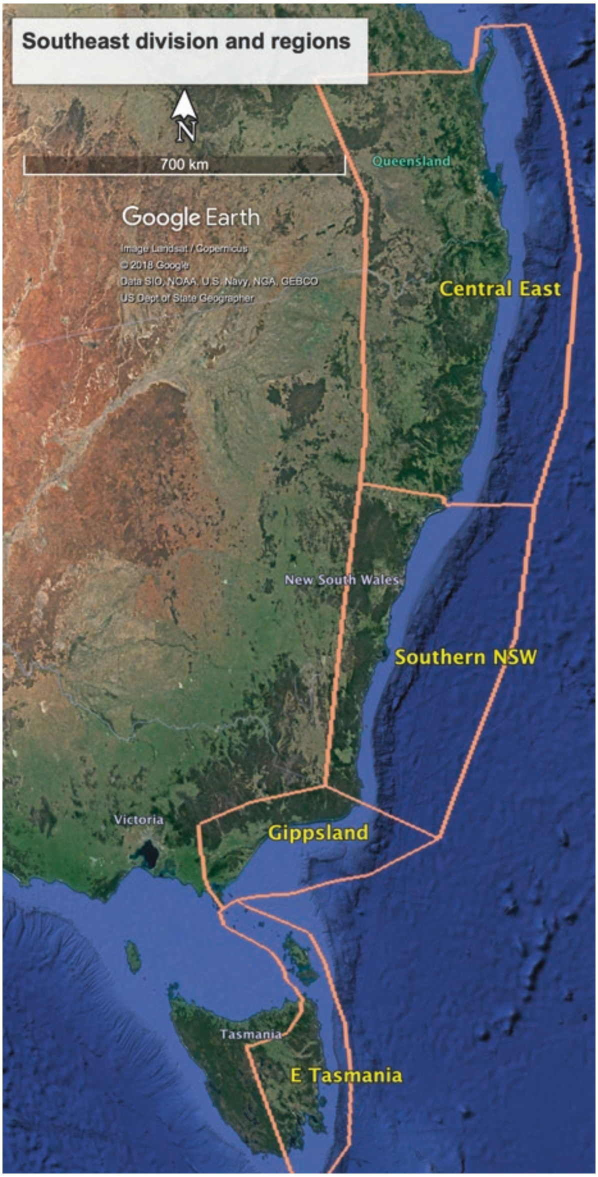

Fig. 17.1 The southeast division includes the entire Southeast Australian and NSW coasts and contains four regions – the central east, southern NSW, Gippsland and east Tasmania. (Source: Google Earth)

to southeast orientation, humid sub-tropical to temperate climate, micro-tides and receipt of predominately southerly swell. Each of the four regions will be discussed in the following four chapters (Chaps 18, 19, 20 and 21).

17.2 Geology

The eastern third of Australia consists of a series of mountain-building oregons that began east of the Tasman Line (Fig. 1.2) in the late Cambrian (600 Ma) and subsequently accreted the eastern third of Australia. Beginning in the west, the Kanmantoo Fold Belt was active between 500 and 330 Ma and extends from western TAS and western VIC up into western NSW. This was followed by the broad Tasman Fold Belt (530–200 Ma) which includes the granite-rich Thompson-Lachlan Fold belt that extends from QLD to TAS and the New England Fold belt that extends from Bowen to Newcastle which formed between 400 and 230 Ma. In between the twofold belts is wedged the narrow 1800 km long Sydney-Bowen Basin into which thick sediments were deposited between 270 and 180 Ma. During this entire period, Australia was located well to the south and formed the northern part of Gondwanaland.

The breakup of Gondwanaland commenced about 180 Ma and rifting along the northwest of Australia started about 154 Ma and spreads counter-clockwise around the continent. Along the southern boundary rifting began about 100 Ma, switching to drifting about 43 Ma (Veevers 2000). As Australia drifted northwards, it gradually opened up the Southern Ocean. Between 85 and 60 Ma, rifting also occurred in the southern Tasman Sea which led to the separation of New Zealand from southeastern Australia and the opening of the Tasman Sea and formation of the NSW, eastern VIC and eastern TAS coast and uplift of the Eastern Highlands. The rifting continued north between 59 and 50 Ma leading to the opening of the Coral Sea and formation of the east QLD coast (Fig. 13.3). The two periods of rifting also resulted in uplift of the Eastern Highlands and associated volcanic activity along the Great Dividing Range.

Today the southeast coast, beginning in southeast QLD, consists of a series of blocks and basins including the Maryborough Basin centred on Hervey Bay, the Gympie and Nambour Blocks along the Sunshine Coast and southern Gold Coast and the Beenleigh Basin centred on Moreton Bay. In NSW the Clarence-Moreton Basin extends down the coast to Yamba, followed by the rugged New England Fold Belt down to Newcastle. The horizontally bedded sedimentary rocks of the Sydney Basin occupy the coast down to Durras, south of which the rugged Lachlan Fold Belt dominates the coast down to southern TAS including Flinders Island. In VIC it forms the hard granitic-metamorphic Croajingolong and Wilsons Promontory coasts, with the low sedimentary Gippsland Basin in between, and the submerged Bass Basin occupying much of Bass Strait. For a more detailed summary of the regional geology, see Roy (1998) and Douglas and Ferguson (1976).

The geology has had a profound impact on the coast. Directly it controls the overall coastal orientation and relief and the size and shape of the coast valleys and estuaries, with the more rugged and resilient fold belts generally having higher, steeper relief and narrower valleys and estuaries and consequently shorter beaches and barriers, compared to the basin coasts, with the Gippsland Basin coast bordered by the Ninety Mile Beach, one of Australia's longest beaches. Indirectly, the denudation of the Eastern Highlands since their uplift 60 Ma has not only carved out the coastal valleys, estuaries and embayments but has supplied sediment to the coast, in particularly the quartz sand eroded from the granite belts as well as the Sydney Basin sandstones. This material dominates the coastal sand of the southeast division, together with a smaller percentage of heavy minerals also eroded from the granite belts (Veevers 2015).

An interesting feature of the coast is the generally steep and deep inner shelf. Thom et al. (2011) examined the evolution of the rock-dominated Sydney coast, a coast with cliffs, rock platforms, buried valleys, bedrock-bound inner to mid-shelf and an outer shelf sediment wedge. They proposed a model of inner shelf-cliff evolution that commenced ~30 Ma in the mid-Oligocene and involved marine planation of the shelf as the rocks were 'peeled back' at a rate of ~1 mm year^{-1} and the detritus transport both longshore and seaward. They also suggested that a similar marine abrasion surface may extend the full length of the southeast coast from Fraser Island to Wilsons Promontory.

Ferland and Roy (1997) cored the central NSW shelf and found that while the inner shelf was quartz-rich, the outer shelf went through phases of cool-water carbonate production. The production occurred at sea-level lowstands when biogenic sand and shell gravel are produced, with the last sequence dating 27–13 ka. During highstands these are replaced on the outer shelf by the deposition of finer-grained carbonate. This also implies that during lowstands the fluvially supplied terrigenous quartz material is not deposited on the outer shelf owing to drier conditions and low runoff.

Kinsela et al. (2017) report that sediment cover across the inner shelf is relatively thin, except where drowned coastal barriers and shelf sand bodies (SSB) have accumulated, with an abrasion surface extending along 300 km of the central to southern NSW coast. Further, they found the extent of the marine abrasion surface off the Sydney coastline suggests that many central and southern compartments may be sediment deficient offshore. These two papers indicate that much of the NSW shelf is swept clear of inner shelf sediment by high wave events, similar to the 'shaved' high-energy southern Australian shelves (James et al. 1994).

17.3 Climate

The Southeast Australian climate is controlled by its latitude (24.5–43.6°S) and the two major pressure systems, the dominating sub-tropical high centred at 30–36°S and the midlatitude cyclones, centred between 50 and 60°S. The highs bring calm, sunny weather with a generally lighter easterly flow of air, peaking with the afternoon sea breezes particularly during summer. The lows deliver a strong west through south flow of cooler, moist air and can penetrate the south of the continent, particularly during winter (Fig. 1.4). In addition, east coast cyclones (EEC) form off the NSW coast throughout the year and when close to the coast bring strong onshore winds, heavy rain and high seas.

The southeast coast has a humid climate that ranges from sub-tropical in southeast QLD to temperate in TAS (Cwa to Cfb). Rainfall occurs year-round with a summer maximum (Table 16.2). Highest rainfall occurs in the Coffs Harbour region (1400 mm), decreasing to 1000 mm at Brisbane and 1200 mm at Sydney. It continues to decrease down the coast to 770 mm at Merimbula and 500 mm at Hobart (Fig. 1.5a, b).

Temperatures are highest in the north averaging 30 °C during summer in Brisbane decreasing to 26 °C at Sydney and 23 °C at Hobart, while in winter these cities have a winter maximum of 22, 16 and 13 °C, respectively (Fig. 1.5c, d).

The dominant winds are controlled by great counter-clockwise spiralling subtropical high (Fig. 1.4). In the north at Maryborough, the 09.00 h winds are from the southeast to south, shifting to south southwest to at Brisbane, to the west-northwest at Sydney, west at Sale and northwest at Hobart. The 15.00 h winds reflect the impact of the sea breeze being predominately east to southeast at Maryborough, east-northeast at Brisbane, northeast though to south in Sydney, bimodal west and east at Sale and northwest and southeast at Hobart. The strong westerly component at Sale and Hobart is driven by the passage of westerly fronts associated with the passage of the midlatitude cyclones. The only predominately onshore winds are in the north (Maryborough) which represent the southern tail of the southeast trade winds and which are responsible for the massive southeast Queensland sand islands. For most of the southeast coast, the dominant strong winds flow offshore, apart from the lighter onshore sea breezes. For this reason, coastal dunes are limited in their location and extent, with large dune systems only occurring on south-facing section of the coast, which receive southwest though southeast winds, such as the Myall Lakes, Stockton Bight, Kurnell and Wreck Bay dunes in NSW, the Cape Howe-Rame Head dunes in Eastern Victoria and the Peron dunes in northeast Tasmania.

17.4 Coastal Processes

The southeast coast is unified by a relatively uniform range of coastal processes including predominately moderate southerly waves, micro-tides and west though south winds.

17.4.1 Waves

Waves along the entire southeast coast are predominately from the south. Figure 16.2 illustrates the three cyclonic sources for waves arriving at Sydney as well as the latitudinal variation in number of storms and their source along the coast, while Fig. 17.2 provides a more detailed view of the major storm types along the coast, subdividing Short and Woodroffe (2009) four types into eight. It also details the latitudinal trends in storm type and their monthly variability. Note the southerly decrease in tropical

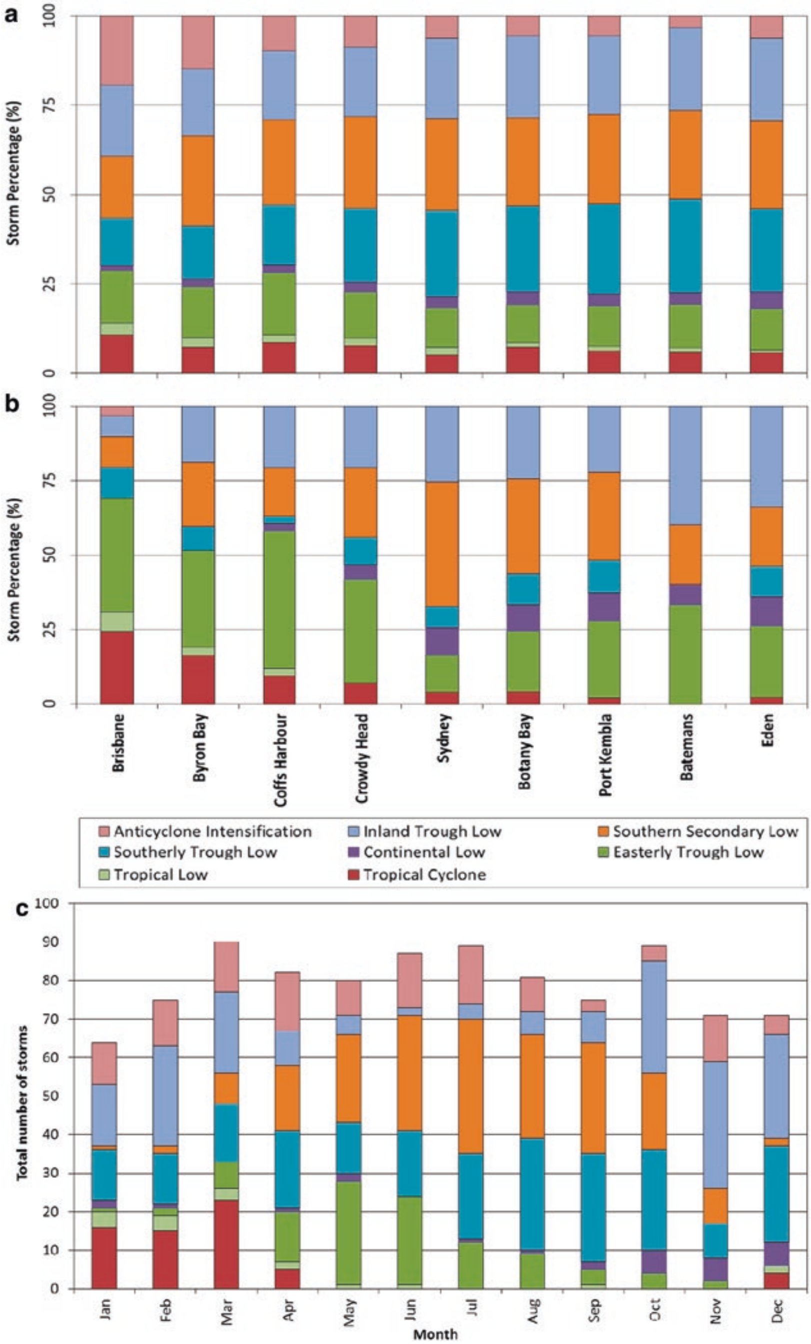

Fig. 17.2 Storm type by percentage for NSW nine waverider buoys for (**a**) all storms, (**b**) for storms >5 m and (**c**) for each month. (Source: Shand et al. 2010)

Table 17.2 NSW wave-generating sources and wave characteristics on NSW coast

Source	Location	Wave height	Wave period	Wave direction
Cyclonic				
Tropical cyclones[a]	Southern Coral Sea	2–3 m	9–10 s	NE
East coast cyclones	Central Tasman Sea	2–4 m	10–12 s	E
Midlatitude cyclones	Southern Tasman Sea	1–3 m	10–14 s	SE
High pressure				
High-pressure systems	Southern coral-Central Tasman seas	0.5–1.5 m	9–10 s	E
Sea breeze[a]	NSW coast	0.5–1 m	6–8 s	NE

[a]Summer only

cyclone and anticyclone storms and maximum of EEC (Southern Secondary Lows) off Sydney. Kulmar (1995) reports that at Sydney, higher waves from the south though southeast wave arrive 58% of the time, with moderate waves from the east through northeast arriving 39%. The waves are derived from five sources listed in Table 17.2. The predominately southerly swell is generated in the southern Tasman Sea and Southern Ocean by the passage of the midlatitude cyclones, which cross south of Australia at a rate of one every 3–4 days (Fig. 16.3). They generate long (8–12 s), moderate south swell (averaging 1–1.6 m) up the east coast reaching the mainland coast as far as Round Hill. These waves arrive at least 200 days of the year. ECC's occur on average ten times each year and deliver easterly waves on average 55 days a year, which at Sydney average a high 2.8 m. Tropical cyclones impact the coast on average 18 days a year and generate northeast to east waves which decrease in height as they travel down the coast (Short and Trenaman 1992). The two other sources of waves are associated with the highs. During summer the highs facilitate the generation of onshore sea breezes which deliver low, short northeast-east waves at Sydney on average 13 days each month. The final source occurs when the high occasionally intensifies and produces strong northeast winds ('black nor'easters') which can generate northeast seas up to 3 m high.

Shand et al. (2010) investigated the source and occurrence of storms ($H_s > 2$ m, over 3 days) on the NSW coast since 1971 and provide the most recent assessment of the type of storms, their seasonality and frequency of occurrence between Brisbane and Eden. They found tropical cyclone and anticyclone intensification impacts decrease to the south, ECC peak in the Sydney region, while midlatitude cyclones have maximum impact in the Sydney region decreasing to the north and south (Fig. 17.2). Likewise, Morim et al. (2016) assessed wave energy potential along the NSW coast and found in peaked in Sydney-Newcastle region, decreasing slightly to the north and south. They also found little seasonal variability in wave energy south of Cape Byron, with variability increasing significantly north of the cape into southeast Queensland.

In a more detailed analysis of the southeast coast wave climate, Mortlock and Goodwin (2015) identified five synoptic-scale wave climates during winter and six during summer, which can be clustered into easterly (trade wind), southeasterly (Tasman Sea) and southerly (Southern Ocean) wave types, each with distinct wave signatures. Goodwin (2005) also identified that wave direction was modulated by trans-Tasman mean sea-level pressure (MSLP), with positive MSLP (cool sea surface temperatures (SST) in SW Pacific) significantly correlated to southerly Sydney mean wave direction; while negative MSLP (warm SST in SW Pacific) is significantly correlated to easterly waves, with direction shifting from 124° to 145°. The shift in direction has implications for both longshore sand transport and beach rotation along the entire coast. Goodwin et al. (2016) also predict that the climate induced tropical expansion will result in a 2.5° poleward shift in the east Australian storm wave climate which will have the overall impact of reducing headland bypassing and northerly longshore sand transport along the central-northern NSW coast.

The NSW coast experiences occasional severe wave attack usually from ECC's, and particularly when a sequence of cyclones occur close together as in 1974 (Foster et al. 1975; Lord and Kulmar 2000; Bryant and Kidd 1975; McLean and Thom 1975) or from an unusual direction as in 2016 (Mortlock et al. 2016; Harley et al. 2017), with You and Lord (2005) finding a strong correlation between the storms and La Nina cycles. These events generated the greatest beach erosion and are the most damaging on the coast.

Browning and Goodwin (2016) examine the occurrence of ECC's since 1851 and found they are more frequent during periods of relatively warm SST in the southwest Pacific and negative Interdecadal Pacific Oscillation (IPO). They also found that during high frequency storm periods, there is a clear clustering of storm types and tracks and latitude of maximum intensification. They recoded the stormiest periods between 1870 and 1880, and 1950s to early 1970s, with below average activity since 1976. Helman and Tomlinson (2018) also examined the role of the IPO over the past two centuries and found that periods of suppressed sea level, beach accretion and drought were associated with strongly positive IPO, while higher sea level, increased storminess and beach erosion were associated with strongly negative IPO. They also found that during the period of positive IPO, since 1974 when accretion would be expected, there has been erosion, especially at the southern end of compartments and suggests that this may be attributed to rising sea level. This however may also be attributed to the northerly beach rotation that also accompanies positive IPO and has been reported for much of the coast (Harley et al. 2011; Short et al. 2014).

The NSW Office of Environment and Heritage (OEH) maintains seven waverider buoys between Byron Bay and Eden which continuously recoded ocean waves. These are managed by the Manly Hydraulics Laboratory and the results displayed in real time as well as summarised at their website (http://new.mhl.nsw.gov.au/data/realtime/wave/). These results clearly show the dominance of 1–2 m, south though southeast swell with periods of 8–12 s occurring throughout the year, with a slightly more easterly (sea breeze) component during summer, particular towards the north. While these record deepwater waves only, Kinsela et al. (2014) developed a coastal wave model that predicts nearshore wave condition along the NSW coast.

17.4.2 Tides

Micro-tides prevail along southeast coast apart from small sections in southeast Queensland and Bass Strait (Fig. 17.3). The tide arrives from an amphrodomic system located southeast of New Zealand, with the tidewave approaching parallel to the south-east coast and arriving almost simultaneously along the TAS, VIC and NSW coast, with a 30-min delay in reaching the southeast QLD coast and a 2-hr delay in reaching Wilsons Promontory (Fig. 17.3). Mean spring range is 1.8 m at Brisbane, 1.3 m down most of the NSW coast and 1 m at Gabo Island, increasing at the southern end of Ninety Mile beach to reach 2 m at McLaughlin Inlet and 3 m at Wilsons Promontory. Along Tasmania's east coast, it fluctuates between 1.1 and 1.3 m (Fig. 17.3). The micro-tides are due in part to the relative steep, narrow continental shelf along the southeast coast, which results in little amplification of the tides, except when entering the shallow Moreton Bay (Brisbane) and eastern Bass Strait, where they are amplified to meso. Tidal currents flood to the north and ebb to the south, with the northerly component assisting the northward wave-driven transport of sediment on the inner shelf.

17.4.3 Ocean Currents

The EAC is the dominant current flowing down the southeast coast. It is a warm western boundary current originating in the Coral Sea, with an injection of warm water from the GBR lagoon. It flows as a continuous current travelling at up to

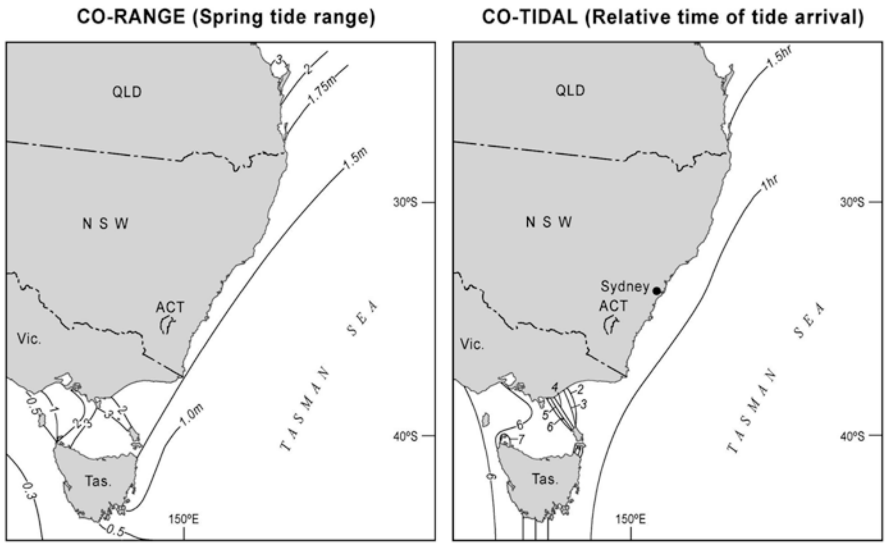

Fig. 17.3 Co-range and co-tidal lines for Southeast Australia. (Source: Short 2007)

7 km h^{-1}, down along the edge of the continental shelf until Seal Rocks, south of which it breaks into 100 km wide clockwise rotating warm-centred eddies (Fig. 1.18), that meander to the southeast. The core of the current however continues south to Tasmania, bringing warm water down the entire east coast (Fig. 1.17).

As discussed in Sect. 16.4.11, upwelling and downwelling occur along the southeast coast. Upwelling is associated with stronger northerly winds, particularly associated with strong hot summer northwesterlies. These winds push the surface waters offshore, which are replaced by cooler bottom water, dropping the temperate a few degrees in a matter of hours. Downwelling occurs when strong southerly winds drive the warm EAC waters towards the shore, raising water temperate by a few degrees. As Fig. 16.5 indicates, these can occur on a regular basis throughout the year, with the strongest upwelling associated with the strong summer northwesterlies.

17.4.4 Sea Surface Temperature

Sea surface temperatures along the southeast coast are controlled by receipt of solar radiation which is dependent on latitude, modified by the EAC which brings warmer water down the coast, and locally by upwelling and downwelling events which can last a few days. Figure 1.17 shows the summer and winter sea temperatures along the southeast coast, which range from north to south between 26 and 14 °C in summer and 22 and 12 °C in winter, with upwelling-downwelling events changing the temperate by a few degrees when they occur. Figure 16.5 also illustrates the seasonal lag in sea temperature, with the maximum reached in February and the minimum in August.

In recent years there has been an increase is sea surface temperature down the entire east coast, which has been linked to climate change. The temperature has been increasing at a rate of 0.1–0.15 °C 10 $year^{-1}$ since 1970, which equated to 0.4–0.6 °C over the past 40 years (Bureau of Meteorology). This rise is enabling tropic marine species to move south, while in Tasmania it has been attributed to the die-off the giant kelp forests, which cannot tolerate the warmer water.

17.4.5 River and Estuaries

The combination of a humid coast rising into the Eastern Highlands has produced numerous coastal streams and rivers draining to the southeast coast (Fig. 1.9). However, owing to the close proximity of the highlands to the coast, their catchments are relatively small in size, with no large southeast coast rivers. Table 17.3 lists the larger rivers down the southeast coast, with the largest the Clarence having a catchment of only 22,220 km^2 and most substantially smaller. Of the rivers listed, only the Shoalhaven and Towamba, and possibly the Moruya and Snowy, are delivering bedload sediment to the coast, with the remainder still infilling their estuaries.

Table 17.3 Major southeast division and regional river systems (catchment >1000 km²)

Region/river	Catchment (km²)
Region QLD05	
Brisbane	13,643
Logan	3822
Region NSW01	
Tweed	1126
Richmond	6878
Clarence	22,220
Nambucca	1341
Macleay	11,273
Hastings	3700
Manning	8080
Region NSW02	
Hunter	21,437
Nepean	21,909
Shoalhaven	7326
Moruya	1500
Tuross	1811
Bega	1956
Towamba	1063
Region VIC01	
Snowy	15,096
Gippsland Lakes	20,449
Region TAS01	
Derwent	9718

Table 17.4 Southeast coast estuarine types

	Drowned valley	Barrier estuary	Coastal lagoon	Total
SE QLD	0	14	0	14
NSW	13	60	110	183
E VIC	0	22	12	34
E TAS	24	48	11	83
Total	37	144	133	314

As a consequence, there has been little terrigenous bedload delivered to the southeast coast during the Holocene.

There are however over 300 estuaries along the southeast coast (Table 17.4), which based on the length of the coast are located on average every 8 km. The OEH estuarine database (http://www.environment.nsw.gov.au/estuaries/list.htm) lists 183 estuaries along the NSW coast ranging from large downed river valleys like Sydney Harbour to small coastal lagoons like Dee Why, while the ABSAMP database contains 176 estuaries. Table 17.4 is compiled from the OEH and ABSAMP databases and Creese et al. (2009) and shows the number of estuarine types by states in the southeast regions. Most of the estuaries are barrier estuaries, connected to the sea via a permanently open inlet. These tend to have larger coastal lagoons and a sufficiently large tidal prism which enables them to remain open. Next are the coastal lagoons which periodically open and close and are often referred to as ‘intermittently closed and open coastal lagoons’ (ICOLS). These tend to have smaller catchments and lagoons with smaller tidal prisms which result in their being close on a regular basis, usually only opening during and following lagoon flooding. The drowned river valleys tend to be the largest, like Broken Bay and Sydney Harbour, and are always open. Note that estuarine classification varies between sources and Table 17.4 should be taken as a guide only and may differ from other sources, particularly in the number of estuaries.

Because of the large number of estuaries along the southeast coast, they play a very important role in the coastal morphodynamics as well as providing habitats for a range of fresh though brackish to marine organisms. For this reason, all estuaries and their habitats are protected and usually managed through estuarine management plans. Their role in coastal morphodynamics is largely related to the fact they act as a sink for marine sands, which are driven though their entrances/inlet by waves, flooding tides and surges and deposited as flood tide deltas (Fig. 1.34). The deltas represent a loss of marine sand to the estuary and from the coastal system, a process that has been occurring throughout the Holocene. In a handful of instances, sand has been dredged from flood tide deltas to nourish adjacent beaches, as has occurred in the case of Port Hacking-Cronulla and the Tweed-Gold Coast.

17.4.6 Coastal Sediments

As stated above very little Holocene sand has and is presently being delivered to the southeast coast via the river systems, with the river and streams for the most part still infilling their estuaries which act as sinks for marine sand. As a consequence, sand along the southeast coast has largely been sourced from the continental shelf, with most being transport shoreward during and following the PMT. The shelf sand is predominately fine to medium quartz grains that has been delivered to the shelf by rivers and streams at lower levels of the sea and deposited on the present shelf as river beds, bayhead deltas, floodplains, flood tide deltas, deltas, beaches, dunes, barriers, SSB’s and nearshore sands. As sea level rose, waves eroded and reworked these features and transported their sand-sized material shoreward. As sea level reached its present level about 7–6.5 ka, this sand was deposited as beaches, barriers, flood tide deltas and SSB’s. There is abundant evidence along the southeast coast that the sea-level stillstand was accompanied by a substantial supply of marine sand, a supply which continued until the inner shelf sources were either depleted and/or an equilibrium profile achieved (see, e.g. Thom 1974; Oliver et al. 2017; Kinsela et al. 2016). Where this has not been achieved, there is evidence sand is still being supplied to the shore in some locations, including northern NSW (Patterson 2007).

17.4.7 Longshore Sediment Transport

The southeast coast is part of one of Australia's major longshore sand transport systems, with sand originating as far south as eastern VIC being transported, with major temporal and spatial interruptions, all the way to Fraser Island and beyond (Veevers 2015). The predominant southerly waves along the southeast coast maintain a net northward transport of sand along the coast. However, the embayed nature of much of the coast, particularly south of Evans Head, results in two types of beaches: drift-aligned and swash-aligned (Sect. 1.6.1). Drift-aligned beaches are those where the predominant southerly waves arrive at a slight angle to the shore resulting in a net northerly drift. These tend to occur on the longer north NSW and southeast QLD beaches, Ninety Mile beach in Victoria and some of the longer beaches in northeast TAS. Sand is moved along these beaches, primarily in the energetic surf zone. Where headlands pose obstacles to this transport, they may be bypassed subaqueously and/or over overpassed by dunes. Bypassing has been recorded on most northern NSW and southeast QLD headlands including Cape Byron, the Tweed-Snapper Rocks, Point Lookout, Cape Moreton, Double Island Point and Indian Head (see, e.g. Short and Masselink 1999; Goodwin et al. 2006, 2013), while dune overpassing has occurred on parts of the eastern Gippsland and NSW-QLD coast. Rates of longshore transport up to 500,000 m^3 $year^{-1}$ have been calculated for the Tweed system, with the sand continuing at varying rates ultimately to Fraser Island where it moves pass the northern tip at Sandy Cape along Breaksea Spit and then is lost down the continental slope to the abyssal plain (Boyd et al. 2008; Fig. 18.2). Some of the sand however also appears to make its way via Great Sandy Strait into Hervey Bay and north to Rodds Bay, with Veevers (2015) finding evidence of NSW heavy minerals on Hummock Hill Island, approximately 2000 km north of potential southern sources.

The most comprehensive review of longshore sand sources and transport on the NSW coast was undertaken by Chapman et al. (1982). They examined the entire NSW coast and mapped the nature and occurrence of obstacles to longshore sand transport. They classified the obstacles as partial, major or complete, which in this book are termed open, leaky or closed to transport. These obstacles can result from the presence of a major headland, such as Long Reef Point in Sydney, and/or the fact the beach is swash-aligned. This implies that refraction of the southerly waves causes them to arrive parallel to the shore causing no net longshore transport. Because of the more deeply embayed nature of much of the central-southern NSW coast, many of the beaches are swash-aligned, which combined with the numerous headlands and estuaries essentially precludes longshore transport for much of the central-southern NSW coast. In general transport is continuous, though interrupted, north from Wooli up to the Tweed. South of Wooli to Cape Hawke, there are series of leaky compartments with limited north transport, while south of Cape Hawke down to Cape Howe, the compartments are primarily swash-aligned and closed, with very limited net northerly transport.

On Ninety Mile Beach, sand moves northward along the beach with apparent bypassing of Red Bluff, Cape Conran, Rame Head and other smaller headlands with the sand ultimately reaching Cape Howe where it is deposited in a large SSB between the Cape and Gabo Island (Ferland and Roy 1997) as well as overpassing the cape into NSW (Fig. 20.4a). While rates have not been calculated, they are expected to be on the order of 100,000's m^3 $year^{-1}$. South of Ninety Mile Beach, the few beaches on the rugged Wilsons Promontory are deeply embayed with no net transport. The east Tasmanian coast has some longer beaches north of Bicheno which may be experiencing northerly longshore transport. To the south the beaches are more embayed with numerous headlands and estuaries and generally swash-aligned, particularly south of Cape Tourville with the SCs and TCs having a range of leaky to closed boundaries.

The above reports on longshore sand transport at present sea level. As Chapman et al. (1982) point out for most of the Quaternary sea level, it has been located between 40 and 60 m below present sea level on the mid-shelf. This is a region that has a more subdued topography which would result in fewer headlands, longer beaches and fewer estuarine sinks. It is therefore suggested that during the more frequent lower sea levels, northward sediment transport would have been more prevalent along more of the coast which includes the southern NSW coast, leading to higher rates of transport. If one considers the volume of the southeast Queensland sand islands and assumes they are Quaternary in age (~2 Ma), then the present maximum rate of 500,000 m^3 $year^{-1}$ would more than account for their estimate volume of 250 km^3 (Short and Woodroffe 2009), the excess lost down the continental slope and abyssal plain (Boyd et al. 2008) and further north on the mainland.

The net result is that sand has been delivered to the southeast shelf since the formation of the coast 60 Ma. During the Quaternary as sea level has oscillated across the shelf on a regular basin (see Fig. 1.42), sand has been moved northwards along the entire coast, with higher rates expected at lower sea level. There has therefore been considerable spatial and temporal variation in the shelf location, length and nature of the transport paths and rates of transport throughout the Quaternary. The ultimate sinks for this sand are no doubt off the northeast Tasmanian coast north of Eddystone Point and in Bass Strait, in east VIC off Cape Howe, and along the 2300 km long NSW-southeast Queensland coast including the southeast sand islands and their estuaries and ultimately Fraser Island, Breaksea Spit and the continental slope (Fig. 1.28), with sand also reaching as far as Rodds Bay, in all a ~2000 km long transport system.

In addition to longshore sand transport, most embayed southeast beaches also oscillate and rotate. Beach oscillation refers to the periodic erosion of the beach by high wave events and their recovery during following periods of lower waves. Some of the more energetic beaches oscillate up to 100 m, though a few 10's m is more common, all the while maintaining a stable net shoreline position. Beach rotation refers to the periodic accretion at one end of an embayed beach while the other end eroded and vice versa. On the southeast coast, this is driven by subtle changes in wave direction, with the usually southerly waves resulting in a northerly rotation, while more easterly waves result in a more southerly rotation. Rotation has been observed with period between 3 and 8 years which have in turn been related to changes in wave direction driven by the Southern Oscillation Index (SOI) (Short and Trembanis 2004; Harley et al., (2011) and the MSLP (Goodwin 2005). More recently Mortlock (2016) has found the rotation is more complex as a result of real-world shoaling processes, bimodal wave conditions and the emergence of different ENSO scenarios. He proposed a new paradigm with rotating nearshore wave direction driving longshore migration of surf zone morphological types.

A more detailed examination of longshore and other mode of sand transport will be provided in the following regional Chaps. 18, 19, 20 and 21.

17.5 Biological Processes

Coastal dune vegetation is the major biological system impacting the open southeast coast and its beach and barrier systems. Most southeast division dunes are well vegetated and stable, with only 9% unstable (Short 2010). Figure 16.6 provides a schematic of a typical stable dune system in NSW. This schema generally applies to the rest of the division, with some of the species changing with latitude. All southeast dune systems consist of the bare sand beach backed by an incipient foredune typically vegetated with grasses (*Spinifex sericeus*), succulents (*Cakile maritima*) and in the north creepers (*Ipomena brasilianis*) and other species. This is backed by the more stable foredune usually vegetated in shrubs, particularly *Acacia longifolia, Leptospermum laevigatum* and *Banksia integrifolia*, again with latitudinal variation. The stable and sheltered hind dune areas have a climax forest vegetation with trees, shrubs and ferns, typically composed of the following: ferns (Bracken *Pteridium esculentum*), shrubs (*Banksia serrata*) and trees (Bangalay *Eucalyptus botryoides*, Blackbutt *Eucalyptus pilularis* and Smooth Barked Apple *Angophora costata*) (see Carolin and Clarke (1991) for a detailed overview of southeast Australian dune plants and Doyle (2018) for an overview of NSW foredunes, their nature, vegetation, stability and degree of human impacts).

The other major coastal biota are the mangroves that occur in all the drowned river valley estuaries and many of the barrier estuaries, but not the coastal lagoons. There are six species in the north at Moreton Bay, two in southern NSW and only one *Avicennia maritima*, in VIC. The southeast mangroves extend down the coast as far as Corner Inlet, with none in TAS. VIC has 12 km^2 of mangroves, while West et al. (1984) mapped all the mangroves in NSW estuaries and found they total 107 km^2 in area with species increasing from one at Wonboyn in the south to five to the Tweed River. The southeast mangroves represent just 0.9% of Australia's mangroves.

17.6 Beach Systems

The southeast division (mainland, bays and islands) has a total of 2331 beaches which occupy 53% of the 4446 km of coast, with an average length of 1.26 km. They range however from pockets of sand <50 m long to the 125 km long Ninety

Table 17.5 Ocean beach number and length for the southeast regions and division

Region	Central east	Southern NSW	Gippsland	East TAS	Division
Beach number	299	521	107	565	1492
Beach length (km)	1008	448	352	383	2191
Total length (km)	1259	1234	449	1097	4039
Beach %	80	36	78	35	54
Mean (km)	2.9	0.86	3.3	0.7	1.5
Max length (km)	89	30	125	18	125

Mile Beach (Table 17.5). All the open coast beaches are exposed to a moderate to occasionally high-energy wave climate and micro-tides and are consequently WD. Within the micro-tidal but sheltered bays (Moreton Bay, Port Stephens, Broken Bay, Sydney Harbour, Botany Bay, Port Hacking) as sheltering increases and waves decrease, the beaches become increasingly TM to TD. The average beach length also reflects the degree of geological control, with the longest average beaches occurring in the central east (2.9 km) which include the long sand islands and longer northern NSW beaches, and Gippsland (3.3 km) with its long Ninety Mile Beach system and where beaches occupy 80 and 78% of the coast, respectively. The shortest average beaches are in the more geologically controlled and heavily embayed southern NSW (0.86 km) and east TAS (0.7 km), and where beaches occupy just 36 and 35% of their coasts, respectively (Table 17.5). Longshore sediment transport is also influenced by beach length with transport operating along the long Ninety Mile Beach and on to the regional boundary at Cape Howe, very limited transport between the short southern NSW beaches and an interrupted though continuous transport from northern NSW to the division boundary at Fraser Island as discussed above (Sect. 17.4.7). The beaches and their transport systems will be presented in Chaps 18, 19, 20 and 21 and are described for each of the southeast states in Short (1996, 2000, 2006, 2007).

17.7 Barrier Systems

There are 481 barriers located along the division which occupy 2042 km (46%) of the coast. They range from the world's largest sand island, the massive Fraser Island in the north, to the long narrow Ninety Mile Beach, to a range of regressive, stable and transgressive systems. Barriers have formed in many of the drowned valleys where they tend to be bordered by rocks and headlands. The longest and largest barriers have however been deposited along the open coast of the Gippsland Basin (Ninety Mile Beach) and on the southeast QLD mid-shelf, where they are anchored by bedrock points (the southeast QLD islands). Most of the northern NSW and southeast QLD barriers onlap and overlap older Pleistocene barriers, with Pleistocene deposits diminishing into southern NSW, but occurring again on the Gippsland coast. Roy and Thom (1981) developed a model of Late Quaternary marine deposition for the central east region which includes deposition in estuaries as flood tide deltas and as regressive and transgressive barriers.

Roy et al. (1995) identified six barrier types along the southeast coast, together with the SSB's, with the major barriers and SSB's mapped by Roy (1998). Figure 17.4 maps the location and type of barriers and SSB's along the southeast QLD and NSW coast. It shows the dominance of sediment-deficient barriers (mainland beaches, receded and stationary) along the steep central-southern NSW coast, with sediment-rich prograded and transgressive dune barriers dominating the lower gradient northern NSW and southeast QLD coast. It also shows location of SSB's which are linked to major headlands and changes in coastal orientation. Table 17.6 confirms some of these observations, with the largest barrier systems in terms of length, volume and per metre volume which are located in the central east region (0–900 km in Fig. 17.4), with their volume an order of magnitude greater than the southern NSW and Gippsland region and two orders of magnitude greater than the east TAS region. The per metre volume also decreased substantially from a high of 57,987 $m^3\ m^{-1}$ in the central east largely associated with the sand islands and well above the Australian regional average of 22,315 $m^3\ m^{-1}$ (Appendix 34.2) to a very low 2630 $m^3\ m^{-1}$ in east TAS, amongst the lowest regional averages in Australia. The details of these barriers and SSB's will be discussed in Chaps. 18 and 19.

17.8 Division Summary

The southeast division is unified by its sub-tropical to temperate humid climate, its overall geological control, its generally east to southeast orientation in a predominately micro-tidal, moderate wave energy and WD environment. Its sediments are largely shelf-derived quartz sand, and overall transport is both onshore and northerly. The PMT flooded a relatively steep inshore forming hundreds of drowned valleys and estuarine systems, together with rocky shore. The PMT stripped much of the inner shelf sand transporting it shoreward to build beaches and barriers occupying ~50% of the coast, together with hundreds of flood tide deltas and at least nine large SSB's (Fig. 17.4). The division is divided into four regions starting in the north with the generally longer southeast QLD and northern NSW beaches, with more active longshore transport, followed by the more rugged and embayed

Table 17.6 Southeast division and region barrier dimensions

Region	No.	Length	Volume (M m^3)	$m^3\ m^{-1}$
Central east	108	926	53,714	57,987
Southern NSW	199	409	6828	14,436
Gippsland	44	343	4436	12,932
East Tasmania	130	364	911	2630
Division	481	2042	65,889	32,266

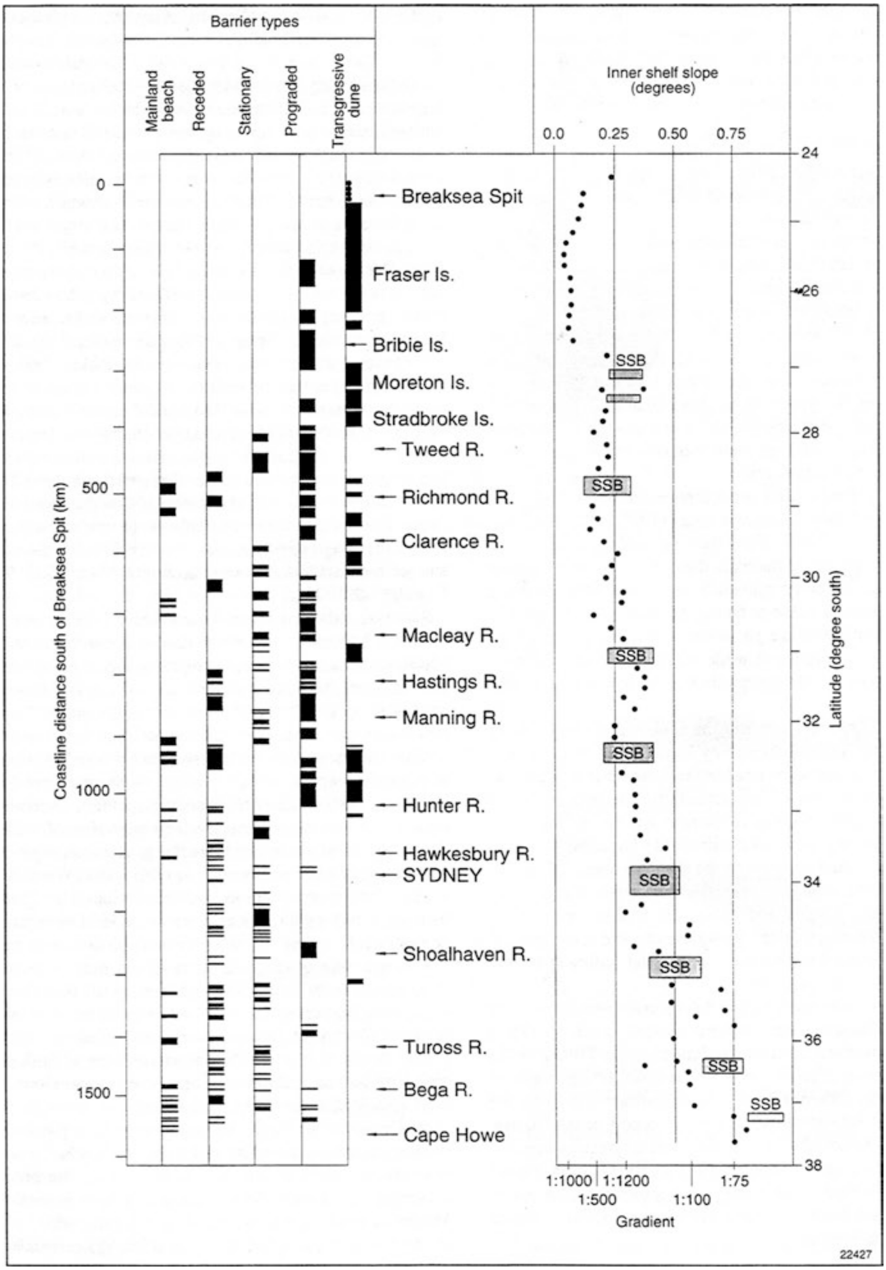

Fig. 17.4 Distribution of barrier types and SSB's in southeast QLD and NSW. (From: Roy 1998). (Reprinted with permission of the Geological Survey of NSW)

central-southern NSW, the south to southeast-facing Gippsland coast including the long Ninety Mile Beach and the rugged east Tasmanian coast, each distinctive, yet retaining their unifying features and processes. Each of these regions is presented in the following four chapters (Chaps. 18, 19, 20 and 21).

This is the most highly developed part of the Australian coast and as might be expected will have considerable exposure of land, property and infrastructure to the impacts of climate change, particularly sea-level rise and changes in wave climate. DERM (2011) predicts for coastal Queensland a 0.26–0.79 m sea level rise of by 2100, a 20 per cent increase in rainfall associated with tropical cyclones, changes in the regional and local frequency of tropical cyclones and an increase in both the mean and maximum wind speed of tropical cyclones in some locations. This will in turn lead to increased frequency of extreme sea-level events, increased coastal erosion, and increased risk of damage to property and infrastructure from inundation and erosion. In NSW where rising sea level and changing wave climate will have the biggest impacts, Kinsela et al. (2017) and Hanslow et al. (2018) mapped and quantified the potential impacts of coastal erosion and estuarine inundation for the entire NSW coast. Their results are presented in Sects. 18.9 and 19.9.

References

Boyd R, Ruming K, Goodwin I, Sandstrom M, Schroder-Adams C (2008) Highstand transport of coastal sand to the deep ocean: a case study from Fraser Island, Southeast Australia. Geology 36:15–18

Browning SA, Goodwin ID (2016) Large-scale drivers of Australian east coast cyclones since 1851. J South Hemisphere Earth Syst Sci 66:1250151

Bryant EA, Kidd RW (1975) Beach erosion, May–June, 1974, central and south coast, NSW. Search 6:511–513

Carolin R, Clarke P (1991) Beach plants of South Eastern Australia. Sainty & Associates, Potts Point, 119 p

Chapman DM, Geary M, Roy PS, Thom BG (1982) Coastal evolution and coastal erosion in New South Wales. Coastal Council NSW, Sydney, 341 p

Creese RG, Glasby TM, West G, Gallen C (2009) Mapping the habitats of NSW estuaries. Industry Investment NSW, Fisheries final report series No, 113, 95 p. http://www.ozcoasts.gov.au/geom_geol/nsw/DIIMappingNSWestuaries.pdf

DERM (2011) Queensland coastal processes and climate change. Queensland Climate Change Centre of Excellence, Department of Environment Resource Management, Brisbane, 49 p

Douglas JC, Ferguson JA (1976) Geology of Victoria, Special publication 5. Geological Society of Victoria, Melbourne

Doyle TB (2018) Foredune morphodynamics in southeast Australia: the roles of humans and vegetation. Ph.D. thesis, School Earth Environmental Science, University of Wollongong, 267 p

Ferland MA, Roy PS (1997) Southeastern Australia: a sea-level dependent, cool-water carbonate margin. In: James NP, Clarke JDA (eds) Cool-water carbonates. SEPM Society for Sedimentary Geology, Tulsa, pp 37–52

Foster DN, Gordon AD, Lawson NV (1975) The storms of May–June 1974, Sydney, NSW. Proceedings of 2nd Australian conference on coastal engineering, Gold Coast, Institution of Engineers Australia, pp 1–11

Goodwin ID (2005) A mid-shelf, mean wave direction climatology for southeastern Australia, and its relationship to the El Nino-Southern oscillation since 1878 AD. Int J Climatol 25:1715–1729

Goodwin ID, Stables MA, Olley J (2006) Wave climate, sediment budget and shoreline alignment evolution of the Iluka-Woody Bay sand barrier, northern NSW, Australia, since 3000 yr BP. Mar Geol 226:127–144

Goodwin I, Freeman R, Blackmore K (2013) An insight into headland sand bypassing and wave climate variability from shoreface bathymetric change at Byron Bay, New South Wales, Australia. Mar Geol 341:29–45

Goodwin I, Mortlock T, Browning S (2016) Tropical and extratropical-origin storm wave types and their influence on the East Australian longshore sand transport system under a changing climate. J Geophys Res Oceans. https://doi.org/10.1002/2016JC011769

Hanslow DJ, Morris BD, Foulsham E, Kinsela MA (2018) A regional scale approach to assessing current and potential future exposure to tidal inundation in different types of estuaries. Sci Rep, published online. 8:7065. https://doi.org/10.1038/s41598-018-25410-y

Harley MD, Turner IL, Short AD, Ranasinghe R (2011) A re-evaluation of coastal embayment rotation in SE Australia: the dominance of cross-shore versus alongshore sediment transport processes. J Geophys Res 116:F04033. https://doi.org/10.1029/2011JF001989

Harley MD, Turner IL, Kinsela MA, Middleton JH, Mumford PJ, Splinter KD, Phillips MS, Simmons JA, Hanslow DJ, Short AD (2017) Extreme coastal erosion enhanced by anomalous extratropical storm wave direction. Sci Rep. nature.com

Helman P, Tomlinson R (2018) Two centuries of climate change and climate variability, east coast Australia. J Mar Sci Eng 6:3. https://doi.org/10.3390/jmse6010003

James NP, Boreen TD, Bone Y, Feary DA (1994) Holocene carbonate sedimentation on the west Eucla Shelf, Great Australian Bight: a shaved shelf. Sediment Geol 90:161–177

Kinsela M, Taylor D, Treloar D, Dent J, Gaber S, Mortlock T, Goodwin I (2014) NSW coastal ocean wave model: investigating spatial and temporal variability in coastal wave climates. In: 23rd NSW coastal conference, Ulladilla, 19 p. http://www.coastalconference.com/project/papers-and-presentations/

Kinsela MA, Daley MJA, Cowell PJ (2016) Origins of Holocene coastal strandplains in Southeast Australia: shoreface sand supply driven by disequilibrium morphology. Mar Geol 374:14–30

Kinsela MA, Morris BAS, Linklater M, Hanslow DJ (2017) Second-pass assessment of potential exposure to shoreline change in New South Wales, Australia, using a sediment compartments framework. J Mar Sci Eng 5:61. https://doi.org/10.3390/jmse5040061

Kulmar MA (1995) Wave direction distribution off Sydney, New South Wales. In: 12th Australasian conference on coastal and ocean engineering, Melborune, Institution of Engineers Australia, pp 175–182

Lord D, Kulmar M (2000) The 1974 storms revisited: 25 years experience in ocean wave measurements along the south-east Australian coast. In: Proceedings of international coastal engineering conference, Sydney

McLean RF, Thom BG (1975) Beach changes at Moruya 1972–74. Coastal Ocean Engineering, Institution of Engineers Australia, National Conference Publication 72, 2:1–11

Morim J, Cartwright N, Etemad-Shahidi A, Strauss D, Hemer M (2016) Wave energy resource assessment along the southeast coast of Australia on the basis of a 31-year hindcast. Appl Energy 184:276–297

Mortlock T (2016) Impacts of enhanced Central Pacific ENSO on wave climate and headland-bay beach morphology. Cont Shelf Res 120:14025. https://doi.org/10.1016/j.csr.2016.03.007

Mortlock TR, Goodwin ID (2015) Directional wave climate and power variability along the southeast Australian shelf. Cont Shelf Res 98:36–53

Mortlock TR, Goodwin ID, McAneney JK, Roche K (2016) The June 2016 Australian east coast low: importance of wave direction for coastal erosion assessment Water 9, 121. https://doi.org/10.3390/w9020121

Oliver TSN, Tamura T, Short AD, Woodroffe CD (2017) Changing rates of sand deposition at Pedro Beach, southeastern Australia: implications for compartment-based management. Proceedings NSW Coastal Conference, Port Stephens. http://www.coastalconference.com/papers.php

Patterson DC (2007) Comparison of recorded Brisbane and Byron wave climates and implications for calculation of longshore sand transport in the Region. In: 18th Australasian conference on coastal and ocean engineering, Melbourne, Institution of Engineers Australia

Roy PS (1998) Cainozoic geology of the coast and shelf. In: Scheibner E (1998) Geology of New South Wales, Geological Survey NSW, Sydney, vol 2, pp 361–385

Roy PS, Thom BG (1981) Late quaternary marine deposition in New South Wales and southern Queensland – an evolutionary model. J Geol Soc Australia 28:471–4898

Roy PS, Cowell PJ, Ferland MA, Thom BG (1995) Wave-dominated coasts. In: Carter RWG, Woodroffe CD (eds) Coastal evolution: late quaternary shoreline morphodynamics. Cambridge University Press, Cambridge, pp 121–186

Shand TD, Goodwin ID, Mole MA, Carley JT, Browning S, Coghlan IR, Harley MD, Pierson WL, Kulmar MA (2010) NSW coastal storms and extreme waves. 19th NSW Coastal conference, Batemans Bay, 14 p. http://www.coastalconference.com/2010/papers2010/Tom%20Shand%20full%20paper.pdf

Short AD (1996) Beaches of the Victorian coast and Port Phillip Bay. Sydney University Press, Sydney, 298 p

Short AD (2000) Beaches of the Queensland coast: Cooktown to Coolangatta. Sydney University Press, Sydney, 360 p

Short AD (2006) Beaches of the Tasmanian coast and islands. Sydney University Press, Sydney, 353 p

Short AD (2007) Beaches of the New South Wales coast, 2nd edn. Sydney University Press, Sydney, 398 p

Short AD (2010) Sediment transport around Australia – sources, mechanisms, rates and barrier forms. J Coast Res 26:395–402

Short AD, Masselink G (1999) Embayed and structurally controlled beaches. In: Short AD (ed) Beach and shoreface morphodynamics. Wiley, Chichester, pp 230–250

Short AD, Trembanis A (2004) Decadal scale patterns in beach oscillation and rotation Narrabeen Beach, Australia- time series, PCA and wavelet analysis. J Coast Res 20:523–532

Short AD, Trenaman NL (1992) Wave climate of the Sydney region: an energetic and highly variable ocean wave regime. Aust J Mar Freshwat Res 43:765–791

Short AD, Woodroffe CD (2009) The coast of Australia. Cambridge University Press, Melbourne, 288 p

Short AD, Bracs MA, Turner IL (2014) Beach oscillation and rotation: local and regional response at three beaches in southeast Australia. J Coast Res 70:712–717

Thom BG (1974) Coastal erosion in eastern Australia. Search 5:198–209

Thom BG, Keene JB, Cowell PJ, Daley M (2011) East Australian marine abrasion surface. In: Bishop P, Pillans B (eds) Australian landscapes, Special Publication 346. Geological Society, London, pp 57–69

Veevers JJ (ed) (2000) Billion-year earth history of Australia and neighbours in Gondwanaland. Gemoc Press, Sydney, 388 p

Veevers JJ (2015) Beach sand of SE Australia traced by zircon ages through Ordovician turbidites and S-type granites of the Lachlan Orogen to Africa/Antarctica: a review. Austr J Earth Sci 62:385–408

West RJ, Thorogood CA, Walford TR, Williams RJ (1984) Mangrove distribution in New South Wales. J Coast Wetland Soc 4:2–6

You ZJ, Lord D (2005) Influence of the El Nino southern oscillation on storm severity along the NSW coast. In: 17th Australasian conference on coastal and ocean engineering, Adelaide, Institution of Engineers Australia, pp 389–392

Chapter 18
Central East Region

Abstract The central east region includes the southeast Queensland coast and sand islands and the northern NSW coast, a total coastline of 1260 km. This is a humid sub-tropical coast with several moderate-sized rivers and many streams draining from the Eastern Highlands to the coast, some building deltas, while most flow to estuaries. Coastal sediments are quartz-rich throughout. The coast is exposed to persistent moderate to occasional high southerly swell which drives a major northerly longshore transport system that extends all the way to Fraser Island and beyond. The transport is however interrupted by numerous headlands and inlets/estuaries including some massive tidal deltas. Wave-dominated sandy beaches occupy 80% of the coast, the beaches backed by the massive sand islands in the north, while there is limited barrier development in northern NSW. This chapter examines the nature of the beaches, barriers and sediment transport within a sediment compartment framework.

Keywords Southeast Queensland · Fraser Island · Northern NSW · Beaches · Barriers · Sediment transport · Sediment compartments

18.1 Introduction

The central east region includes the southeast Queensland coast and sand islands and the northern NSW coast south to Cape Hawke. The region contains one of Australia's longer and more interesting longshore sediment transport systems with sand eroded from the granite belt and sandstones of the eastern highlands being delivered by rivers to the NSW coast and then transported up the coast throughout the Quaternary to accumulate on the southeast Queensland coast and sand islands, in particular Fraser Island, the largest accumulation of marine sand on earth. While Fraser has trapped massive volumes of sand, some bypasses the island and is ultimately lost down the continental slope to the north of the island, thereby completing the transportation system that began more than 2000 km to the south. Transport through the system fluctuates at considerable spatial and temporal scales, with Quaternary sea-level oscillations controlling the temporal changes while coastal

A. D. Short, *Australian Coastal Systems*, Coastal Research Library 32,
https://doi.org/10.1007/978-3-030-14294-0_18

Table 18.1 The central east region and its six PCs (QLD05.0-03 and NSW01.01–03)

PC No.[a]	Name	Boundaries	Beach ID[b]	No. of beaches	km[c]	Total km
Central east QLD05 and NSW01						
QLD05.01	SE Islands	Sandy Cape-Skirmish Pt	Fraser Is 1-10	10	0–139	139
			QLD 1528-1556	29	5618–5792	174
QLD05.02	Moreton Bay	Skirmish Pt-Amity	QLD 1557-1579	23	5792–5985	193
QLD05.03	Moreton Is-Gold Coast	C Moreton-Pt Danger	Moreton Is 1-15	15	0–87	87
			QLD 1580-1601	22	5985–6091	106
NSW01.01		Pt Danger-Yamba	NSW 1-43	43	0–167	167
NSW01.02		Yamba-SW Rocks	NSW 44-137	94	167–368	201
NSW01.03		SW Rocks-Cape Hawke	NSW 138-200	63	368–560	192
			Islands	*35*		*226*
			QLD 1528-1601	*74*		*473*
			NSW 1–200	*200*		*560*
		Central east total		*309*		*1259*

[a]NCCARF compartment number
[b]ABSAMP beach ID
[c]Distance clockwise from state borders

geology (headlands, estuaries, etc.) and more recently human intervention (training walls, groynes, nourishment and sand bypassing) affecting the spatial variation.

This region contains 1259 km of coast between Sandy Cape at the tip of Fraser Island in QLD and Cape Hawke in NSW (Table 18.1). It consists of three systems, the roughly 400 km long southeast Queensland open coast section, including the islands, that trends essentially due south; the sheltered 240 km of shoreline in Moreton Bay located in lee of Bribie, Moreton and Stradbroke islands; and the northern NSW coast that trends south-southeast from the border at Point Danger for 560 km to Cape Hawke. The northern NSW coast has acted as a source, sink and conduit for sand transport throughout the Quaternary, at both high and low sea levels. Much of the sand originated in the adjacent eastern highlands, from where it has been eroded and transported by rivers to the coast and then transported northwards by waves into QLD. Along the northern NSW coast, much of the accommodation space was filled by Pleistocene deposits resulting in relatively little Holocene barrier deposition; however once past the Point Danger, considerable volumes of sand have been transported and deposited in the larger southeast estuaries (including Broadwater, Moreton Bay and Great Sandy Strait) and in particular the large bedrock-tied sand islands (Stradbroke, Moreton, Bribie, Cooloola and Fraser) where they blanket earlier Pleistocene deposits. The longshore transport system is however not continuous, particularly at present high sea level where it is interrupted by numerous headlands, rocky sections, trained river mouths and estuaries.

This region contains six PCs which are listed in Table 18.1 and illustrated in Fig. 18.1. In QLD, they include both the mainland coast and southeast sand islands, as well as Moreton Bay (PCs:QLD05.01–03) (Fig. 18.1a), while in NSW they extend down the coast to Cape Hawke as PCs:NSW01.01–03 (Fig. 18.1b). The nature of this region, its beaches, barriers, transport system and PCs and SCs is presented below.

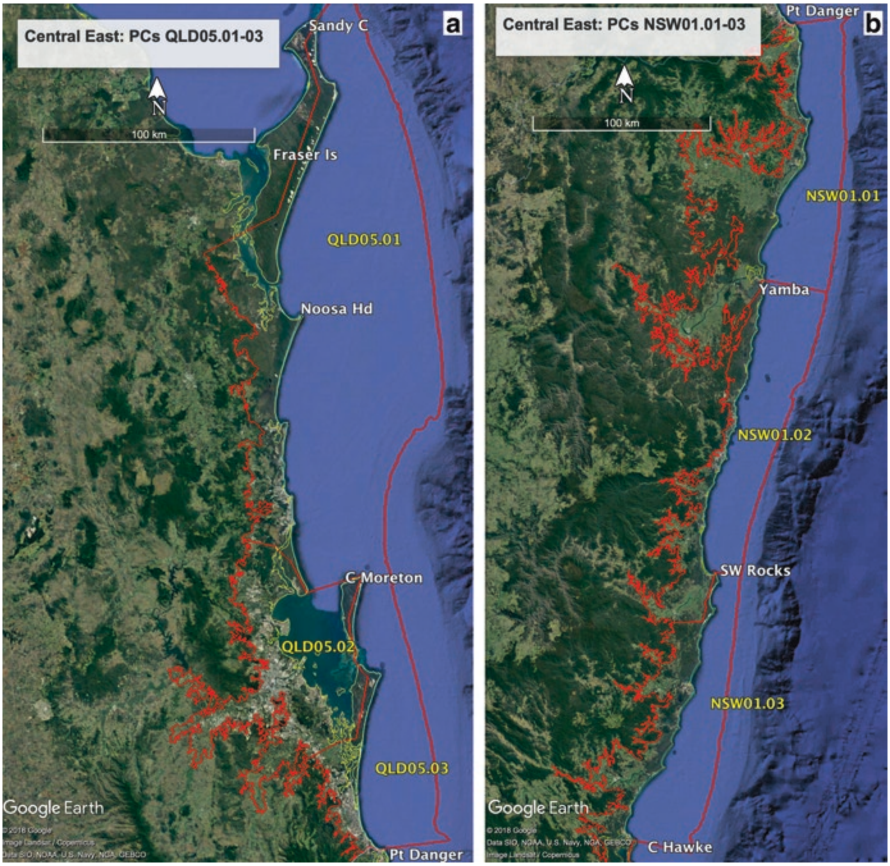

Fig. 18.1 Central east region and its six PCs located in (**a**) southeast Queensland (PC: QLD05.01-03) and (**b**) northern NSW (PC: NSW01.01-03). Red lines delineated PC boundaries, with inner red line outlining coastal river catchments. (Source: Google Earth)

18.1.1 Geology

As discussed in Sect. 17.2, the eastern highlands and New England Fold Belt parallel the central east region and have been a source of quartz sand that has been supplied to the coast. This is particularly the case in the Carboniferous granites that extends from inland of the Gold Coast down to Coffs Harbour. North of the Gold Coast are the sand-rich coastal lowlands of southeast Queensland including both the sand islands and the adjacent sandy coastal plain, known as the Wallum (Bryan and Coaldrake 1976). Their Quaternary history is described by Coaldrake (1960, 1962), while the Quaternary geology of the Sunshine Coast is described by Hekel and Day (1976), North Stradbroke Island by Whitlow (2000a) and the Gold Coast by Whitlow (2000b).

18.1.2 Sediments

Sediments have been delivered to this region since the formation of the coast and uplift of the eastern highlands ~60 Ma. The sand eroded from the highlands has been transported by coastal rivers (Table 17.3) to be deposited at the coast. This system has been operating throughout the Quaternary and probably back into the Tertiary, delivering a continuous stream of sand to the coast. Sircombe (1999) and Veevers (2015) investigated the age and origin of zircon, a heavy mineral found in the coastal sands and which originates in the same granite belts that supply the quartz sand. Veevers found zircon up to 700 Ma originated in the Lachlan Fold Belt, with younger 300–400 Ma-old zircon originating in the New England Belt. He also traced sand from as far south as Mallacoota in eastern Victoria, indicating this may be the most southerly source of the sand.

Veevers also found that some of the sand has been through three cycles of erosion-deposition. The oldest zircon-sand originated 1300-1000 Ma and 700-500 Ma in the Transgondwanan Supermountains atop the East African-Antarctic Supermountains. This material was deposited in the Sydney-Bowen Basin, lithified and subsequently eroded from the Triassic Hawkesbury sandstone. In southern NSW sand was added from the 400 Ma Bega-Moruya batholith (via Snowy, Towamba, Bega, Tuross, Moruya rivers) and the Sydney Basin (via the Shoalhaven, Nepean and Hunter rivers) and in northern NSW added from the 350-250 Ma New England Fold Belt (via Manning, Hastings, Clarence, Richmond and Tweed rivers) (Table 17.3; Fig. 18.2). The sand has been deposited at the coast as rivers, deltas and barriers spread from the present shoreline to the outer shelf. Once deposited it has been reworked onshore by multiple Quaternary sea-level oscillations and then alongshore by northerly wave transport, with numerous regional sinks and the ultimate sinks at Fraser Island and the shelf-slope, and along the mainland coast to at least Hummock Hill Island in Rodds Bay (Veevers 2015), a coastline distance from Mallacoota of roughly 2200 km (Fig. 18.2).

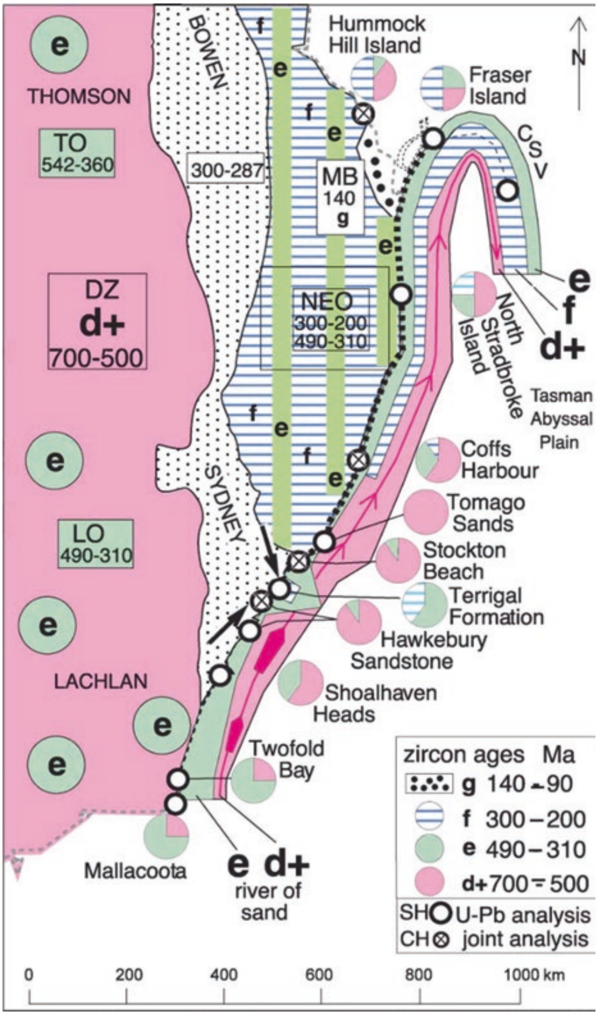

Fig. 18.2 Southeast Australia showing the age component of zircon in the coastal sand (pie diagrams) and its age and sources: (**e**) Bega-Moruya Batholith, (**e**–**f**) New England Oregon and (**d**) Lachlan Orogen. The sand is ultimately transported as far as Hummock Hill Island and Fraser Island where it flows over the shelf edge into the Tasman Abyssal Plain. (From: Veevers 2015)

Beach sand along the central east region is predominately very-well to well-sorted, fine to medium quartz sand grains (mean = 0.24 mm, $\sigma = 0.1$, sorting = 0.37), together with small percentage of carbonate (2–5%) and heavy minerals (Fig. 18.3; Table 18.2), the size distribution in agreement with You et al. (2014). The uniformity of this sand over a distance of 1200 km is an indication it is part of one continuous sediment system. The aberrations in the trends depicted in Fig. 18.3, where coarser carbonate-rich sand occurs, are all located along the rockier sections of

Table 18.2 Beach sand characteristics of central east PCs and region

	QLD05	NSW01	Central east
n	68	189	257
Size (mm)	0.25	0.24	0.24
σ (mm)	0.1	0.1	0.1
Sorting	0.36	0.38	0.37
σ (sorting)	0.14	0.42	–
Carbonate %	1.1	4.9	3.9
σ %	2.3	5.2	5.0
Range %	1–13	1–35	–

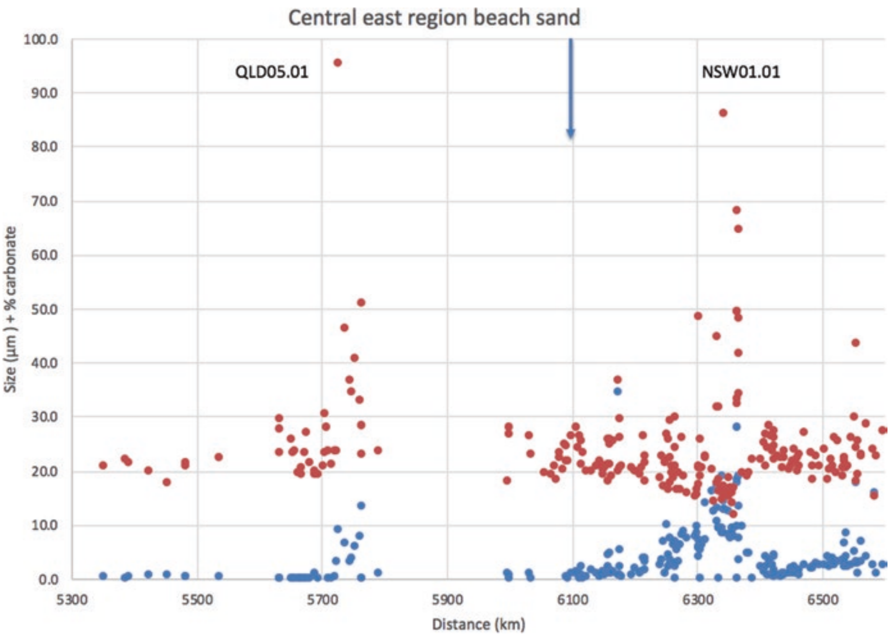

Fig. 18.3 Central east region beach sand size (µm, red) and % carbonate (blue). Distance is clockwise from NT/QLD border, with NSW distance (commencing at 6090 km – arrow) added to Queensland. See Table 18.1 for km distance for each of the PCs

coast centred on Caloundra (~5750 km) and Coffs Harbour (6310–6370 km). McKellar (1975) found that the beach sands from the Hawkesbury River north to Fraser Island are quartz-rich, with small percentages of heavy minerals dominated by rutile, zircon and ilmenite, but with little or no feldspars or other light minerals. As will be seen in the next three chapters (Chaps. 19, 20, and 21), similar fine-medium, quartz-rich sand extends all the way down the southern NSW and Gippsland coasts, extending this system into eastern Victoria, with similar sand also along the east Tasmania coast.

The open coast of the central east region is exposed to a relatively uniform microtidal regime and moderate to occasionally high energy wave climate, as discussed in Sect. 17.4. Mean spring tide range ranges from 1.8 m at Brisbane Bar to 1.3 m down the NSW coast (Fig. 17.2). Waves are predominately from the southeast with height increasing from a mean H_s of 1.2 km at Point Lookout to a maximum of 1.6 m at Sydney, with period between 8 and 12 s (Table 17.2).

The EAC flows down the coast, usually located just seawards of the continental shelf (Fig. 17.2). However, it can impinge on the coast, particularly at its most easterly points, Point Danger (Wyllie and Tomlinson 1989; Heron et al. 2001; Helyer et al. 2012) and Cape Byron (Gordon 1987; BMT WBM 2013b), which as will be seen can be a major impediment to longshore sand transport.

18.1.3 Beaches

There are 299 beaches along the central east coast. They average 2.9 km in length, twice the Australian average, and occupy 1008 km (80%) of the coast, well above the Australian average of 50%. The greater length of the beaches and their dominance is due to the large accumulations of near continuous sand on the sand islands and the generally larger coastal embayments along the mainland northern NSW and southeast Queensland coast that have infilled to form the generally longer beaches with fewer headlands and rocky sections of coast. The open coast beaches are entirely WD and predominately double-barred (Fig. 18.4), a product of the

Fig. 18.4 Typical double-barred beach on Cooloola (QLD 1531) with outer LBT and inner TBR. (Photo: AD Short)

Table 18.3 Central east region beach types and states

BS	BS	n	%	Total (km)	Mean (km)	σ (km)	% (km)
3	RBB[a]	17	5.7	137.9	8.1	21.4	13.7
4	TBR[a]	145	48.5	608.4	4.2	7.3	60.4
5	LTT	59	19.7	152.9	1.4	3.5	15.2
6	R	51	17.1	55.6	1.1	1.9	5.5
7	R + LTT	8	2.7	7.5	1.7	2.3	0.7
10	B + RSR	1	0.3	0.35	0.35	–	0.0
11	B + SF	17	5.7	37.0	2.2	2.5	3.7
12	B + TSF	1	0.3	8.5	8.5	–	0.8
		299	100	1008	2.9	–	100.0

[a]These are predominately inner bar states on a double-bar system, with LBT outer bar.

fine-medium sand exposed to a moderate to high wave climate in a micro-tidal regime. The outer bar is usually LBT and inner bar TBR-RBB (74%) a combination similar to that found by Short (1999, Fig. 7.15) for all NSW double-barred beaches. In contrast the sheltered shores of Moreton Bay have predominately TD with a few TM beaches (Table 18.3). See Short (2000, 2007) for a description of each of the region beaches.

18.1.4 Barriers

Most of the beaches along the central east coast are backed by barrier systems. The barrier can be divided into two sections, the massive QLD sand island barriers and the smaller Sunshine Coast, Gold Coast and northern NSW barriers. The QLD barriers occupy 435 km (62%) of the coast and in NSW 453 km (80%), with a combined regional total of 888 km and 70.5% of the coast, all well above the Australian average. The predominance of sandy shores is due to four factors: an energetic southerly wave regime to transport the sand northwards; a massive northern sediment sink that has accumulated an abundance of sand; the inner-mid shelf location of the sand islands, largely free of bedrock; and the broader northern NSW embayments leading to longer beaches and barriers. What however distinguishes the two sections are the size and volume of their respective barriers. The southeast Queensland barriers covers an area of 259,880 ha and have a volume 31,139 M m^3 (Table 18.4), compared to an area of 31,085 ha and volume of 3185 M m^3 for northern NSW, with the Queensland barriers an order of magnitude greater in size and volume. Essentially the NSW beaches act as a conduit and in places as a source for the sand, while it largely accumulates in southern Queensland where they represent the largest accumulation of marine sands on earth, roughly 238 km^3 (Table 18.5). Note that Table 18.5 represents the total Quaternary island volume, compared to Holocene only in Table 18.4.

Table 18.4 Central east: PCs QLDO5.01-03 Holocene barrier dimensions

QLD:05	QLD05.01	QLD05.02	QLD05.03	Total
No.	15	5	7	27
Total length (km)	293.1	51.6	90.7	435.4
Mean min width	530	400	1070	–
Mean max width	3500	3200	2600	–
Mean height (m)	10	5	12	–
Area (ha)	221,960	14,530	23,390	259,880
Unstable (ha)	15,000	600	2450	18,050
Total volume (M m^3)	23,363	330	8436	32,139
Unit volume (m^3 m^{-1})	79,710	640	65,564	73,791

Table 18.5 Southeast Queensland sand islands: Quaternary size and volume

Barrier sand island	Area (ha)	Volume (km^3)	Unit volume (m^3 m^{-1})	Ten episodes (m^3 m^{-1})	6000 year (m^3 m^{-1} $year^{-1}$)
Fraser	184,000	184	1,472,000	147,200	24.5
Cooloola	18,000	18	339,623	33,962	5.7
Bribie	15,000	0.8	24,194	2419	0.4
Moreton	14,530	8.7	228,947	22,894	3.8
North Stradbroke	26,000	26	684,211	68,421	11.4
South Stradbroke	1950	0.2	8478	847	0.1
Total	259,480	237.7	784,488	78,448	13.1

The extent and dominance of the southeast Queensland barrier is also evident in Fig. 17.4 which plots the barrier type and extent between Fraser Island and Cape Howe. The Queensland barriers are the largest and most extensive transgressive barriers, whereas northern NSW has predominately prograded and some stationary barriers. Roy et al. (1980) and Roy and Thom (1981) developed an evolutionary model for Late Quaternary marine deposition in southeast Queensland and NSW with most deposition occurring in regressive and transgressive barriers and estuarine flood tide deltas. The model fits within a framework of a stable shelf, inherited geological control, major Quaternary sea-level oscillations and wave-driven northerly sand transport with negligible fluvial input. Roy and Stephens (1980a, 1980b) examined the factors that influence the type of barriers in southeast Australia and found they are related to the degree of embaymentisation which determines whether the systems are open to bypassing or closed; wave energy which varies within embayments and delivers sand to the shore; offshore sand loss, as at Cape Byron; the inherited quartz sediment; and substrate control. These barriers are examined in more detail in the following sections.

18.2 QLD05 Southeast Queensland

Southeast Queensland coast (QLD05.01-03) consists of a 457 km long section of open coast containing the large Fraser Island; the Cooloola ‘island’; the Sunshine Coast; Bribie, Moreton and Stradbroke islands; and the Gold Coast, together with the sheltered Moreton Bay with 242 km of shore, in total 699 km of coast. The islands represent a large accumulation of sand derived and transported from the NSW coast. They dominate the open coast with Fraser Island (125 km long), Cooloola (59 km), Bribie (31 km), Moreton (52 km) and the Stradbroke islands (71 km), combined occupying 338 km (48%) of the coast, including 74% of the open coast. The islands are predominately sand with Fraser, Cooloola, Moreton and North Stradbroke tied to small northern headland anchor points. The mainland Sunshine and Gold Coast sections are a mix of rocky headlands and beaches of variable length, while Moreton Bay has a mix sand and rocky mainland shore and the rear of the sand islands as its outer eastern shore.

This subregion has a wide mix of open coast development, from the sparsely developed, natural and largely unpopulated islands to densely populated strips of coast. The sand islands have the following permanent populations: Fraser (200), Cooloola (100), Bribie (35000), Moreton (300), North Stradbroke (2200) and South Stradbroke (100). On the mainland Rainbow Beach has 1200 and Noosa and the Sunshine Coast strip 300,000 and the massive Gold Coast 600,000, bringing the total population to about 1,000,000. In addition, Moreton Bay is bordered by Brisbane city (2,000,000) and its extensive bayside suburbs. In total, this subregion contains some of Australia’s most pristine coastal environments as well as is one of Australia’s most populated, highly developed and rapidly growing sections of coast.

18.2.1 Rivers and Creeks

There are 23 rivers, creeks and inlets located along the ocean section of coast, with few delivering sand to the coast. The open coast rivers are small (Noosa, Maroochy, Caboolture and Nerang rivers all with catchments less than 1000 km^2) and drain into estuaries depositing their bedload in bayhead deltas, while their entrances act as sediment sinks for flood tide deltas. The large inlets between the islands also act as major sediment sinks. Moreton Bay contains the largest river, the Brisbane (13,643 km^2) which is supplying sediment to the bay, with the smaller Caboolture (354 km^2) and Pine (806 km^2) rivers to the north and Logan River (3822 km^2) and small Pimpama and Coomera rivers to the south.

18.2.2 Coastal Processes and Sediments

As mentioned above the open coast is micro-tidal and WD with northerly longshore transport of well-sorted fine to medium quartz sand driven by predominately moderate southeast swell. Gourlay (1975) found that waves at Caloundra in the centre of the region consisted of seas (1.5–2 m high, T = 7–8 s) and swell (0.7–01 m, T = 8–10 s), together with occasional summer cyclone waves to 4 m (T = 11–13 s) with waves arriving year-round with a slight summer (October–March) maximum. Allen and Callaghan (1999) found that the highest waves arriving on the coast are generated by east coast and tropical cyclones with a H_s of 6.2 m (10 year RI) and 7.2 m (100 year RI). McSweeney and Shulmeister (2018) examined the role of the SOI in modulating the occurrence of storms and waves in southeast Queensland. They found that during positive SOI ex-tropical storms were more frequent leading to a +0.10 m increase in mean monthly wave height and 6° anticlockwise shift in wave direction, leading to substantial beach erosion. Tides are micro ranging from 1.8 m at Brisbane Bar to 1.3 m at Point Danger.

Figure 18.5 shows the longshore trends in sand size and percent carbonate for PC:QLD05. It is uniformly fine to medium with carbonate 0–5%, except in the Caloundra area (Point Berry-Shelly Beach (5720–5765 km)) where it reaches up to 14%. This uniformity and trend are indicative of longshore transport, together with local carbonate enrichment along the rocky Caloundra section. The sand enters this PC at the Tweed and ultimately exits north of Fraser Island via Breaksea

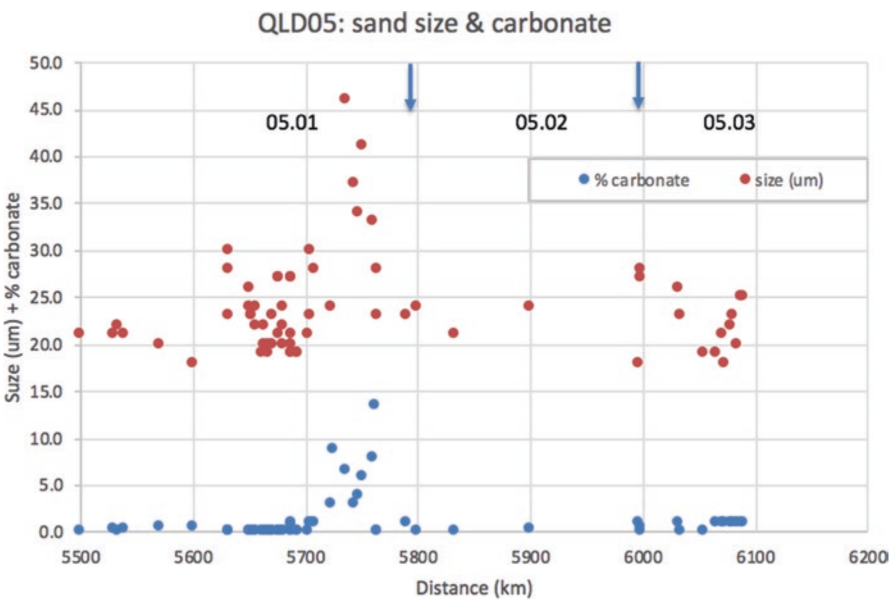

Fig. 18.5 PC:QLD05 beach sand size (μm) and % carbonate. Distance from the NT/QLD border. Arrows indicate PC boundaries, with QLD-NSW border at 6090 km

Spit, with numerous leakages along the way into the dunes, inlets including Great Sandy Strait and possibly offshore.

18.2.3 Beaches

PC:QLD05 has 508 km of beaches which average a long 5.1 km and occupy 72.5% of the coast. The open coast receives moderate to occasionally high waves which combine with the generally fine sand (0.2–0.3 mm) to maintain predominately WD double-barred beach systems with a usually LBT outer bar and TBR and RBB inner bars (69%), the remainder LTT (11%) and R (9%) (Table 18.6). Bar number averages 1.7–1.9 and there are usually 1350 beach rips on the inner bars. The sheltered Moreton Bay has a mix of TM and TD beaches (11%) with a mean of just 0.35 bars and no beach rips. The longest beaches are along the Fraser Island coast, followed by the Moreton to Gold Coast, with shorter beaches in Moreton Bay (Table 18.7).

Table 18.6 Southeast Queensland – PC:QLDQ05 beach types and states

BS	BS	n	%	Total (km)	Mean (km)	σ (km)	% (km)
3	RBB[a]	7	7.1	111.6	16	32.8	22.0
4	TBR[a]	33	33.3	240.6	7.1	12	47.4
5	LTT	13	13.1	57.8	4.4	13.1	11.4
6	R	19	19.2	43.9	2.4	2.6	8.6
7	R + LTT	8	8.1	7.5	0.9	0.71	1.5
10	B + RSF	1	1.0	0.35	0.3	–	0.1
11	B + SF	17	17.2	37.4	2.1	2.5	7.4
12	B + TSF	1	1.0	8.5	8.5	–	1.7
		99	100	507.6	5.1		100

[a]These are predominately inner bar states on a double-bar system

Table 18.7 Central east region PCs beach characteristics

PC:QLD/NSW	QLD05.01	QLD05.02	QLD05.03	NSW01.01	NSW01.02	NSW01.03
n	65	23	37	43	94	63
Beach length (km)	423	32	176	143	165	144
Mean length (km)	6.5	1.4	4.8	3.3	1.75	2.0
Orientation (deg)	112	152	138	98	99	101
Embaymentisation	0.9	0.75	0.8	0.76	0.76	0.76
Gradient (deg)	4	–	2.8	2.9	3.4	3.2
Beach width (m)	23	10	20	93	81	78
Surf zone width (m)	116	2.5	77	115	77	93
Number sand ridges	–	9 (n=1)	–	–	–	–
Sand flat (width, m)	–	500 (n=13)	–	–	–	–
Mean number bars	1.7	0.35	1.9	1.6	1.15	1.4
Number rips	832	0	512	308	514	445

The open coast beaches are not only longer but tend to face east with wider beaches and surf zones, compared to the Moreton Bay beaches, 13 of which have intertidal sand flats averaging 500 m in width.

18.2.4 Barriers

PC:QLD05 contains the largest barrier systems in Australia and probably the world, cumulating in the massive Fraser Island. As Tables 18.4 and 18.5 show, QLD05.01 (Fraser, Cooloola and Bribie islands) dominates with 81% of the sand, followed by Moreton and Stradbroke islands (19%). The large barriers all consist of multiple episodes of dune transgression, usually in the form of parabolics to long-walled parabolics, dating back well into the Quaternary, with most sand deposited during and following each sea-level transgression and highstand. The only major regressive barrier is Bribie Island which is sheltered by Moreton Island and has a 4 km wide series of up to 25 regressive beach-foredune ridges. Table 18.5 lists the size of each of the major islands. This includes their area, volume, volume per metre of beach, then assuming the islands accumulated during approximately ten episodes, the volume deposited per episode, and finally based on this the rate of deposited per metre per year, assuming 6000 years of deposition. These are very rough estimates to be used as a guide only but do indicate the size and volume of the islands and that at these rates, the islands could readily be deposited during the Quaternary.

Fraser Island dwarfs the other islands in this region and for that matter anywhere in Australia. However, what must be taken into account is that Fraser (together with Cooloola, Moreton and North Stradbroke) has accumulated during multiple highstands of the sea and represents the long-term Quaternary evolution, rather than just the Holocene evolution as is the case with many Australian barriers. The total volume of 184 km^3 is massive, but if we assume sand is being delivered to southeast Queensland at the present rate of 0.5 M m^3 year^{-1}, it would take ~0.37 Ma to deliver this amount. As Fraser dates to at least 0.7 Ma (Tejan-Kella et al. 1990), this is more than enough time, with the excess deposited in estuaries, diverted into Great Sandy Strait and beyond, and to the north of Fraser down the continental slope (Boyd et al. 2008), as is discussed below.

The long-term deposition of dune systems along this section of coast is also confirmed by the presence of submerged parabolic dunes extending along 70 km of shelf between Moreton and Fraser islands (Passosa et al. 2019). The dunes are located 40 km offshore in 60 m of water, and their parabolic size and shape are similar to the modern Fraser Island parabolic dunes. They owe their preservation to the fact they are composed of carbonate-rich sand which was cemented (dune calcarenite) prior to inundation some 12 ka. Similar submerged and preserved parabolic dunes are also found off the central west WA coast (see Sect. 32.9.4).

This subregion contains one of the world's largest longshore sediment compartment systems, which is divided into three PCs and ten SCs (Table 18.8). It represents the terminus and sink for much of the sand, some of which originated more than 2000 km to the south. Each of the PCs and SCs is discussed below.

Table 18.8 PC:QLD05 and its ten SCs (05.01.01-06)

PC No.[a]	Name	Boundaries	Beach ID[b]	No. of beaches	km[c]	Total km
QLD 05.01.01	Fraser Island	Sandy Cape-Indian Hd	Fraser Is 1-7	7	0–38	38
QLD 05.01.02	Fraser Island	Indian Hd-Double Is Pt	Fraser Is 8-10	3	38–139	101
	Rainbow Beach	Inskip Pt-Double Is Pt	1528-1530	3	5618–5647	29
QLD 05.01.03	Noosa estuary	Noosa River	0			0
QLD 05.01.04	Cooloola	Double Is Pt-Noosa Hd	1531-1536	6	5647–5706	59
QLD 05.01.05	Sunshine Coast	Noosa Hd-Caloundra	1537-1555	19	5706–5761	55
QLD 05.01.06	Bribie Island	Caloundra-Skirmish Pt	1556	1	5761–5792	31
PC QLD 05.01		*Sandy C – Skirmish Pt*		*39*		*313*
QLD 05.02.01	N Moreton Bay	Skirmish Pt-Brisbane R- C. Moreton	QLD 1557-1575	19	5792–5860	68
			More Is 7-15, 1-4	13	40–87 + 1–2	49
QLD 05.02.02	S Moreton Bay	Brisbane R-Amity	1576-1579	4	5860–5985	125
PC QLD 05.02		*Moreton Bay*		*36*		*242*
QLD 05.03.01	Moreton Is-Stradbroke Is-	C. Moreton-Pt Lookout	More Is 5-6	2	2–40	38
			1580-1584	5	5985–5999	14
QLD 05.03.02	Gold Coast	Pt Lookout-Pt Danger	1585-1601	17	5999–6091	92
PC QLD 05.03		*C. Moreton to Pt Danger*		*24*	*40–87*	*144*

[a]NCCARF compartment number
[b]ABSAMP beach ID
[c]Distance from NT/QLD border

18.3 PC:QLD05.01 Sandy Cape–Skirmish Point

This section commences at Sandy Cape, the northern end of PC:QLD05.01, and work its way south through the six open coast SCs to Skirmish Point, the southern tip of Bribie Island.

18.3.1 SCs:QLD05.01.01-02 Sandy Cape–Double Island Point

SCs:QLD05.01.01-02 contains Fraser Island and Wide Bay-Rainbow Beach (Fig. 18.6), the former containing 184 km^3 of sand, which represents a per metre volume of 1,472,000 m^3 m^{-1} for the 125 km long island. While the dunes have not yet been dated, dating of the Cooloola (Tejan-Kella et al. 1990), Moreton (Brooke et al. 2015) and North Stradbroke Island dunes (Walker et al. 2018) indicates they may date at least to 0.725 Ma, as will be discussed below.

Fig. 18.6 SCs:Q05.01.01-02 extend along the east coast of Fraser Island. (Source: Google Earth)

Table 18.9 PC:QLD05.01 Beach types and states

BS	BS	n	%	Total (km)	Mean (km)	σ (km)	% (km)
3	RBB[a]	7	17.9	111.7	16	32.8	37.5
4	TBR[a]	16	41.0	122.5	7.7	13.2	41.1
5	LTT[a]	7	17.9	52.4	7.5	11.3	17.6
6	R	9	23.1	11.3	1.25	2.15	3.8
		39	100	297.9	7.6	–	100

[a]These are predominately inner bar states on a double-bar system

This is a predominately sandy shoreline with the 39 beaches having an average length of 7.6 km and occupying 95% of the shore. The beaches are generally well-exposed double-bar systems with an outer LBT-RBB and inner TBR-RBB (79%, Table 18.9) with a mean of 1.7 bars and the inner bar containing 832 beach rips. There are only 9 R beaches occupying just 4% of the shore and seven LTT covering 18%, some of these as inner bars.

Sand enters this PC at Double Island Point where it bypasses around the point from Cooloola, manifesting itself as elongate sand spits on the western side of the point. Rip embayments associated with the spits cause periodic erosion of the high dunes, exposing soil horizons hence the term 'rainbow' referring to these coloured palaeosols that back the beach in Rainbow Bay. The spit gradually merges with the beach about 3 km west of the point to continue the transport system. Figure 18.6 illustrates the sand movement around the point. The sand bypasses the eastern side of the point at a depth not visible on the Google Earth images. Wave refraction around the point visible in Fig. 18.7a, b, c, possibly assisted by flooding tides, appears to drive the subaqueous and subaerial transport. The pulse first appears as small attached subaqueous sand waves extending about 200 m offshore and an ephemeral beach on the western tip of the point. The sand emerges in part as a ~100 m wide subaerial spit that extends to the southwest as an elongate spit up to 3 km long, impounding a lagoon in its lee (Fig. 18.7a). Seawards of the spit shore transverse sand waves extend up to 500 m offshore (Fig. 18.7b) and represent the main sand transport route and mechanism. An inlet drains the lagoon and when close to shore forms a transitory rip, which scours a rip embayment and can result in erosion of the backing beach and dunes (Fig. 18.8). The spit finally attaches to the beach about 3 km from the point and the sand merges with the beach (Fig. 18.7) to continue its northerly transport. At times more than one spit may be active as shown in Fig. 18.7d, e, f. This sequence follows the model of headland bypassing proposed by Short and Masselink (1999, p. 242). Based on the images, the spit has a volume on the order 1.25 M m^3. If it moved at a rate of 4 m day^{-1}, this would equate to 500,000 m^3 $year^{-1}$, the rate at which sand is moving along the most exposed beach in this region. An examination of the images suggests it could be moving at a rate of 3 m day^{-1}. However, a more detail study is required to obtain an accurate estimate.

McSweeney and Shulmeister (2018) examined the behaviour of the 20 km long Rainbow beach-Inskip Point shoreline between 1958–2013 and found it has retreated at –0.29 m $year^{-1}$. They further found that during positive SOI higher more

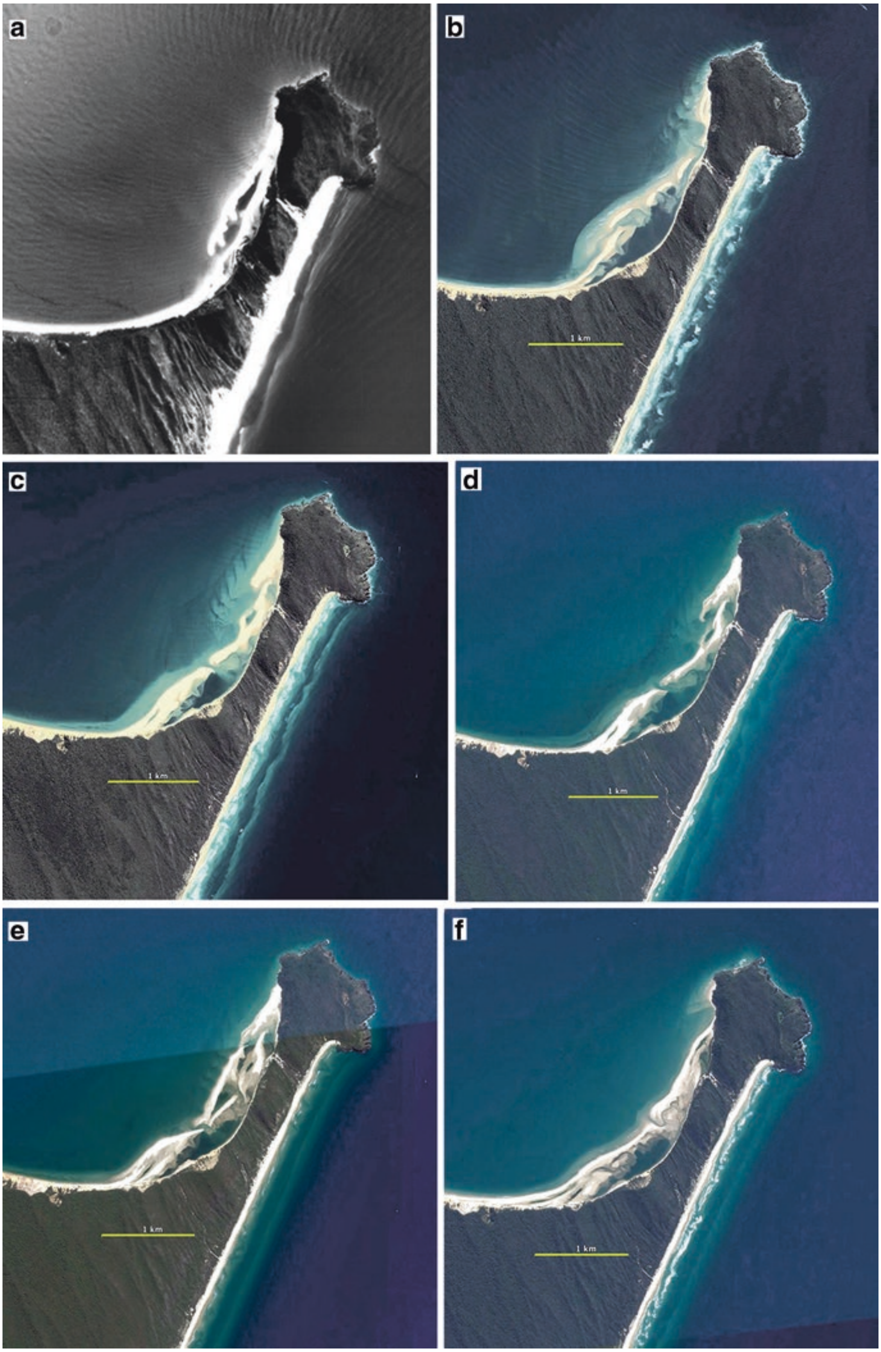

Fig. 18.7 Double Island Point in (**a**) 6-1962, (**b**) 5-2012, (**c**) 5-2013, (**d**) 8-2013, (**e**) 5-2014 and (**f**) 9-2016 (Source: Google Earth). The elongate spit is always present. It forms, then moves down the shore impounding a lagoon and finally attaches to the shore about 3 km from the point. Note the subaqueous sand waves on the western side of the spit and the parabolic dunes overpassing from Cooloola. (Source Figs. 18.8b–e: Google Earth)

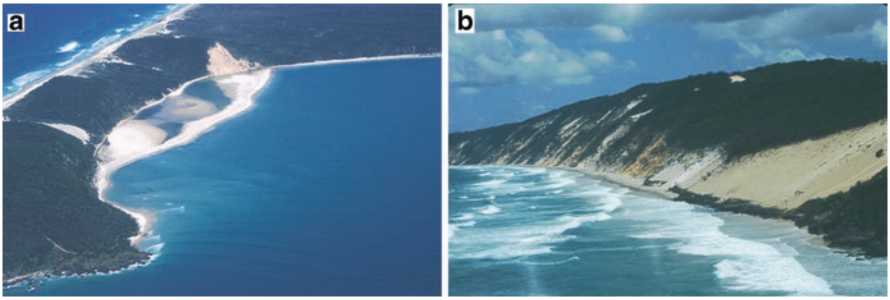

Fig. 18.8 (**a**) Sand wave-spit, lagoon and dune scarped by rip erosion in lee of Double Island Point (31.10.1994) and (**b**) scarped 100 m high transgressive dunes on Rainbow Beach (QLD 1530) exposing the 'coloured' sands and Pleistocene coffeerock at the base of the dunes. (Photos: AD Short)

easterly waves generated substantial beach erosion, while during negative SOI waves are lower and more from the south-southeast. They also suggested that these periodic shifts will impact beach erosion, longshore sand transport and the sediment budget. In addition to the bypassing, sand has overpassed the point as transgressive sand dunes, which accounts for the dunes up to 100 m high backing the beach, and deposited unknown quantities of sand on Rainbow Beach. When the dunes are active, bare sand is delivered directly to the beach; however as they are now vegetated, it is only released when it is eroded by the transitory rips and integrated back into the longshore transport system. Today this would represent a relatively small amount of sand. The eroding dunes are exposing both the coloured sands and coffeerock at their base (Fig. 18.8b); the coloured sands represent iron oxides moving down through the B horizon of the podsolic dune soil with the coffeerock and indurated layer deposited at the water table. Ward et al. (1979) investigated the coffeerock exposed at Rainbow Beach and found it was Pleistocene in age with elevation up to 3 m above present and could possibly be 400 ka old. The blowout activity on the 100 m high crest of the scarped dunes just to the north of this section has been dated by Ellerton et al. (2018) at 2.6–2.5 ka and 0.3 ka. They suggest their origin is anthropogenic and most likely initiated by burning of the protective vegetation.

Once the sand is in the Rainbow Beach system, it is transported 20 km northwards in the single- and then double-bar system to Inskip Point and its 1.5 km wide tidal inlet. Some sand is lost into the inlet and into Great Sandy Strait (SC:QLD05.01.03), while the remainder is incorporated in ebb tide delta which extends 6.5 km offshore, ultimately arriving on Hook Point on the southern tip of Fraser Island. While much of the eastern Fraser Island coast is receding and cutting into the high dunes, there has been an episode of shoreline regression along the southern 30 km north from to Hook Point. The regressive ridges are 2.5 km wide at the point narrowing northwards to where they are replaced by dune transgression. This regression may be related to the Holocene fall in sea level coupled with the development of the large ebb tide delta which partly shelters the widest section.

From Hook Point sand is transported 90 km northwards in the double-bar system to Indian Head and Waddy Point, both of which are bypassed and overpassed, feeding prominent sand waves-spits on their northern sides (Fig. 18.9a). Once onto the northern Orchid Beach, the sand travels 33 km to Sandy Cape and then onto Breaksea Spit (Figs. 18.9b, 18.10 and 18.11). This sand is supplemented by occasional erosion and scarping of the tall 'coloured' dunes (up to 100 m high) that back the beach. It then moves along and across the 25 km long subaqueous spit. Once on the bayside of the spit, it is transported by strong ebb tidal currents flowing out of Hervey Bay to the shelf edge located at the northern tip of the spit. At this point the

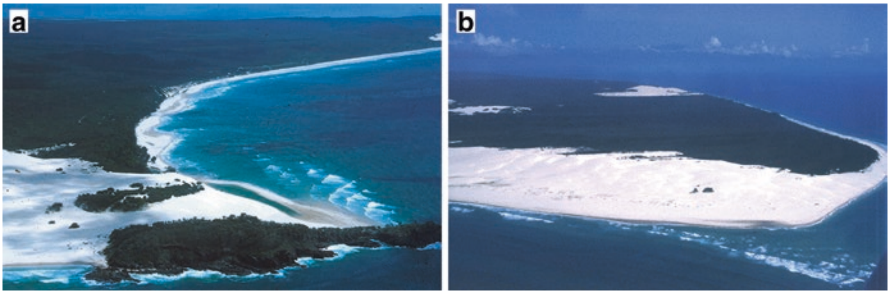

Fig. 18.9 (**a**) Indian Head is both bypassed and overpassed by sand; (**b**) the dynamic Sandy Cape at the northern tip of Fraser Island and the beginning of Breaksea Spit. (Photos: AD Short)

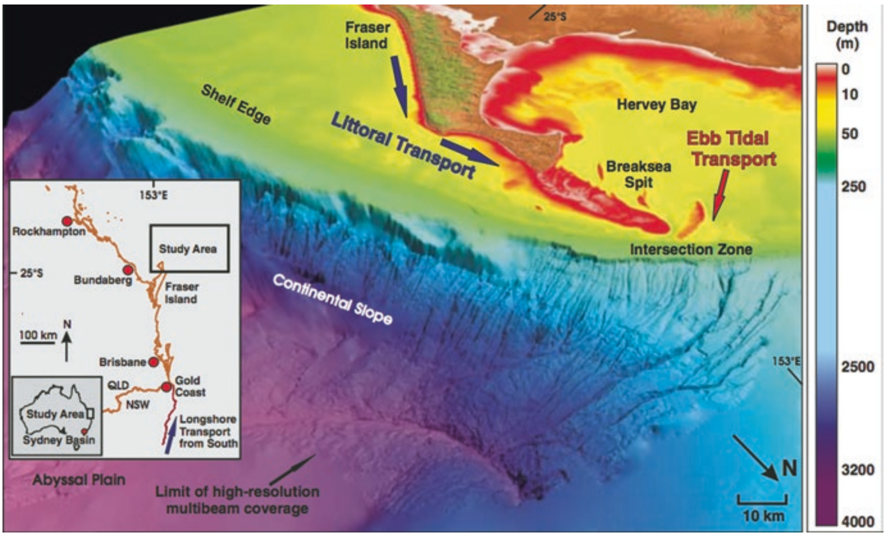

Fig. 18.10 The seabed north of Fraser Island showing the bathymetry and the direction of longshore sand transport to Breaksea Spit and its intersection with ebb tidal currents flowing out of Hervey Bay. (Source: Boyd et al. 2008, reproduced with permission of the Geological Society of America)

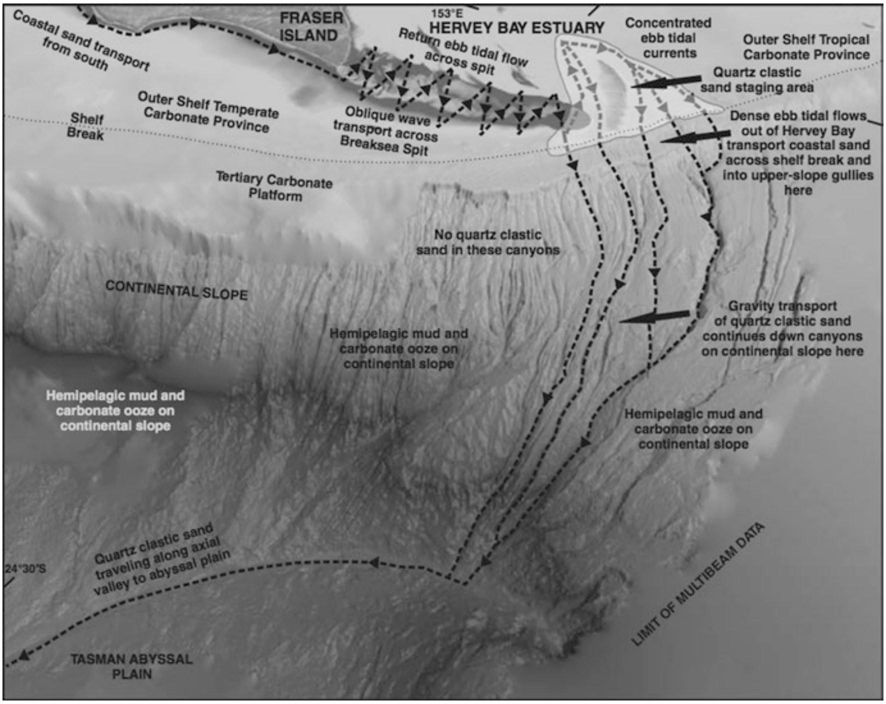

Fig. 18.11 Schematic sketch of longshore sand transport along northern Fraser Island and across Breaksea Spit, from where it is transported by strong ebb tidal currents to the shelf edge and then by gravity transport down the continental slope to the Tasman Abyssal Plain. (Source: Boyd et al. 2008, reproduced with permission of the Geological Society of America)

tidal currents transport the sand to the edge, from where gravity transports it down the slope to the Tasman Abyssal Plain (Boyd et al. 2008; Fig. 18.10). The abyssal plain represents one of two ultimate sinks for the sand, the other being Great Sandy Strait and the coast north of Hervey Bay up to at least Rodds Bay 450 km to the north (Veevers 2015).

Harris et al. (1996) found the EAC impinges on the outer shelf off northern Fraser Island in depth between 40 and 140 m for periods of days at a time and has bottom currents up to 1.3 m s^{-1} sufficient to transport gravel size carbonate material to the south. In addition, they found high wave events occurring during these periods can initiate movement of even larger particles. These processes would assist in transporting sand to the shelf edge.

The five main sand islands (Fraser, Cooloola, Bribie, Moreton and North Stradbroke) have been investigated to varying degrees. Ward (1978) provided one of the earlier assessments of the origin of North Stradbroke Island, with Stephens (1982) confirming the Pleistocene and Holocene origin of the dune sand. Background information on the Cooloola dunes and landscape are provided by Thompson (1981) and Thompson and Moore (1984). The age of the sand islands is presently based on

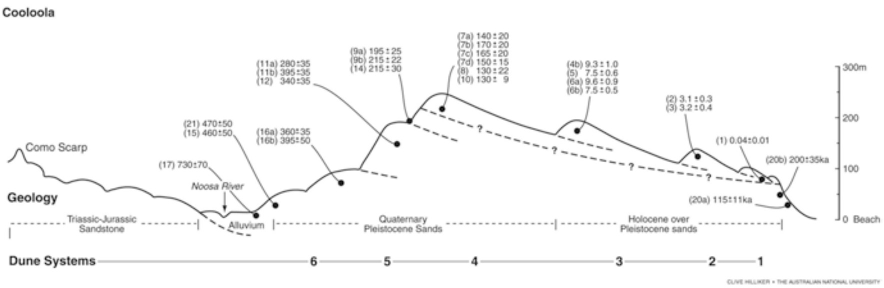

Fig. 18.12 Schematic sketch of Cooloola dune cross-section showing the age of the dune sequences and their soils (based on Tejan-Kella et al. 1990). (Source: Lees 2006, reproduced with permission of the Coastal Education and Research Foundation)

dating of the dune sequences at Cooloola by Thompson (1992) and Walker et al. (2018) and Cooloola and North Stradbroke Island by Tejan-Kella et al. (1990) and Moreton Island by Brooke et al. (2015). These results are taken to be representative of all four high islands (Fraser, Cooloola, Moreton and North Stradbroke). Tejan-Kella et al. (1990) found the inner dunes are Quaternary in age and dated 730 ka, followed by Pleistocene dunes aged 120 ka, 90 ka and the most recent 10 ka. Thompson (1992) dated the innermost Cooloola dunes at >460 ka, followed by sequences at 395–195 ka, 170–173 ka, 79.6 ka, 7.5 ka, 3.2–3.1 ka and 0.04 ka. Lees (2006) compiled these dates into the sequence shown in Fig. 18.12, which shows the inner Quaternary dunes between 730 and 195 ka in age, overlain to the east by the younger Pleistocene (170–130 ka) and then Holocene dunes (9.6 ka–present). More recently Brooke et al. (2015) dated the Moreton Island dunes and found substantial emplacement occurred between 540 and 350 ka, while at Cooloola Walker et al. (2018) identified ten stratigraphic units with the innermost dating 730 ka, the highest at 320 m dating ~140 ka and the youngest dating 0.1 ka. While the full chronology remains to be clarified and tested on Fraser Island, these dates indicate that dune sand has been accumulating on the islands in association with each sea-level transgression and highstand, going well back into the Quaternary. At each highstand another layer of dune sand is added as each island increases in width and height. The volumes and rates indicated in Table 18.5 are based on an assumption there have been ten episodes of dune emplacement, which on the larger island, which average 100 m in height, would equate to an average of 10 m thickness of dune deposited during each episode.

18.3.2 SC:QLD05.01.04 Double Island Point–Noosa Head

SC:QLD05.01.04 extend for 145 km from Double Island Point at the northern tip of Cooloola to Skirmish Point the southern tip of Bribie Island (Fig. 18.13). Cooloola and Bribie Island are both large barriers which are sinks for the northerly moving

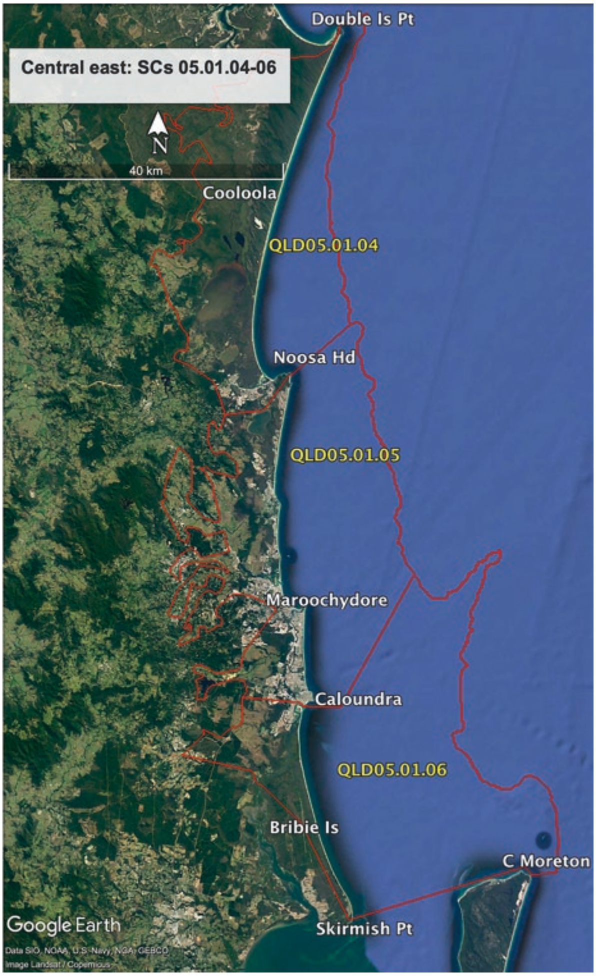

Fig. 18.13 SCs:QLD05.01.04-06 includes the Sunshine Coast with Cooloola to the north and Bribie Island to the south. (Source: Google Earth)

sand, while along the 60 km of coast in between (Noosa to Caloundra), the coast is a bedrock-controlled with less accommodation space and acts more of a conduit for the sand transport, rather than a sink, with limited barrier development.

The Cooloola barrier system operates in the same way as Fraser Island. Sand moves into the system around Noosa Head, with the sand pulses generating fluctuations in the size of Noosa's Main Beach. It is then interrupted by the partially trained 100–300 m wide Noosa Inlet, the walls constructed in the later 1970s to both train the entrance and act as a terminal groyne for the nourished Main Beach (Lloyd 1980). Chamberlain and Tomlinson (2006) investigated the Noosa entrance dynamics and found that 1 M m^3 of sand had been dredged from the Noosa estuary and placed on the beach between 1978 and 2001 which was sufficient to maintain the longshore sand transport and an equilibrium beach, with 80,000 m^3 $year^{-1}$ required to maintain Main Beach into the future. Coughlan (1989) assessed sediment transport through the Noosa system and found that while 110,000 m^3 $year^{-1}$ was bypassed around Noosa Head, 160,000 m^3 $year^{-1}$ was transported out of the system leaving a deficit of 50,000 m^3 $year^{-1}$. In order to manage this, the Noosa River training walls was extended by 200 m, a 150 m long groyne built midway along Main Beach and the beach nourished. The trained Noosa ebb tide delta extends 300 m offshore, and while some sand may be lost into the inlet, it is assumed most moves around the delta and onto Cooloola Beach (Fig. 18.14a) and begins moving northwards along the 52 km long double-barred beach. It ultimately reaches Double Island Point, where as seen in Fig. 18.7 it bypasses and overpasses the headland and links with Rainbow Beach (SC:QLD05.01.02). Cooloola like Fraser dates back into the Quaternary and consists of multiple episodes of transgressive dune activity in the form of parabolics to long-walled parabolics (Fig. 18.12), most of which are

Fig. 18.14 (**a**) Double-bar system (RBB and TBR) along Sunshine Beach (QLD 1539), (**b**) Caloundra and partly sheltered single-bar Currmundi and Dicky beaches (QLD 1550-51), (**c**) the dynamic Pumicestone Inlet between Kings Beach and Bribie Island (QLD 1555-56) and (**d**) the sheltered Woorim Beach (QLD 1556) on Bribie Island. (Photos: AD Short)

stable today. Also, like Fraser Island the outer dunes are scarped and the soil horizons exposed as 'coloured' sands, no doubt contributing some sand to the transport system.

18.3.3 SC:QLD05.01.05 Noosa Head–Caloundra (Sunshine Coast)

SC:QLD05.01.5 is a 55 km long east-facing section of coast with three sweeping headland-tied arcuate embayments which contains 19 embayed beaches (Fig. 18.13). The SC commences at Noosa Head and trends south for 18 km to Point Arkwright, then another 18 km to Mooloolaba and finally 14 km to Caloundra (Fig. 18.14b, c), with each embayment bordered by small headlands and rocks that separate the beaches. It appears that sand enters the system at Caloundra and moves northwards bypassing Point Cartwright and Pt Arkwright and the smaller headlands and is transported in the double-bar systems along the beaches (QLD 1537-54) to Noosa Head which it bypasses to enter SC:QLD05.01.04. Most of the beaches are well exposed with southerly wave averaging 1.2 m, which combine with the fine sand to maintain the double-bar system, with a few single-bar beaches sheltered in lee of the main headlands. All the longer exposed beaches are backed by minor to moderate vegetated transgressive dunes that extend on average a few hundred metre inland as parabolic dunes. At the northern end of Peregian Beach, the dunes extend for 3 km to the northwest and in the past overpassed Noosa Head. All the dunes are now stable, well-vegetated and near the coast covered by residential and other developments.

There are a number of management issues along this section of coast including the dynamic mouth of the Maroochy River, which has had some small groynes installed combined with minor beach nourishment (Andrews et al. 2001), and inside the Pumicestone Passage, at Caloundra, around Mooloolaba and at Coolum beach where infrastructure and facilities have been exposed to erosion. The Sunshine Council is proposing to managing these issues with a combination of seawalls, geotextile groynes and minor beach nourishment (BMT WBM 2013a).

BMT WBM (2013a) used the CREC formulae (CREC 1984) to calculate longshore sand transport along this coast and estimated it increased from zero at Caloundra Headland to 3700 m^3 $year^{-1}$ at Currimundi and 23,300 m^3 $year^{-1}$ at Sunshine Beach, which, while significantly smaller than rates calculated for the Gold Coast, represent a net loss of sand from the beach system leading to shoreline recession rates between Currimundi and Sunshine of between 0.01 and 0.05 m $year^{-1}$ (Barnes et al. 2011). This finding supported the observations by Jones (1992) who suggested the persistent trend in erosion north of Currimundi is the result gradients in longshore transport occurring north of the Caloundra Headland. He attributed the low rates of long-term recession to the wide shallow inner shelf bathymetry, causing incoming waves to refract, becoming almost shore parallel and resulting in only weak alongshore currents and low transport rates. In addition, he suggested onshore sediment supply from the inner shelf may also reduce the magnitude of the shoreline erosion driven by the littoral drift gradients. BTM WBM (2013a) also suggested shoreline recession occurs when there is a deficient in the longshore transport, when sand is lost to sediment sinks particularly estuaries and when it is lost to dunes. They also suggested there may be a small supply of inner shelf sand owing to the flat disequilibrium offshore profiles.

18.3.4 SC:QLD05.01.06 Bribie Island (Pumicestone Passage–Skirmish Point)

Bribie Island (SC:Q05.01.06) is sheltered from east through south waves by Moreton Island and the large Moreton Bay ebb tide shoal that parallels the island's eastern shore and extends between 5 and 20 km offshore. While Bribie Island barrier has a reasonably large area, it is the smallest of the islands by volume (Table 18.5) owing to its lack of dune transgression and consequently low height. The low waves maintain a lower energy R beach and have built the regressive barrier (Fig. 18.14d). The island consists of a low swampy Pleistocene inner barrier up to 4 km wide and a Holocene outer barrier that is composed of a series of up to 20 ridges that increase in width from 1 km in the north to 4 km in the south, with south-trending recurved ridges in the south, all indicating a reversal of sand transport to the south in this SC. This is also supported by GHD (2011) who found that sea level rose to between 0.4 and 1 m above present by 6.5 ka and stabilised at this present level by 3 ka, during which time Bribie Island grew to the south. This transport may be driven by a combination of northeast waves and refracted southerly waves, assisted by flooding tidal currents which parallel the beach. They also found that Pumicestone Passage is acting as a sink with sand being transported into the passage along the southwestern shore Bribie Island, with rate decreasing from 25,000 m^3 year^{-1} at the mouth to a few thousand m^3 year^{-1} 5 km into the passage. Finally, they proposed that future rising sea level will cause the island to continue to prograde to the south, while the northern Pumicestone Passage inlet would widen due to increased scouring owing to increased tidal currents. The possibility of the northern spit being breached has been discussed by PPATF (2009) who found the breach could be caused by a combination of increasing in tide range, rising sea level and cyclone storm surges.

18.3.5 PC Overview

The Fraser Island to Bribie Island PC is part of the terminus for the southeast coast sand transport system and thoughout the Quaternary has been in receipt of fine to medium quartz-rich sand, sand which has built the regressive Bribie and massive dunes of Cooloola and Fraser. This is a dynamic coast with sand continuing to move northwards to its ultimate sink on the shelf north of Fraser Island. Changing climate will have a number of impacts along this coast. Rising sea level will primarily impact the extrusive wetlands and marine ecosystems of Pumicestone Passage, the Noosa River and Great Sandy Strait, as well as the Noosa canal estate, all experiencing an increase in tidal prism and flows and becoming more prone to inundation and flooding, as well as opening more accommodation space on their flood tide deltas. Changing wave climate will impact wave direction and rates of sand transport which will have implications along this drift-aligned coast. Any changes in tropical and east coast cyclone frequency and intensity will impact the frequency and degree of beach oscillation and occurrence of extreme water levels and severe beach erosion.

18.4 PC:QLD05.02 Moreton Bay

Moreton Bay is bounded by the Brisbane mainland in the west and Moreton and North and South Stradbroke islands in the east. It is approximately 60 km long, up to 30 km wide narrowing to the south with an area of 1500 km^2. The bay has approximately 260 km of mainland and Stradbroke-Moreton island shoreline, roughly half on the more irregular northwest-trending mainland coast and half on the straighter more northerly trending island coast (Fig. 18.15). It contains two SCs which occupy the northern and southern half of the bay (Table 18.8). It is connected to the sea via the 15 km wide TD north-facing northern entrance (Northwest and Northeast Channels) between Bribie and Moreton islands, the 3 km wide northeast-facing South Passage between Moreton and North Stradbroke islands and the 1 km wide east-facing WD Jumpinpin Inlet between North and South Stradbroke islands. Spring tide range increases slightly inside the bay to reach 2.1 m at the Brisbane Bar. Waves are restricted to local seas generated by the bidirectional wind regime. At Brisbane the strongest winds arrive from the south to southeast, which generate waves onto the western shore of Moreton and North Stradbroke islands, and from the northeast to east, which generate waves arriving on the western mainland shore of the bay. The waves are usually short (<5 s) and low (<0.5 m).

18.4.1 Rivers, Streams and the Bay

One moderate-sized and four small rivers flow into the bay. From the north these are Pumicestone Passage (761 km^2), Caboolture (354 km^2), Pine (808 km^2) and the larger Brisbane (13,100 km^2) in the northern bay and the Logan-Albert (3157 km^2) and very small Pimpama, Coomera and Nerang in the south. The Caboolture, Pine and Brisbane rivers are delivering sediment to the bay and have built fluvial deltas at their mouths.

Fig. 18.15 Moreton Bay (SCs:QLD05.02.01-02) is sheltered by Moreton and North Stradbroke islands and partly filled by two large tidal deltas and the Brisbane River delta. (Source: Google Earth)

Tides enter the bay primarily through the North Passage, followed by South Passage with a minor amount through Jumpinpin Inlet. The tides and wind generate a clockwise circulation within the bay with water flowing down the eastern side and up the western side. Residence time for water is 3–5 days at North Passage, increasing to 110–120 days at the Brisbane River mouth (Dennison and Abal 1999).

The bay has 14,000 ha and seven species of mangroves, most located along the more sheltered western shore particularly in associated with the tidal creeks, along the western shore of North Stradbroke Island and in the sheltered southern Broadwater area (Dowling 1979). Tropical seagrass meadows also occur in the shallower parts of the bay including the South Passage flood tide delta. They are however most prolific in Eastern Bay, Waterloo Bay and northern Deception Bay

(Dennison and Abal 1999), the latter an area of considerable sedimentation (Flood 1979). McPhee (2017) provides an overview of the entire bay and its geology, biology and ecology.

The Moreton Bay area experienced a higher Pleistocene sea level which Pickett et al. (1984) estimated was +3 m 105 ka based on evidence from Amity on Moreton Island, with Gourlay and Hacker (1983) reporting a 1.4 m Holocene higher level between 5 and 4 ka and Lovell (1975) also finding higher sea level evidence in Moreton Bay. Hekel et al. (1979) examined the Holocene evolution of the bay and found it has been a sink for marine and fluvial sediments since 6 ka when sea level was ~1 m higher. They found the North Passage appears to consist of reworked sands that were flooded by the sea, whereas the South Passage has modern beach sand. The Brisbane River was a wide funnel-shaped estuary 4.4 ka, then filled with marine sand followed by regressive mangrove swamps and beach ridges (Gourlay and Hacker 1983) and narrowed to become a now incipient digitate delta which has deposited mud up to 10 m thick for up to 10 km into the western bay. Harris et al. (1992) also found that the river deposits sand for several kilometres into the bay, before grading to prodelta mud. Evans et al. (1992) examined the stratigraphy of the delta and found it contained both low sea-level channels and five high sea-level depositional sequences dating back to 340 ka each 10–20 m thick. They found the present delta has a river-dominated mouth that becomes WD to the northwest and is depositing Holocene sands up to 10 km into the bay.

Sediments on the eastern side of the bay are dominated by tidal delta sands composed of quartz. These are associated with the large Northwest and Northeast channels and the smaller South Passage. Subtidal sand banks associated with the tidal deltas have been investigated by Harris et al. (1992) and Pattiaratchi and Harris (2002). The western side of the bay has fluvial delta deposits at the river mouths grading into the pro delta mud, while between the two zones is a central to southern area of muddy sand with minimal deposition (Harris and Jones 1988). Maxwell (1970) mapped the bay sediments and identified three facies which are dependent on source and wave and current energy: a uniform clean sand is associated with the large tidal deltas and the eastern island shores and the western bay shorelines; a mud facies occurs in the deeper north-central bay, the mud originating from the Brisbane River; and a muddy sand facies has spread eastwards across the bay floor and surrounds the deeper mud facies.

18.4.2 Beaches

The combination of low wind waves and tides up to 1.8 m maintains TM and TD beaches in the bay, together with a few WD beach on the northern ocean shore of Moreton Island. As Table 18.10 indicates, the B + SF dominate by length, followed by B + TSF and B + RSF (Fig. 18.16). These are mainly located in the northwest of the bay between Bongaree and Deception Bay (QLD 1559-62) and on the northern

Table 18.10 PC:QLD05.02 beach types and states

Q05.02							
BS	BS	No.	No. (%)	Total km	Mean (km)	σ (km)	km (%)
4	TBR	3	8.3	0.2	0.07	–	0.3
5	LTT	2	5.6	2.4	1.2	–	3.4
6	R	4	11.1	14.5	3.6	2.1	20.6
7	R + LTT	8	22.2	7.5	0.9	1.4	10.6
10	B + RSF	1	2.8	0.4	0.4	0	0.5
11	B + SF	17	47.2	37	2.2	2.6	52.5
12	B + TSF	1	2.8	8.5	8.5	–	12.1
		36	100	70.5	1.9		100

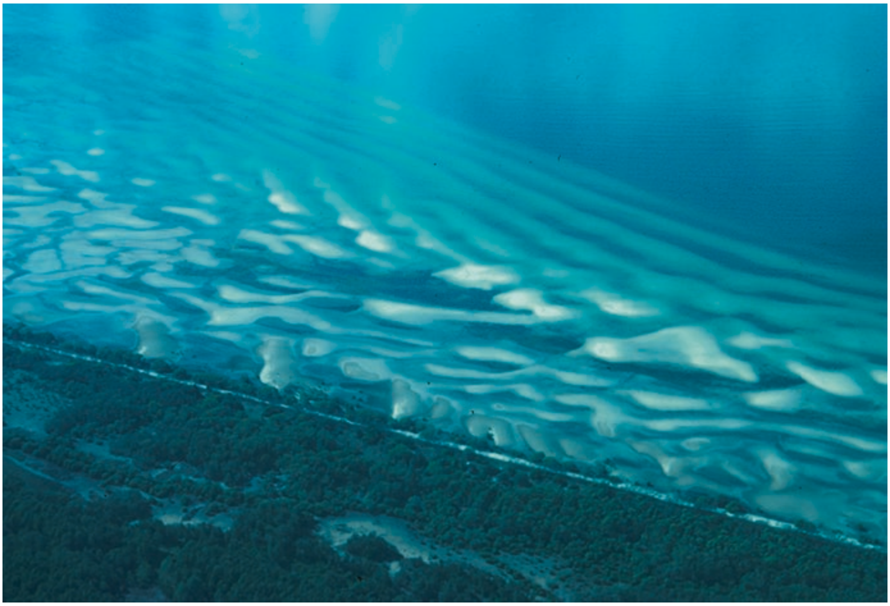

Fig. 18.16 Seven-hundred meter wide ridged sand flats off Goodwin Beach (QLD 1560) typical of the low energy shoreline of Moreton Bay. (Photo: AD Short)

side of the Brisbane River (Woody Point to Cribb Island QLD 1572-5) and on the western shore of North Stradbroke Island (Adams Beach to One Mile QLD 1576-8). The TM R + LTT are located along the more exposed central sections of the bay between Scarborough Beach and Scotts Point (QLD 1564-71), with the long R beach on the sheltered northern shore of Moreton Island (MOR 7-15). The beaches only occupy 70 km (27%) of the shore, with most of the bay shore occupied by mangroves and low bluffs.

18.4.3 Barriers

The low energy bay beaches are backed by 13.5 km of barriers, all low regressive beach ridge systems, with an area of only 30 ha and volume of 1.5 M m^3, which represents just 110 m^3 m^{-1} of beach. The larger volumes shown in Table 18.5 are related to the dunes backing the northern shore of Moreton Island. Brooke et al. (2008a) investigated the 700 m wide Beachmere barrier located in Deception Bay west of Bribie Island and adjacent to Goodwin Beach (QLD 1560-1) (Fig. 18.15). It faces south into the bay and is a low energy TD B + RSF with the flats extending 200–500 m into the bay. They found the barrier was eroded between 2.5 and 1.7 ka and then underwent a 1.5 ka period of accretion, with the outer ridges now eroding. They suggest these changes may be due to switches in the nearshore sand transport. Brooke et al. (2008b) also investigated the indurated sand (coffeerock) at Beachmere and found that indurated gravely channel fill dated 77 ka, while adjacent dune sand dated 98 ka. They concluded that pedogenic induration occurs over long periods (up to 90,000 years) and that deposits between 1.6 and 2.6 ka show only incipient induration.

18.4.4 SCs:QLD05.02.01-02 North and South Moreton Bay

The bay contains two SCs with QLD05.02.01 covering the northern half of the bay and QLD05.02.02 southern half (Fig. 18.15). Away from the tidal inlets and river mouths, sand transport is very limited around the bay shore and mainly related to subaqueous movement associated with the tidal flows in the tidal deltas, as investigated by Harris et al. (1992). The smaller rivers have deposited small tidal deltas composed of lithic sands at their mouths, but this sand is not reworked to any extent. The major shoreline transport that occurs along the northern and western shore of Moreton island is driven by a combination of waves and flooding tidal currents. Along the protruding Redcliffe peninsula, Harrison (2013) reported northerly sand transport at between 5000 and 10,000 m^3 $year^{-1}$. However, the transport is interrupted by groynes, breakwaters, headlands, revetments and land reclamation, all of which intercept northward sand transport leading to localised updrift accumulation and downdrift erosion. On the northern shore of the bay, this transport is manifest at Beachmere by an elongate 5 km long west trending spit that terminates in a series of recurves which has deflected the mouth of Caboolture River. In the southern half of the bay transport is limited to the South Passage tidal delta, the southern network of tidal channels that link with Jumpinpin Inlet, and ultimately the Gold Coast's Broadwater and Seaway. For the most part however, the bay is a sink for marine, fluvial and in situ organic sediments.

18.4.5 PC Overview

Moreton Bay is a 1500 km^2 V-shaped sheltered bay bordered by the Brisbane mainland to the west and the rear of the Morton and Stradbroke sand inlands to the east. It has received marine sands via the large tidal deltas located between the islands and fluvial sand and mud from the Brisbane and smaller west coast rivers. These are reworked by the strong tidal flows in the inlets and along the eastern shore and lesser wind waves along the western shore. The bay contains rich ecosystems including extensive seagrass meadows and mangroves adjacent to Queensland's largest city and port. Rising sea level will impact these tidal-related ecosystems, especially the mangroves as they attempt to shift shorewards on a highly developed western shoreline. The western shore also contains extensive low-lying shores, which include canal estates, while the southern bay has several developed low-lying islands all of which will be exposed to increased inundation and flooding.

18.5 PC:QLD05.03 Moreton Island–Stradbroke Island–Gold Coast

The 144 km long stretch of coast between Cape Moreton at the northern tip of Moreton Island and Point Danger on the QLD-NSW border contains some of the most natural and most developed sections of the Australian coast. The three islands, Moreton and North and South Stradbroke, remain in a primarily natural state, particularly on their ocean side, while to the south, the Gold Coast, its barrier and backbarrier, is the most highly developed strip of land on the Australian coast. Whereas the islands have populations of 300, 2300 and 100, respectively, the Gold Coast has 600,000 people and growing. The entire coast is however linked by the stream of fine, well-sorted quartz-rich sand that crosses the border at the Tweed-Point Danger and continues on up the Gold Coast and along the three islands, all ultimately heading for Fraser Island. This is very much a long-exposed east-facing sandy shore, anchored by a few headlands and separated by a series of creeks and tidal inlets, with sand comprising 138 km (96%) of the 144 km of shoreline. This PC contains two SCs:QLD05.03.01-02 (Table 18.8).

18.5.1 River and Creeks

The only steams that reach the open coast are the small Currumbin (54 km^2) and Tallebudgera (97 km^2) creeks. All other mainland drainage including the Logan-Albert (3157 km^2), Coomera and Nerang rivers flows into the Broadwater estuary which connects to the sea via Jumpinpin Inlet (McCauley and Tomlinson 2006) and the Broadwater-Seaway (Whitlow 2005; Tomlinson 2017). All the creeks and tidal inlets act as sediment sinks, with none supplying sand to the coast, though since the Seaway was constructed in 1984–1986, the change in tidal hydraulics has led to an export of Broadwater tidal delta sand out through the Seaway (Tomlinson 2017).

18.5.2 Sediments and Processes

Beach sand remains uniform along this PC as well-sorted, fine to medium quartz sand, with <1% carbonate, dominates throughout (Fig 18.2). Mean spring tide range is 1.3 m, with waves predominately moderate swell from the south with a mean H_o of 1.2 m and period 8–10 s. The southerly waves are generated by midlatitude cyclones in Southern Ocean, while easterly waves are generated by summer tropical cyclones, east coast cyclones and sea breezes. McGrath and Patterson (1973) found the Gold Coast has a mean $H_s = 1.2$ m ($T = 9$–10 s), with no marked seasonal variation, though summer and autumn are a little more severe than winter and spring.

18.5.3 Beaches

Beaches occupy 138 km (96%) of the PC, reflecting the dominance of sand in this major long-term compartment sink. All the beaches are WD with exposed double-barred beaches occupying 119 km (86%) of the beaches, with a mean of 1.9 bars. TBR dominate the inner bar, with usually 512 beach rips, while the remaining sheltered beaches (14%) are either LTT or R (Table 18.11). The beaches are orientated east-southeast (110°), slightly curved with 0.77 embayment ratio and average a long 5.8 km in length. They are composed of fine sand resulting in a low gradient swash zone (2.8°) and generally wide low gradient surf zone averaging 80 m and up to 150–200 m wide on the double-bar systems. The long-exposed drift-aligned beaches are extremely dynamics due to both their rip-dominated surf zone and throughput of northerly sand transport. Whyte et al. (2005) recorded northerly rip channel migration averaging 8 m d^{-1} and reaching 50 m d^{-1} along the Gold Coast.

Table 18.11 PC Q05.03 beach states

QLD05.03							
BS	BS	No.	No. (%)	Total (km)	Mean (km)	σ (km)	% (km)
4	TBR[a]	15	62.5	117.9	7.9	11.9	85.3
5	LTT	4	16.7	3	0.75	0.7	2.2
6	R	5	20.8	17.3	3.5	6.8	12.5
		24	100	138.2	5.75		100

[a]Inner bar of double-bar system

18.5.4 Barriers

This PC contains the southernmost three of the sand islands: Moreton, North and South Stradbroke. Both Moreton and North Stradbroke are high islands and have followed the same mode of evolution as Fraser and Cooloola, consisting of multiple episodes of dune transgression extending well back into the Quaternary (Fig. 18.12). Moreton Island has a volume of 8.7 km^3 and North Stradbroke 26 km^3, while the low South Stradbroke is just 0.195 km^3. The remaining low narrow barrier of the Gold Coast totals just 0.143 km^3, bringing the entire PC to total barrier volume of 35 M km^3.

Brooke et al. (2015) investigated the chronology of the Moreton Island dune fields and proposed a model whereby substantial dune emplacement occurred between 540 and 350 ka, with the dunes active as sea level transgressed the inner continental shelf (~20 m below present sea level) depositing dunes above present sea level, followed by dune transgression at present sea level, the rise in sea level partly truncating and cliffing the earlier dunes. They recorded subsequent dune episodes at 96 ka and Holocene dune activity at 5.75, 1.28 and 0.9 ka. The results suggest that much sand was mobilised from the low gradient inner shelf to supply the dunes and that most dunes were emplaced between 540 and 96 ka.

North Stradbroke Island was investigated by Ward (1978) who identified eight Quaternary land units. Stephens (1982) found that the island is composed of both Pleistocene and Holocene dunes, while Whitlow (2000a) provides a detailed overview of the island's geology and geomorphology, though he did not undertake any dating. In a review of the chronology and evolution of the sand islands, Miot da Silva and Schulmeister (2016) concluded that while both marine and climate factors have played a role in their development understanding, the thresholds that trigger dune development remain a challenge.

In addition to the movement of transgressive dunes onto each of the barriers, there has been secondary barrier evolution and shoreline modification around the base of the islands, particularly along the northern shores of Moreton and North Stradbroke which are receiving sand that has moved up their east coasts and bypassed around their northern points. On Moreton Island sand is bypassing Cape Moreton (and overpassing in the past) and being transported along its 10 km northern shore as a series of elongate sand spits to the Comboyuro Point, the northwestern tip of the island. This area has undergone up to 1.8 km of shoreline progradation as a series of regressive spits that have moved westwards around the corner of the island and extend up to 5 km down the western shore of the island. The Rainbow Channel between Moreton and North Stradbroke islands is particularly dynamic and has resulted in severe erosion on both Moreton Island's Cloherty Peninsula and Amity Point on North Stradbroke. Bryant and Tomlinson (1995) attribute this in part to the opening of Jumpinpin Inlet in 1898 which has led to an increase in tidal flow through the Rainbow Channel.

On North Stradbroke sand is bypassing around Point Lookout (as well as past overpassing) and moving along its 11 km long northern shore to and around Amity

Point. This sand has built the 1.5 km wide regressive Flinders beach barrier. Gontz et al. (2014) investigated this system and found the barrier contains inner elements related to the 120 ka Pleistocene sea level high, with most of the barrier deposited after 7 ka following the PMT, assisted by a slight ~1 m fall in sea level that occurred along the northeastern Australian coast (Lewis et al. 2015) (Fig. 18.17). Along the entire eastern shore of the island is the Eighteen Mile Swamp, a regressive shoreline that consists of a ~0.5 km wide dune-capped barrier backed by the freshwater swamp that widens from 0.15 km in the north to 2 km in the south. Flood and Grant (1984) and Flood et al. (1986) investigated the swamp and found its formation was not related to a fall in sea level; rather about 0.6 ka, a northward and coastwise migrating spit joined the coast near Point Lookout, following which the backing lagoon rapidly changed from marine to freshwater and peat began accumulating.

South of Jumpinpin Inlet, the barriers extend for 55 km almost continuously to Point Danger. They are low and narrow, with the only minor dune transgression occurring on 21 km long South Stradbroke Island, south of which is the 16 km long Gold Coast and then the remaining beaches and headlands down to the border. Grimstone (1975) noted that the Gold Coast had an inner Pleistocene and outer Holocene barrier systems. These systems and the geology of the Gold Coast region, its barriers and backbarriers, have been mapped in considerable detail by Whitlow (2000b).

18.5.5 Sand Transport

This entire PC is experiencing massive northerly sand transport along its exposed eastern shores, with the northern shores of Moreton and South Stradbroke, together with the large inlets and passages acting as partial sinks. The first major study of the Gold Coast beaches by Delft (1970) recognised the pronounced northerly transport with most occurring in the breaker zone within 100 m of the shore, but transport extending out across the shoreface to as far as 0.6 km from shore. There have been numerous studies of the Gold Coast and its sediment budget, some of which are summarised below, while the Seaway and Tweed sand passing project websites (see References) provide much useful information. Grimstone (1975) proposed that sand was delivered to the Gold Coast from the shelf at low sea level with predominately onshore shelf supply between 5 and 3 ka, with entirely longshore supply since 2 ka. Chapman (1978) examined the sediment budget for the entire region suggesting sand was also coming from erosion of Pleistocene dunes between Brunswick Heads and Iluka. Patterson (2009) estimated longshore sand transport rates between Shark Bay (SC:NSW01.01.04) and North Stradbroke Island (SC:QLD05.03.01). He found that transport was >200,000 m^3 $year^{-1}$ between Shark |Bay and Ballina, increasing to 460,000 m^3 $year^{-1}$ at Tallows Beach, then slowly increasing to peak at 620,000 m^3 $year^{-1}$ at The Spit and dropping to ~550,000 m^3 $year^{-1}$ along South and North Stradbroke islands. These estimates have been confirmed at the Tweed and Seaway through the operation of the two sand pumping systems that endeavour to pump at rates that approximates the natural rate of transport.

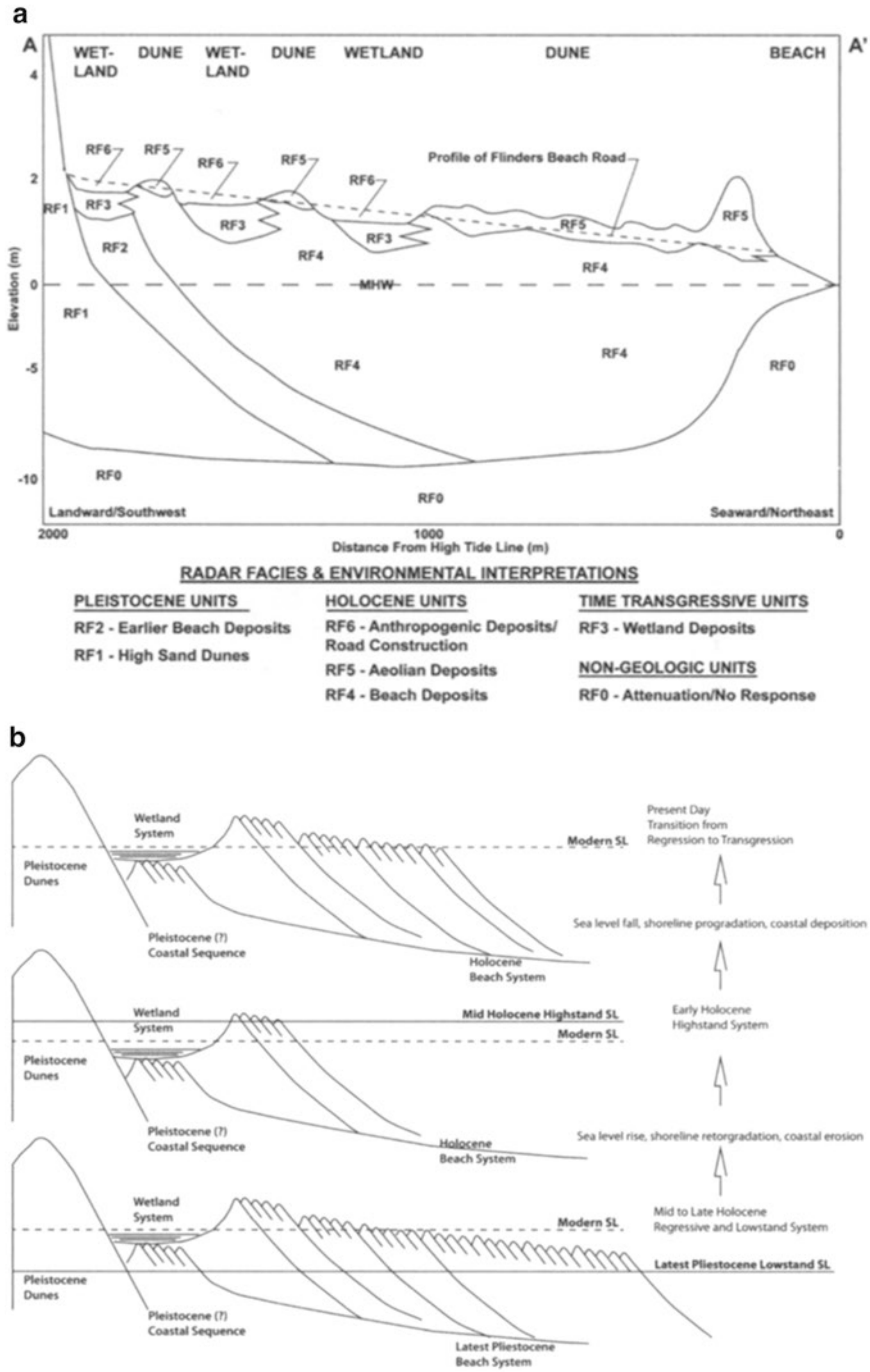

Fig. 18.17 (**a**) Schematic diagram of Flinders Beach stratigraphy with Pleistocene transgressive dunes (RF1) on the left and an earlier beach (RF2) and the regressive beach ridges (RF4 and 5) and wetlands (RF3) and (**b**) conceptual model of the evolution of the Flinders beach regressive barrier. (Source: Gontz et al. 2014, reproduced with permission of the Coastal Education and Research Foundation)

The present Gold Coast sand management system was developed in response to severe cyclone erosion, exacerbated by trapping of sand at the Tweed River entrance and loss of sand into the old Nerang entrance, both of which were degrading the Gold Coast beaches and South Stradbroke Island. Delft (1970) estimated that between 1900 and 1970, sand moved into the old Nerang inlet and deposited approximately 10 M m^3 of sand in the Broadwater at an average rate of 140,000 m^3 $year^{-1}$, as well as maintaining a migratory, hazardous inlet and progressively eroding South Stradbroke Island. Patterson (2007a, b) estimated that prior to the construction of the Seaway, 80,000 m^3 $year^{-1}$ of sand was lost into the Broadwater, which lead to a substantial shoaling of this section of the Broadwater. In addition to this loss, sand began accumulating on Letitia Spit at a rate of 230,000 m^3 $year^{-1}$ following the construction of the Tweed River training walls in 1962 (Pattearson and Patterson 1983; Tomlinson and Foster 1987), with an estimated at 4 M m^3 of sand trapped, which resulted in a loss of 270,000 m^3 $year^{-1}$ or 1.7 M m^3 of sand from the Gold Coast beaches (Macdonald and Patterson 1984). Two kilometres to the west, the construction of the Kirra groyne in 1972 leads to an updrift accumulation of 0.3 M m^3, while the downdrift Kirra beach lost 0.5 M m^3 (Robinson and Patterson 1975) and eroded the beach back to the seawall. Combined these two structures both represented a temporary loss of sand from the transport system which had severe downdrift impacts in the form of severe beach erosion of the southern Gold Coast beaches particularly during cyclonic wave attack.

In order to manage the movement of sand through the system and to reduce the loss into the Broadwater and trapping of sand on Letitia Spit, two sand pumping systems were established. The northern Seaway training walls and sand pumping system began operation in 1986 (Witt and Hill 1987; https://www.gcwa.qld.gov.au/sand-bypass-system/). This system changed the hydrology of the system with 0.12 M m^3 $year^{-1}$ of sand now being exported from the Broadwater through the Seaway and longshore sand pumped under the Seaway onto South Stradbroke Island (Tomlinson 2017). Sedigh et al. (2016) reviewed evolution of the Seaway ebb tide and found it was receiving sand from the Broadwater (up to 0.1 M m^3 $year^{-1}$) as well as leakage past the bypassing jetty and had accumulated ~8 M m^3 since its construction in 1984. They also found that the sand bypassing system has bypassed an equivalent volume of sand and combined between 0.48 and 1.05 M m^3 $year^{-1}$ bypass the entrance, the rate dependent of the frequency of southeast storm events. To the north of the entrance, they found that between 0.48 and 0.77 M m^3 $year^{-1}$ continues up South Stradbroke Island, the deficit (~0.3 M m^3 $year^{-1}$) residing on the delta.

The Tweed River sand pumping system began operation in 2000 with an initial pumping of up to 1 M m^3 $year^{-1}$ during the catch-up phase to clear the backlog on Letitia Spit. Castelle et al. (2009) found the overpumping was successful in restoring Greenmount and Kirra beaches and far more efficient than using dredged sand, the latter requiring extending periods of low waves to work itself onshore. Today the Tweed pumps on the order of 0.55 M m^3 $year^{-1}$ (Ackworth and Lawson 2012) together with ~0.04 M m^3 $year^{-1}$ bypassing naturally (Patterson et al. 2012) and the Seaway ~0.63 M m^3 $year^{-1}$ (Tomlinson 2017) in order to maintain the natural movement of sand northwards along the coast. BMT WBM (2015) and Ware (2016) provide an overview of the Tweed bypass system.

Since the 1960s beach nourishment has also taken place along the Gold Coast beaches. In the 1990s sand was sourced from the Tweed River flood tide delta (3.6 M m^3 in 1995, Dyson et al. 2001) and from offshore of the Gold Coast, with periodic dredging of the Tweed ebb tide delta continuing. The most recent nourishment project in 2017 dredged sand from offshore water depths >18 m deep and delivered 3 M m^3 of sand to the beaches (GCCC 2017).

In addition to the sand pumping and beach nourishment, the 30 km of Gold Coast beaches have a beach management plan that includes a terminal seawall located at the rear of the beach and extending the length of the coast; a terminal groyne at Greenmount to trap sand and widen the beach; sand pumping from Tallebudgera Creek to Burleigh Heads; an upgraded surfing reef at Narrowneck (Tomlinson 2008); the establishment, fencing and maintenance of foredunes along the entire beach; and beach scarping as required following erosion events and with plans for a second surfing reef off Palm Beach (Mortensen et al. 2015) and sand backpassing from the Seaway to Surfers Paradise (Royal Haskoning 2017). All of this is designed to maintain the beaches and beach amenity in a condition suitable to the local and visitor beach goers, as well as to provide asset protection during cyclone events by maintaining a wide beach to satisfy the storm demand.

18.5.6 SC:QLD05.03.01 Cape Moreton–Point Lookout

SC:QLD05.03.01 extends from Cape Moreton down the east coast of Moreton Island, across South Passage and along the northern shore of North Stradbroke Island to Point Lookout (Fig. 18.15). As mentioned above both islands are part of the longshore sand transport system that extend up the southeast Queensland coast. Sand is bypassing around Point Lookout and moved along the northern Flinders Beach to Amity across the massive 4 km wide ebb tide delta to the southern shores of Moreton Island then continuing up the island (Fig. 18.19a). At Amity the South Passage tidal channel has rotated counter-clockwise and scoured right to the shore, the shoreline retreating by up to 300 m in the past 150 years and presently threatening several houses. This sand is lost into the channel to accumulate on the large tidal delta that occupies the passage and extends up to 17 km into Moreton Bay. The delta has an area of ~250 km^2 and represents a massive sink of Holocene sand that has been removed from the longshore system. On Moreton Island sand moves up the coast to Cape Moreton which it bypasses and continues along the northern shore as a series of long narrow sand spits that are both feeding sand to the northwest corner (Comboyuro Point) of the island and the massive 600 km^2 15 km wide tidal delta between the point and Bribie Island.

18.5.7 SC:QLD05.03.01 Point Lookout–Point Danger

SC:QLD05.03.02 begins at Point Lookout and extends down North and South Stradbroke islands and along the Gold Coast to the border at Point Danger (Figs. 18.18 and 18.19b-f). As discussed above sand is moving into this SC from NSW via the Tweed sand pumping system (Fig. 18.19f) and then moving along the Gold Coast (Fig. 18.19d) and under the Seaway (Fig. 18.19c) via its pumping

Fig. 18.18 SCs:QLD05.03.02 – North and South Stradbroke islands and the Gold Coast. (Source: Google Earth)

Fig. 18.19 (**a**) The southeast tip of Moreton Island (MIs 5) is extremely dynamic owing to the adjacent tidal delta and sand transport, (**b**) Dune Rocks and Point Lookout at the northern tip of North Stradbroke Island with sand bypassing and overpassing the headland (QLD 1584-085), (**c**) the Seaway training walls and Breaksea Island (QLD 1590-91), (**d**) the Gold Coast (QLD 1591), (**e**) Greenmount Beach and terminal groyne (QLD 1590) and (**f**) Snapper Rocks-Point Danger with Tweed River training walls and Letitia Spit in the background (QLD 1600-01). (Photos: AD Short)

systems to South Stradbroke Island. In addition to the assisted natural movement of ~0.5 M m^3 $year^{-1}$, the supply has been augmented since the 1960s by periodic sand nourishment from the Tweed River flood tide delta and offshore. In the past sand has been lost into the smaller southern inlets, with D'Agara and Tomlinson (2001) reporting major sand loss into Currumbin Creek during a cyclonic event and Saeede et al. 2018 estimating 35,000 m^3 $year^{-1}$ is lost into Currumbin Creek, the Broadwater and Jumpinpin inlets. Only the Broadwater losses have been contained, while ongoing minor losses are expected into the other inlets. As discussed above this is the most heavily managed and modified section of the Australian coast, a result of a naturally eroding and highly vulnerable shoreline owing to a deficiency in transport rates and exposure to periodic high wave events all backed by a highly capitalised foreshore, barrier and backbarrier depression. The barrier systems in their natural state consist of the large high North Stradbroke Island, south of which the barriers are relatively low, narrow and exposed and south of the Seaway highly developed. The South Stradbroke to Point Danger barriers range in width from 0.5 to 1 km and average up to 10 m in height. Besides experiencing net shoreline recession, they are exposed to major shoreline oscillations in response to high wave events and downdrift of headlands to the movement of sand pulses associated with headland bypassing, which induces additional oscillation in shoreline width. The natural shoreline dynamics has been further exacerbated by the construction of the Tweed training walls, the Greenmount (Fig. 18.19e) and Kirra groynes and the Tallebudgera Creek training wall. These have now been rectified by construction of the Tweed sand pumping system, shortening of the Kirra groyne, sand pumping from Tallebudgera Creek and the Seaway sand pumping system, together with periodic beach nourishment from the Tweed flood tide delta and offshore.

18.5.8 PC Overview

This PC represents the southern part of the massive southeast Queensland sand transport system and sediment sink. Today as in the past, sand is both moving through the system at rates averaging 0.5 M m^3 $year^{-1}$ and being lost into the several sinks, in particular the tidal deltas between the islands and down the continental slope past Fraser Island, with minimal loss at present into the transgressive dunes. In addition, the Gold Coast sand management system is both assisting in the maintenance of this transport and injecting periodic large pulses of sand (few M m^3) as part of Gold Coast beach nourishment projects. This is a highly dynamic PC with a predominately WD sandy shoreline that is exposed to impacts of tropical and east coast cyclones that generate severe shoreline erosion. Moreton and North Stradbroke islands are generally well elevated and free from inundation with erosion cycles accommodated by the natural beach and foredune and consequently have low vulnerability. In contrast, the Gold Coast has a highly developed low-lying barrier and hinterland, with the barrier intensely developed and canal estates occupying the former backbarrier depressions and lagoons, formerly known as Stephens Swamp (Whitlow 2000b). The beaches are already exposed to beach erosion and storm surges and the estates exposed to storm surges and river flooding. Rising sea level, changing wave climate and changing frequency and intensity of cyclones will all impact this coast into the future, with the biggest threat from more intense tropical and east coast cyclones which could lead to severe shoreline erosion/recession, higher storm surges and greater inundation, especially if accompanied by flooding rains. In addition, modulations in wave climate and in particular wave direction will impact rates longshore sand transport and headland bypassing (Goodwin et al.

2014). The present Gold Coast sand management system, including terminal seawalls, dune management, beach nourishment and the two sand pumping systems, will all need to be maintained and perhaps even boosted to prepare for and accommodate these impacts.

18.6 Northern NSW (NSW01)

The southern half of the central east region (NSW01) extends for 560 km from the QLD-NSW border at Point Danger down the NSW coast to the prominent 224 m high Cape Hawke (Fig. 17.1). This is a relatively straight and continuous section of coast that faces east-southeast (100°) with generally longer beaches separated by rocky headlands, together with a few rockier sections with shorter beaches around Broken Head, Lennox Head, Coffs Harbour, Iluka, Angourie and south of South West Rocks. In all 200 beaches occupy 453 km (81%) of the coast and average 2.3 km in length, both well above the Australian average. Like the southeast QLD coast to the north, this is also an active part of the northerly longshore sand transport system that has its origins in southern NSW (Fig. 18.3). This subregion contains three PCs and ten SCs, each of which is discussed below.

18.6.1 River and Creeks

Eight small- to moderate-sized rivers discharge to the northern NSW coast (Table 18.12), most of which have been trained. The rivers originate in the granite belt of the New England plateau and at lower sea levels deliver quartz sand and small percentages of heavy minerals to the coast and contribute significantly to the coastal sediment budget and the northerly longshore transport system. While these rivers have developed extensive floodplains in their lower reaches, few are presently contributing bedload material to the coastal system. Roy and Crawford (1977) concluded that none of the rivers have delivered bedload to the coast in the past

Table 18.12 Major northern NSW coastal rivers and their catchment area

River	Catchment (km^2)
Tweed	1126
Richmond	6878
Clarence	22,220
Bellinger	1039
Nambucca	1341
Macleay	11,273
Hastings	3699
Manning	8080

10,000 years, though more recently Goodwin et al. (2006) estimated the Clarence is delivering between 10,000 and 15,000 m^3 $year^{-1}$ to the coast. Most of the rivers however have acted as sediment sinks with marine sand moving into the river mouths and contributing to the extensive flood tide deltas. Modelling of the Tweed River entrance suggests that 30,000 m^3 $year^{-1}$ is lost into the estuary (Chapman et al. 1982). In addition to the rivers, there are 33 smaller rivers and creeks which drain to the coast, each of which has formed estuaries containing flood tidal deltas largely composed of marine sands. Kinsela et al. (2017) mapped the total estuary delta area for each of the nine NSW PCs. They found that the deltas had a combined area of 70 km^2, of which 66% are located in the three northern NSW PCs and the remainder in the six southern NSW PCs. As the deltas act as sediment sinks for coastal sand, it indicates the relative amount of sand lost to these systems in northern NSW. Hanslow et al. (2018) mapped the present and potential inundation of land and properties in 184 NSW estuaries which are discussed in Sect. 18.9. The origin and evolution of NSW estuaries was investigated by Roy (1984) and their structure and function by Roy et al. (2001).

18.6.2 Coastal Processes and Sediments

As described in Sect. 17.3, the wave climate of the north coast is very similar to southeast QLD, with predominately southerly swell with an average H_s of 1.5 m and period of 10 s, together with higher more easterly swell from tropical cyclones and east coast cyclones and low to moderate onshore seas generated by easterly winds and summer sea breezes. Shand et al. (2010) and Glatz et al. (2017) summarised data from the eight NSW waverider buoys (Byron Bay, Coffs Harbour, Crowdy Head, Newcastle, Sydney, Port Kembla, Batemans Bay and Eden) (see MHL website http://new.mhl.nsw.gov.au/data/realtime/wave/) to provide an overview of the NSW wave climate including coastal storms and extreme waves, with storms being defined when $H_s > 3$ m > 1 h. All of the sites have a modal wave of between 1.4 and 1.6 m with a period 9–10 s and a maximum wave between 6 and 8 m. Figure 17.2 shows the eight storm types and their area of impact along the NSW coast, together with their monthly occurrence, while Table 18.13 shows the direction of storms at Byron Bay, Sydney and Batemans Bay, with a pronounced dominance of a southerly storm waves at all sites and only a small percent of storm waves from the northeast through east. The level and distribution of wave energy along the coast was also investigated by Morim et al. (2016), while Baird (2017) developed a nearshore wave transformation tool for estimating inshore wave height along the entire NSW coast.

Tides along the entire NSW coast are micro-tidal with a mean spring range of 1.3 m and maximum range of 2 m, with the tidal wave arriving almost simultaneously along the coast as shown in Fig. 17.3.

Sea level along the NSW coast was reviewed by Thom and Roy (1983) and more recently by Sloss et al. (2007). Sloss et al. found it reached between −15 and − 11 m around 9 ka, −5 m at 8 ka, −3.5 m between 8.3 and 8 ka and its present level

Table 18.13 Storm frequency and direction for selected NSW sites

	Byron Bay	Sydney	Batemans Bay
NE	1.0	0.4	0.7
ENE	1.5	2.8	3.3
E	6.5	4.4	5.8
ESE	6.5	4.9	8.7
SE	12.7	9.2	13.2
SSE	28.1	27.1	35.5
S	30.4	49.2	32.1
SSW	1.5	2.0	0.2
%	100	100	100
Total	612	687	448

Based on Glatz et al. (2017)

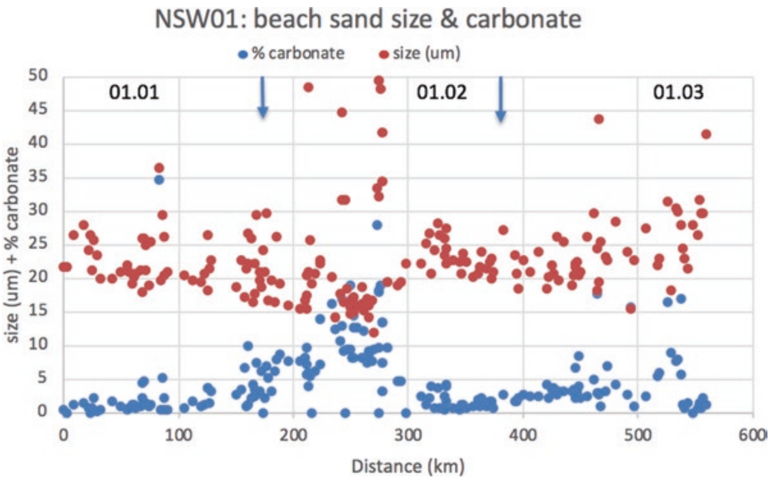

Fig. 18.20 Northern NSW sand size and percent carbonate. Arrows indicate NSW PC boundaries. Distance from the QLD/NSW border at Point Danger

between 7.9 and 7.7 ka. It then continued to rise between +1 and + 1.5 m between 7.7 and 7.4 ka, followed by a gradual fall in sea level to 2 ka, similar to the trend illustrated in Fig. 1.42. Likewise, Switzer et al. (2010) found evidence for a 1–1.5 m higher sea level that lasted until at least ~2.5–2 ka.

Beach sand along the northern NSW coast is largely identical to the sand in southeast QLD (Table 18.2; Figs. 18.3 and 18.20), which is to be expected as northern NSW is the source of the QLD sand. The sand is predominately fine (0.24 mm), well-sorted quartz sand with an average of 5% carbonate. The areas of coarser carbonate-enriched sand are all associated with rockier sections of coast, as at Boulder beach (35% carbonate), the Bluff (10%) and Red Rock (13%). In contrast, some of the longer northern beaches are <1%. Roy and Stephens (1980a) found along the NSW coast that the beach sand occupies the inner nearshore to depths of 5–12 m, with fine sand extending into the outer nearshore (15–30 m), beyond which are mid-shelf muddy sand.

18.6.3 Beaches

The northern NSW subregion (NSW01) has 200 beaches, all of which are WD. The combination of fine sand and moderate to occasionally high waves maintains double-bar systems on most of the longer beaches, with TBR dominating the inner bar (mean length = 3.3 km, 83% by length), with a total of 1267 beach rips (Table 18.7) followed by the higher energy RBB (2.6 km, 6%), with the outer bar usually RBB or LBT, and an average of between 1.15 and 1.6 bars. The lower energy LTT and R are numerous (79 beaches) but occupy only 11% by length (0.8 and 0.4 km) with many associated with the headlands and rockier sections (Table 18.14).

18.6.4 Barriers

The decrease in barrier volume that commences at South Stradbroke Island continues down the NSW coast. This is a coast transporting, rather than accumulating Holocene sediments. PC:NSW01 has a total of 81 barriers with a total volume of 3185 M m^3, which represents just 6% of the southeast QLD barriers. Likewise, they have a per metre volume of just 7034 m^3 m^{-1}, again a fraction of the QLD volumes (Table 18.15). Most of the barriers tend to be low (~10 m), relatively narrow (few hundred metres), with predominately stable surfaces (91% vegetated) and receding, with most backed by or overlapping Pleistocene inner barriers. The recession is manifest in the exposure of backing Pleistocene barriers including white Pleistocene dunes (e.g. Broadwater), coffeerock (numerous locations) and exposed tertiary vegetation (e.g. Woody Bay). There are a few wider regressive barriers around Iluka (Goodwin et al. 2006) and Tuncurry (Roy et al. 1997), and a few experiencing minor dune transgression as at Hat Head and Killicks beach, but for the most part, they are low, narrow and stable or recessional.

Table 18.14 Subregion NSW01 beach types and states

BS	BS	n	% no	Total km	Mean km	σ km	%km
3	RBB[a]	10	5	26.2	2.6	3.5	5.8
4	TBR[a]	111	55.5	375	3.3	4.8	82.8
5	LTT[a]	48	24	39.1	0.8	1.4	8.6
6	R	31	15.5	12.6	0.4	0.9	2.8
		200	100	452.9	2.3	–	100

[a]These are predominately inner bar states on a double-bar system, with LBT outer bar

Table 18.15 Central east: PCs NSW01.01–03 Holocene barrier dimensions

NSW01	NSW01.01	NSW01.02	NSW01.03	NSW01	QLD05	Q05 + NSW01
No.	21	38	22	81	27	108
Total length (km)	143.25	162.7	146.9	452.9	473.4	926.3
Mean min width	250	275	195	–	–	–
Mean max width	800	800	500	–	–	–
Mean height (m)	6	11	10	–	–	–
Area (ha)	16,060	7560	7465	31,085	259,880	290,965
Unstable (ha)	646	464	1587	2697	18,050	20,747
Total volume (M m^3)	1048	1411	690	3185	50,529	53,714
Unit volume (m^3/m^{-1})	7316	8664	4701	7034	116,051	57,987

The absence of large barriers on the NSW coast north of Tuncurry can be attributed to two factors. First is the presence of Pleistocene barriers (including Tuncurry) that occupy much of the accommodation space, leaving little room for Holocene barriers, which is also the case with the sand islands. Second is the lack of strong onshore wind to build large transgressive dune systems. Unlike the southeast Queensland coast dominant winds along the north coast are from the southwest and largely blow offshore (Fig. 18.21), with small- to moderate-sized transgressive dunes only occurring at the northern end of Hat Head and Killicks beaches, both of which curve round to face southeast. The afternoon summer northeast sea breezes are of insufficient velocity to generate substantial aeolian transport into the dunes. The only substantial NSW barriers and transgressive dunes occur in the Myall Lakes, Stockton Bight, Kurnell and Wreck Bay, all of which face southeast to southerly into the dominant southerly winds and southerly waves and which are discussed in Chap. 19.

18.6.5 Sand Transport

This subregion is part of the major east coast sand transport system (Fig. 18.3). The first attempt at explaining sand transport along the coast by Halligan (1906) suggested that sand was transported offshore by waves and then moved longshore by currents. Roy and Crawford (1977) in an assessment of north coast river mouths found the coast has a negative sediment budget with sand primarily lost to longshore transport and into the dunes, with minor amounts lost into the estuaries, offshore, and trapped by training walls, in agreement with Ford (1963) and Hails (1967). Patterson (2007a) concluded sand is being transported northwards along the beaches and around the headlands, with rates increasing from 100,000 m^3 $year^{-1}$ in the south to over 500,000 m^3 $year^{-1}$ at the Tweed. To accommodate this increase, as well as make up for losses into the several inlets and river mouths and offshore at Cape Byron, sand is eroded from north coast beaches and their often Pleistocene dunes.

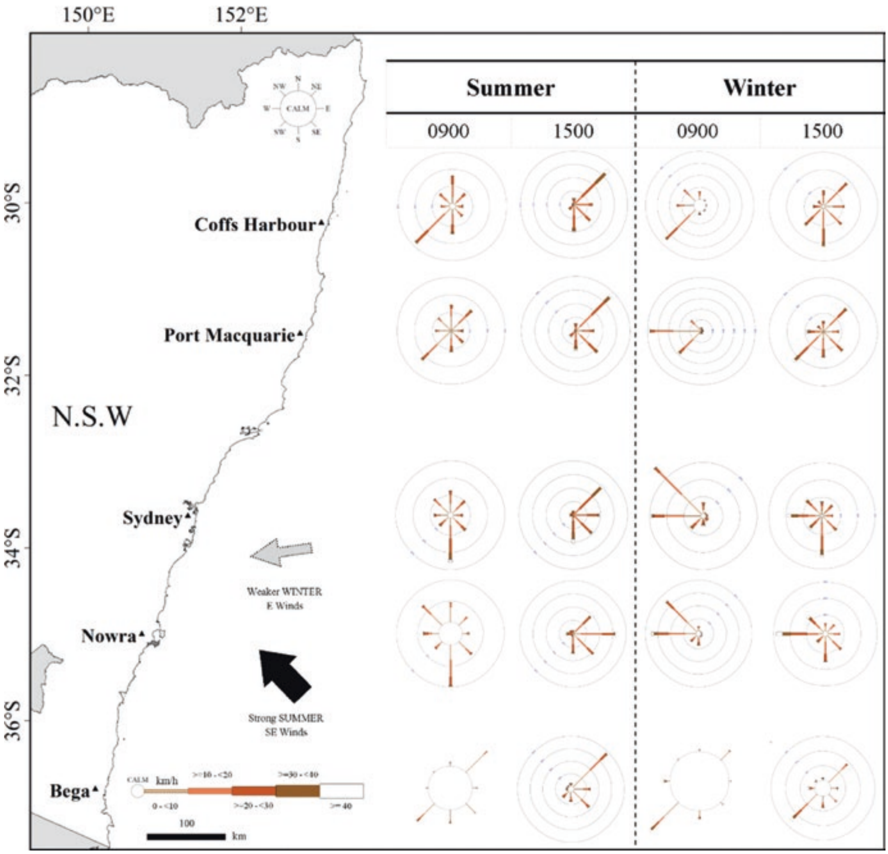

Fig. 18.21 NSW 09.00 and 15.00 summer and winter wind roses for selected coastal stations. (Source: Shand et al. 2010)

In addition, Patterson (2012) suggests some sand is still being sourced from the upper active profile out to depths of about 18 m, while Goodwin et al. (2006) concluded the Clarence River is delivering some sand to the system. BMT WBM (2013b) estimated there is a shortfall in sand transport between the Clarence and the Gold Coast of 350,000–400,000 m^3 $year^{-1}$ which would correspond to an average loss of 2.3–2.7 m^3 m $year^{-1}$ and a shoreline recession of 0.15–0.18 m $year^{-1}$. However, they also found sand is being supplied from the inner northern NSW shelf at a rate of 0.5–1.0 m^3 $year^{-1}$ which would offset the loss and reduce the recession to less than 0.1 m $year^{-1}$.

The transport system has also been interrupted by 16 trained river systems and harbour breakwaters, each of which is generated updrift accumulation, downdrift erosion and generally interrupting the sand supply as discussed above for the Tweed River. Table 18.16 lists the structures and rates their impact according to Nielsen and Gordon (2016). Young et al. (2017) reviewed the hazards the entrance bars (ebb

Table 18.16 Northern New South Wales training walls and breakwaters[c]

River/inlet	Structure	Date constructed[a]	Impact and rating[b]
Tweed	2 training walls	1962	Major[c]
Byron Bay	Jonson St groyne	1975	Minor
Cudgen	2 training walls	1966	Minor
Mooball Ck	2 training walls	1976	Minor
Brunswick	2 training walls	1960	Major[c]
Richmond	2 training walls	1900	Major
Evans Head	2 training walls	1959	Minor
Clarence	2 training walls	1901	Moderate
Wooli	2 training walls	1960s	Minor
Coffs Harbour	Harbour breakwaters	1892, 1928	Major[a,b]
Bellinger	2 training walls	1965	Moderate
Nambucca	1 training wall	1890	Minor
Macleay	2 training walls	1896	Major
Hastings	2 training walls	1901, 1938	Minor
Camden Haven	2 training walls	1901	Minor
Crowdy Head	Boat harbour	1960s	Minor
Tuncurry	2 training walls	1901, 1966	Major[a,b]

[a]Coltheart (1997)
[b] [a]good; [b]bad; [c]ugly (Nielsen and Gordon 2016)
[c]See Coghlan et al. (2013) for list of groynes and training walls in SE QLD and northern NSW

tide deltas) pose to navigation and as a way of reducing this hazard proposed that sand could be dredged from the bars and placed on coastal erosion hotspots, or ‘Bar to Beach’ as they called it. An excellent history of the NSW ports, training walls and their construction is provided by Coltheart (1997).

Table 18.17 provides a list of estimates of rates of longshore sand transport within PC:NSW01. In general, the transport increases from south to north reaching a peak of 500,000 m^3 year^{-1} at the Tweed and then increasing to 550,000 m^3 year^{-1} on the Gold Coast. Despite this increase there are numerous potential sediment sinks along the entire NSW coast including offshore with EAC (e.g. Byron Bay), offshore flood jet (e.g. Shoalhaven), offshore river jet with EAC (e.g. Tweed), onshore aeolian (e.g. Stockton Bight), inshore estuary (e.g. Port Hacking) and onshore overwash (e.g. New Brighton) (Gordon 1987). More details on the transport along the coast including headland bypassing and sediment sinks and losses are presented in the following discussion of each of the SCs, with BMT WBM (2015) providing the latest assessment in the Tweed region. Table 18.17 provides an insight into the spatial variability in longshore transport and its general increase northwards and Table 18.16 some of the structures and river mouths that interrupt and in places syphon off the sand. In addition, there are other factors listed above, all of which severely compromise and modulate the movement of sand northwards along the northern NSW coast. The table also indicates the considerable variation, at times by an order of magnitude, between transport estimates. As Thom et al. (2018) state,

Table 18.17 Estimate rates of longshore sand transport in PC:NSW01

km[a]	Location	Rate (m^3 $year^{-1}$)	References
0	Gold Coast	550,000	BMT WBM (2015)
0	Tweed	550,000	Ackworth and Lawson (2012)
4	Letitia Spit	550,000	Ackworth and Lawson (2012)
8	Cudgen Head	480,000	Mariani et al. (2013)
21	Norries Head	470,000	Mariani et al. (2013)
30	Hastings Point	>180,000	Gordon et al. (1978)
50	Brunswick Head	110,000	Gordon et al. (1978); Stephens et al. (1981)
55	Cape Byron-Brunswick	500,000	Thom et al. (Thom et al. 2018)
60	Cape Byron	400–450,000	Patterson (2010)
60	Cape Byron	400,000	BMT WBM (2013b)
62	Tallow	65,000	Stephens et al. 1981; van Senden et al. (1997)
62	Tallow	450,000	Thom et al. (Thom et al. 2018)
90	Richmond River	260,000	Patterson (2007b)
100	Evans Head-Richmond R	300,000	Thom et al. (Thom et al. 2018)
154	Shark Bay	250,000	Patterson (2007b)
160	N of Clarence River	200,000	Thom et al. (Thom et al. 2018)
165	Clarence River	75,000	Floyd and Druery (1976) and Goodwin et al. (2006)
165	Clarence River	150–200,000	BMT WBM (2013b)
223	Wooli	10–30,000	RH DHV (2016)
282	Coffs Harbour	75,000	Lord and Van Kerkvoort (1981a, 1981b) and Gordon (1987)
282	Coffs Harbour	70,000	Stephens et al. 1981; Van Senden et al. (1997)
316	Bellinger River	60,000	BMT WBM (2014)
330	Nambucca	60,000	BMT WBM (2013c)
346	Scotts Head	60,000	BMT WBM (2013c)
364	Trial Bay (Kempsey coast)	65,000	BMT WBM (2013c)
445	Port Macquarie	20–50,000	PWD (2014)
526	Old Bar-Crowdy Head	70,000	Worley Parsons (2010)
560	Cape Hawke	30–200,000	Chapman et al. (1982) and Roy et al. (1997)

[a]Distance in km from QLD/NSW border

'transport rates have been subject of numerous and at time conflicting estimates both within and between leaky tertiary compartments'. They also found considerable uncertainty in the amount of sand currently transport onshore from the inner shelf and called for more work in this area to accurately assess both onshore and longshore transport rates.

18.7 PC:NSW01.01 Pt Danger–Clarence River (Yamba)

The northern PC:NSW01.01 extends south from Point Danger for 167 km to the mouth of the Clarence River at Yamba. This is a rapidly growing region with well-established towns and villages strung along the coast, many in nodes separated by undeveloped reserves and national parks. Beginning in the north is Tweed Heads (10,000 population), followed by Kingscliff (10,000), Cabarita (3500), Brunswick Heads (2000), Byron Bay (9000), Lennox Head (8000), Ballina (26,000), Evans Head (6000), Iluka (2000) and Yamba (6500).

The PC is part of the Clarence-Moreton Basin whose softer sedimentary rocks have been eroded to form broader valleys, which at the coast are manifest in the longer beaches and fewer headlands. As a consequence, this is a predominately sandy PC containing 43 beaches averaging 3.3 km in length that occupy 144 km (86%) of the coast (Table 18.18). The beaches are composed of fine quartz-rich sand and exposed to southerly waves averaging about 1.5 m which maintain a predominately double-bar system with a TBR inner bar dominating (92.5%) and the lower energy LTT and R restricted to beaches sheltered by headlands and bays. The beaches typically face east (98°) and are slightly embayed (0.76), wide with a low gradient swash zone (2.9°) and double-barred with an average of 1.6 bars and 308 beach rips usually operating along the inner bars (Table 18.7).

This PC has received considerable attention owing to the impact of the Tweed training walls (Fig. 18.22a) on Letitia Spit and the Gold Coast beaches, the periodic erosion at Kingscliff (Fig. 18.22b), the ongoing erosion at Belongil Spit and the impact of Cape Byron and the Richmond and Clarence river training walls on longshore sediment transport, each of which is discussed below. The PC contains four SCs with boundaries at Point Danger, Cape Byron, Richmond River, Evans Head and Yamba (Table 18.19; Fig. 18.23).

18.7.1 SC:NSW01.01.01 Point Danger–Cape Byron

SC:NSW01.01.01 occupies 61 km of coast between Point Danger and Cape Bryon the eastern tip of Australia (Fig. 18.23a). It consists of six long beaches separated by small headlands. Sand is moving northwards along the beaches and bypassing Cape

Table 18.18 PC:NSW01.01 beach types and states

BS	BS	n	%	Total km	Mean (km)	σ (km)	% (km)
3	RBB[a]	2	4.5	5.5	2.75	–	3.8
4	TBR[a]	32	75.0	133.6	4	7.1	92.5
5	LTT	6	13.6	3.6	0.6	0.9	2.5
6	R	3	6.8	1.7	0.6	–	1.2
		43	100	144.4	3.28		100

[a]These are predominately inner bar states on a double-bar system, with LBT outer bar

Fig. 18.22 (**a**) Duranbah Beach (NSW 1) and the Tweed River training walls and sand pumping jetty in background; (**b**) Cudgen Inlet, training walls and migratory sand wave and rip (arrows) at Kingscliff (NSW 3). Note the severe rip-induced erosion preceding the sand wave. (Photos: AD Short)

Table 18.19 Subregion northern NSW01 PCs and SCs

PC No.[a]	Name	Boundaries	Beach ID[b]	No. of beaches	km[c]	Total km
NSW 01.01.01		Pt Danger-C. Byron	1-15	15	0–61	61
NSW 01.01.02		C. Byron-Richmond R	16-28	13	61–92	31
NSW 01.01.03		Richmond R-Evans Hd	29-30	2	92–123	31
NSW 01.01.04		Evans Hd-Yamba	31-43	13	123–167	44
PC:NSW 01.01		*Pt Danger-Richmond R*	*NSW 1-43*	*43*	*0–167*	*167*
NSW 01.02.01		Yamba-Wooli	44-74	31	167–228	61
NSW 01.02.02		Wooli-Bare Bluff	75-93	19	228–263	35
NSW 01.02.03		Bare Bluff-Coffs Harbour	94-112	19	263–290	27
NSW 01.02.04		Coffs Hbr-Nambucca Hd	113-127	15	290–333	43
NSW 01.02.05		Nambucca Hd-SW Rocks	128-137	10	333–368	35
PC:NSW 01.02		*Richmond R-SW Rocks*	*NSW 44-137*	*94*	*167–368*	*201*
NSW 01.03.01		SW Rocks-Tacking Pt	138-170	33	368–450	82
NSW 01.03.02		Tacking Pt-Crowdy Hd	171-184	14	450–508	58
NSW 01.03.03		Crowdy Hd-Black Hd	185-192	8	508–540	32
NSW 01.03.04		Black Hd-C Hawke	193-200	8	540–560	20
PC:NSW 01.03		*SW Rocks-C. Hawke*	*NSW-138-200*	*63*	*368–560*	*192*
		Subregion total	*NSW 1-200*	*200*		*560*

[a]NCCARF compartment number
[b]ABSAMP beach ID
[c]distance from QLD/NSW border

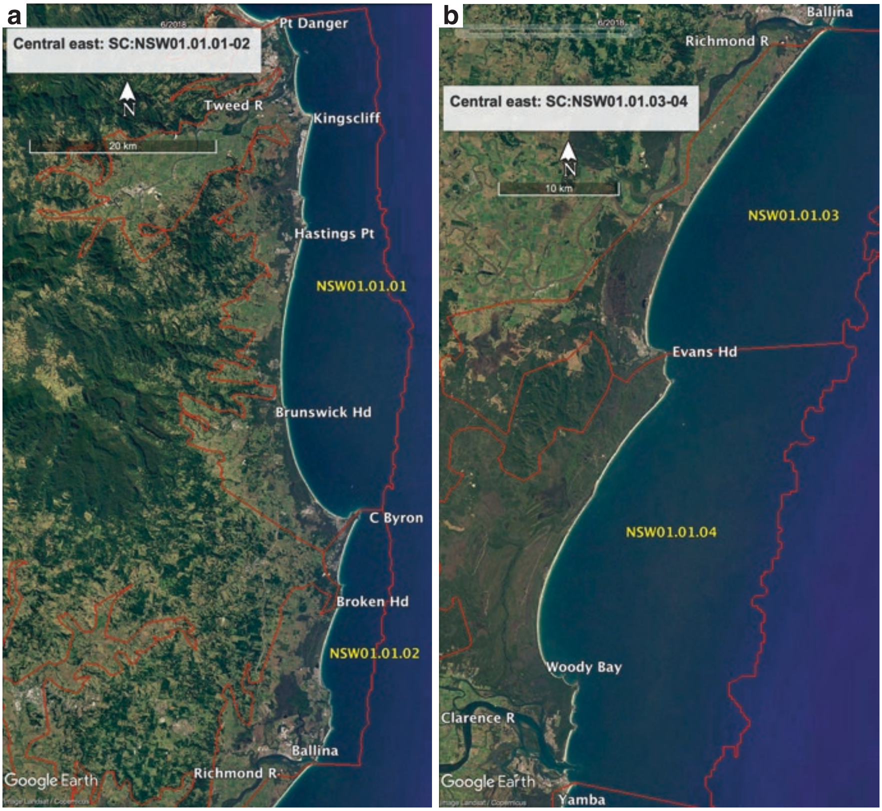

Fig. 18.23 (**a**) SCs NSW01.01.01-02 and (**b**) SCs:NSW01.01-03-04. (Source: Google Earth)

Byron, Brunswick Heads, Hastings Point, Norries Head, Cudgen Head and Fingal Head before arriving at Tweed where it is pumped under the river to Snapper Rocks (Fig. 18.22a). Sand is also being lost to the Cape Byron subaqueous spit, a large shelf sand body (SSB). This and other losses result in a transport shortfall which is made up in part by ongoing beach and dune recession along the PC. At Belongil, Gordon et al. (1978) observed recession of up to 1 m year^{-1}, with an average recession between 1885 and 2000 of 0.8 m year^{-1} (Goodwin et al. 2013). This is an erosional hotspot, and as mentioned above, BMT WBM (2013b) concluded the average rate of recession of northern NSW beaches should be <0.1 m year^{-1}.

As discussed in Sect. 18.5 the construction of the Tweed River training walls, commencing in 1962, trapped ~4 M m^3 of sand on the southern Letitia Spit (Macdonald and Patterson 1984) until a sand pumping system became operational in 2000 and is presently pumping sand at a rate of about 450,000 m^3 year^{-1} (Ackworth and Lawson 2012). The pumping removed the trapped sand and resulted in recession of Letitia Spit beach between 2000 and 2010 back to its original pretraining wall shoreline position. The recession was greatest (120 m) at the northern training wall decreasing to 20 m at Fingal. Sand has however continued to bypass the southern Fingal Head (4 km) in large subaqueous pulses on the order of 200,000 m^3 $year^{-1}$ and then move along Letitia Spit at rates between 250,000–1,000,000 m^3 $year^{-1}$, averaging about 550,000 m^3 $year^{-1}$ (Ackworth and Lawson 2012).

Cudgen Head (8 km south of the Tweed) like most headlands along the northern NSW coast experiences headland bypassing, leading to periodic pulses of sand along Kingscliff Beach (Short and Masselink 1999). These pulses can initiate severe shoreline erosion (Fig 18.24b), which at Kingscliff in 2010–2012 resulted in the construction of defences to protect the surf club, caravan park and bowling club. It is estimated 480,000 m^3 $year^{-1}$ is moving around the headland (Fig. 18.24) with 470,000 m^3 $year^{-1}$ moving around Norries Head (21 km) located 13 km to the south, a differential of 10,000 m^3 $year^{-1}$ which Mariani et al. (2013) suggest is made up of thought recession of Cabarita beach of 0.1 m $year^{-1}$. At Hastings Point (30 km), Gordon et al. (1978) calculated a minimum rate of 180,000 m^3 $year^{-1}$ and at Brunswick Heads (50 km) of 110,000 m^3 $year^{-1}$. Roy (1975) mapped the Quaternary geology of the Cudgen area and concluded it was a mature coast now experiencing net recession, the recession masked by short-term beach oscillations.

At Cape Byron (60 km), sand is moving up the Tallow Beach (Fig. 18.25a) and moving subaqueously along the outer bar and along the base of the 1.3 km long headland to the tip of the cape, where some is periodically transported offshore (southeast) into a subaqueous spit (SSB) by the EAC (Gordon et al. 1978), estimated at 50,000 m^3 $year^{-1}$ by BMT WBM (2013b). The rest bypasses the headland and becomes manifest as a sand pulse on Wategos Beach (volume ~400,000 m^3 $year^{-1}$), before moving down the Pass as an elongate migratory spit which usually impounds a lagoon between the spit and the beach, with a rip exiting the southern end of the lagoon (Fig. 18.26). It then merges with Clarke Beach and continues its northerly transport onto Main and Belongil beaches (Fig. 18.25b) following the sequence proposed by (Short and Masselink 1999) and similar to that operatring at Double Island Point (Fig. 18.7). Patterson (2007b, 2010) calculated this bypassing is on the order of 400,000–450,000 m^3 $year^{-1}$. Goodwin et al. (2013) investigated this system using historical bathymetric data and found two mechanisms for bypassing. During unimodal east-southeast waves, the sand moves around the headland and across the embayment, while during bimodal south-southeast and east-northeast, it splits between cross embayment and inner nearshore. They attribute these changes in wave climate to the impact of the Interdecadal Pacific Oscillation (IPO). Goodwin also found that sand was being lost offshore to the spit and that the rate of transport around the headland was within the first-order calculation of Patterson. They estimated the sand pulses moving along the Pass towards Main Beach each contain between 150,000 and 200,000 m^3 which moved at rates between 120,000 and 240,000 m^3 $year^{-1}$. The northern end of Byron Bay contains the narrow but highly developed Belongil spit that has a long history of erosion-related issues (Carley et al. 2017). BMT WBM (2013b) summarised Belongil spit situation noting it was exposed to immediate storm demand (150–200 m^3 m^{-1}), long-term shoreline recession, impact of Belongil protection works including end effects, migration of Belongil Creek, wave overtopping of parts of the spit and future inundation of Belongil Creek

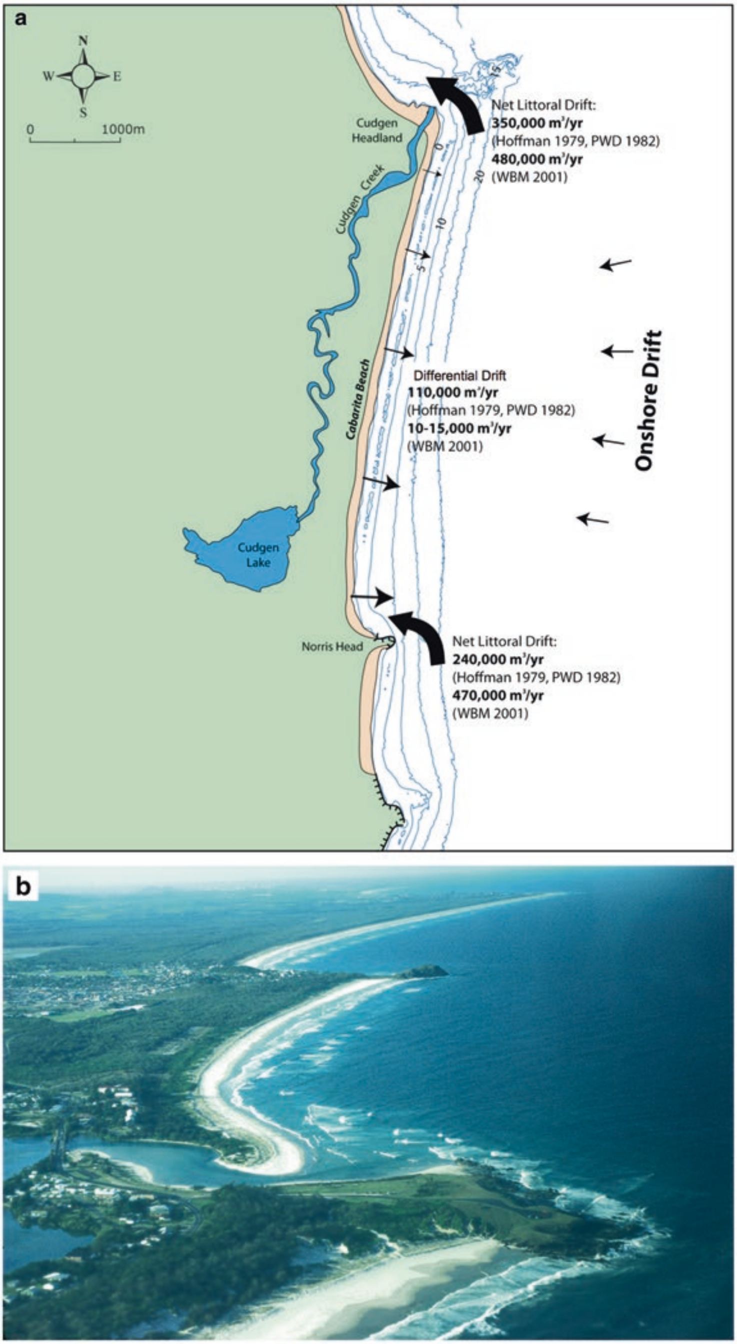

Fig. 18.24 (**a**) Estimated rates of onshore and longshore sand transport between Norries Head and Cudgen Head (Kingscliff). (Source: Mariani et al. 2013, reproduced with permission of the Water Research Laboratory) and (**b**) view north from Hastings Point to Norries Head and Cabarita Beach (NSW 6-4). (Photo: AD Short)

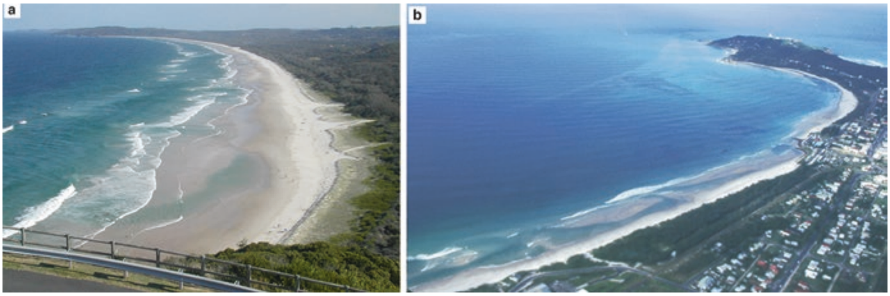

Fig. 18.25 (**a**) Tallow Beach which supplies and to Cape Byron and (**b**) Cape Byron the easterly most tip of Australia with Belongil beach in the foreground. (Photos: AD Short)

Fig. 18.26 Google Earth images of Cape Byron (15.03.18) showing (**a**) outer bar extending seawards of headland, (**b**) sand along the base of the headland, (**c**) sand accumulating around the northern tip of the cape, (**d**) sand moving south into Wategos Beach, (**e**) sand extending west past Wategos, (**f**) waves running down. The Pass and moving sand subaqueously and subaerially to link with Main Beach and (**g**) remnants of a spit trapped lagoon and inlet/rip. Also note the considerable wave refraction around the cape, the oblique waves assisting the sand transport. (Source: Google Earth)

Fig. 18.27 (**a**) Richmond River mouth showing Lighthouse and Shelly beaches (NSW 27-28) in foreground and (**b**) eroding Pleistocene dunes and exposed coffeerock at Broadwater (NSW 29). (Photos: AD Short)

estuary, all of which makes it one of the major NSW coastal hotspots. Finally, investigations by Doyle (2018) indicate that the 10 km long Belongil to Brunswick section may be experiencing northerly rotation since at least 1990, with the northern Brunswick beach experiencing ongoing accretion, while Belongil erodes.

18.7.2 SC:NSW01.01.02 Cape Byron–Richmond River/Ballina

SC:NSW01.01.02 continues south from Cape Byron for 31 km to the Richmond River mouth at Ballina (Fig. 18.24a and 18.27a). It contains two longer beaches (Tallows and Seven Mile) and two rocky sections (Broken Head and Lennox-Ballina). Sand is bypassing the Richmond River and moving northwards around Lennox Head and then Broken Head to reach Tallows Beach and ultimately the cape. The Richmond River training walls (90 km) were built between 1890 and 1910 and extended in the 1960s. This led to the trapping of sand against the southern wall and the formation of Lighthouse Beach against the northern wall and downdrift beach erosion at Lennox Head and Seven Mile Beach (Patterson (2007b). Natural bypassing was restored by about 1990 (Huang et al. 1999) and is presently bypassing the river mouth at a rate of about 260,000 m^3 $year^{-1}$ with the eroded beaches only now beginning to stabilise (Patterson 2007b). The only property at risk is at Lennox Head where several houses were constructed in the hazard zone and are now a coastal hotspot protected by a seawall (Lord et al. 1993).

18.7.3 SC:NSW01.01.03 Richmond River–Evans Head

SC:NSW01.01.03 consists of one long beach extending for 31 km from the Richmond River to Evans Head. Sand is moving around Evans Head (122 km) and up the long South Ballina-Evans Head beach. Owing to a short fall in sand the beach is receding and along the Broadwater section (112 km) is exposing white leached Pleistocene dunes rising in places to 20 m, together with thick layers of coffeerock outcropping on the beach and inner surf zone (Fig. 18.27b) all indicative of shoreline recession. Photogrammetry between 1953 and 2010 indicates that beach is receding at 0.5 m year^{-1} (Worley Parsons 2012).

18.7.4 SC:NSW01.01.04 Evans Head–Clarence River/Yamba

SC:NSW01.01.04 is dominated by the 28 km long curving Ten Mile Beach bordered by rocky sections and smaller embayed beaches at the northern Evans Head and southern Woody Head-Yamba and includes the trained mouth of the Clarence River (Fig. 18.23b). Sand moves into the system crossing the Clarence River mouth, bypasses the rocky sections and continues northwards via Woody and Shark bays. Recession of Woody Bay and Ten Mile Beach indicates there is a shortfall in the volume transported which is being supplemented by beach recession. Goodwin et al. (2006) investigated this system which extends for 8 km longshore, is up to 2 km wide and capped by up to 15 regressive foredunes. Based on the orientation and age of the ridges, they were able to reconstruct the rates of longshore sand transport over the past 3 ka which they found is driven by subtle changes in wave direction. They found that during the past 3 ka, there has been considerable shoreline regression between the Clarence and Shark Bay, regression that has now turned to recession.

At the southern PC boundary, the Clarence River (165 km), Goodwin et al. (2006) found that sand is moving past the river mouth and along the embayed Iluka-Woody Head shoreline and episodically bypassing into Woody Bay and then onto Shark Bay. The rate of transport has been estimated at ~75,000 m^3 year^{-1} by Floyd and Druery (1976) and Goodwin et al. (2006). Goodwin et al. further found that there has been no significant change in the rate of longshore transport over the past 3 ka and that the present shoreline recession at Woody and Shark bays cannot be attributed to a decrease in supply. At Shark Bay (154 km) midway between the Richmond and Clarence rivers, Patterson (2007b) estimated the transport rate at ~200,000 m^3 year^{-1}. Whether sand is being sourced from the shoreface, as proposed by Cowell et al. (2001); erosion of updrift compartments, as proposed by Chapman et al. (1982); or both remains to be resolved.

18.7.5 PC Overview

This is a very dynamic and vulnerable PC with 83% of the coast composed of generally exposed drift-aligned sandy beaches, some of which are receding. The entire 170 km long system is part of a major continuous longshore transport system that increases in volume from 250,000 m^3 year^{-1} at the Clarence to 500,000 m^3 year^{-1} at the Tweed. Some of this sand is lost onshore to tidal deltas and offshore to SSB's. The shortfall is being made up from shoreline recession on some of the longer beaches and possibly limited input from the Clarence River. It remains to be resolved whether sand is being sourced from the shoreface; however more recent work by Patterson (2007b) and BMT WBM (2013b) indicate this is becoming a more likely source. Rising sea levels will accelerate the rate of recession, while any changes in wave climate will affect the rate of sand transport which would have implications throughout this drift-aligned system.

18.8 PC:NSW01.02 Yamba–South West Rocks

PC:NSW01.02 commences on the southern side of the Clarence River at Yamba and continues south for 201 km to South West Rocks and includes the small Nambucca and moderate-sized Macleay and Hastings rivers (Fig. 18.1b; Table 18.12), all of which are sinks for marine sands. This PC is part of the New England Fold Belt whose resilient sedimentary and metasedimentary rocks dominate the rocky sections of coast and have been eroded to form small valleys in the north widening a little to the south. The coast is dominated by 94 beaches which occupy 165 km (82%) of the shore. However, they are interrupted by the rocky sections south from Yamba, around Minnie Waters and between Woolgoolga and Coffs Harbour which shorten the beaches to a mean length of 1.75 km. The shorter beaches tend to be lower energy LTT and R (16%), while the more exposed longer beaches (mean length 3 km) are predominately double-barred with a LBT outer and TBR-RBB inner bar (83%), which have a total of 514 beach rips (Tables 18.7 and 18.20). The beaches tend to face east (99°) and are slightly embayed (0.76), with a low to moderate gradient swash zone (3.4°), with an average of 1.15 bars and a 77 m wide surf zone (Table 18.7).

The PC contains 38 barriers that occupy 147 km (73%) of the coast, with a relatively low per metre volume of 8664 m^3 m^{-1} (Table 18.15). The barriers tend to be short (mean 4.2 km), low (mean 11 m), narrow (270–800 m) and vegetated, with dune transgression restricted to Station Creek, Hat Head and Killick beaches. More extensive Pleistocene barriers back a number of the barriers, particularly in the north between Angourie and Station Creek. The PC contains five SCs (Table 18.19) which are discussed below.

Table 18.20 PC:NSW01.02 beach types and states

BS	BS	n	%	total km	mean (km)	σ (km)	% (km)
3	RBB[a]	6	6.4	9.1	1.5	1.7	5.5
4	TBR[a]	42	44.7	127.3	3	2.8	77.3
5	LTT	26	27.7	18.6	0.7	0.8	11.3
6	R	20	21.3	9.7	0.5	1.1	5.9
		94	100	164.7	1.8	–	100

[a]These are predominately inner bar states on a double-bar system, with LBT outer bar

18.8.1 SC:NSW01.02.01 Yamba–Wooli/Barcoongere

SC:NSW01.02.01 occupies 61 km of coast between Yamba and Wooli river mouth, including most of the Yuraygir National Park coastline (Fig. 18.28a). It trends almost due south as a series of curving slightly embayed beaches averaging 1.5 km in length (σ = 2.2 km). Apart from Yamba (6000), this is a largely undeveloped coast dominated by Yuraygir National Park which surrounds small settlements at Brooms Head (200), Minnie Waters (200), Diggers Camp (20) and the larger Wooli (500). Most of these communities are located on high ground and/or well back from the shoreline, apart from part of Brooms Head and Wooli which are both NSW coastal hotspots.

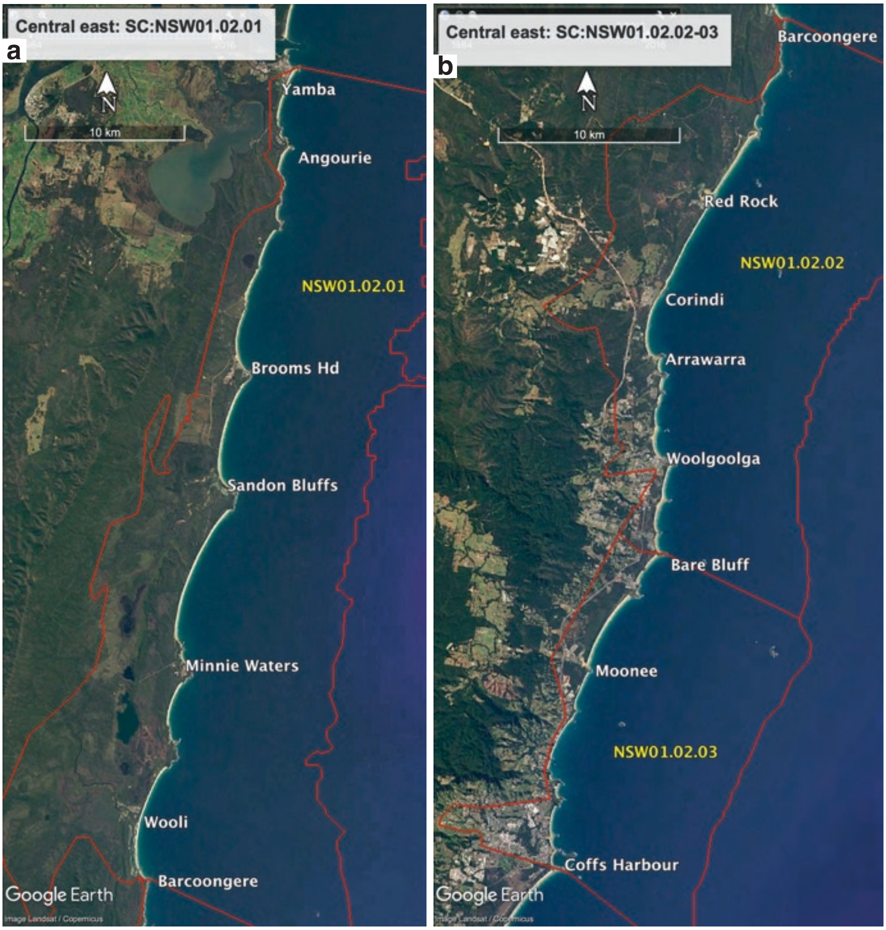

Fig. 18.28 (**a**) SCs NSW01.02.01 and (**b**) 01.02.02–03. (Source: Google Earth)

Skene and Roy (1985) investigated the Quaternary geology of the Wooli region and found the embayments filled with both Pleistocene and Holocene marine and terrestrial sediments. However, they found there was limited Holocene accommodation space resulting in sand moving northwards through the system, with some sand being deposited in a SSB that parallels Bare Point out to 40 m depth. They also found the Holocene barriers were narrow usually consisting of a foredune abutting bedrock or Pleistocene barriers. Based on this and the presence of exposed Pleistocene dunes, they concluded the coast has receded in the past and is continuing to slowly recede, with most sand in transit through the system, moving along the beaches and bypassing the headlands, which Chapman et al. (1982) suggest were only a partial obstacle to sand transport.

RH DHV (2016) found that Wooli has 50 properties at immediate risk and 150 predicted to be at risk by 2100. They also report a longshore transport rate at Wooli between 10,000 and 30,000 m^3 $year^{-1}$ with approximately 1000 m^3 $year^{-1}$ moving into the northern dune field and 500 m^3 $year^{-1}$ lost into the Wooli flood tide delta (Fig. 18.29a), with unknown offshore losses to the SSB expected during severe storms. As a consequence, Wooli Beach has receded between 0.3 and 0.5 m^3 $year^{-1}$ between 1942 and 2006 and placed the beachfront property at risk. In addition, part of the village is prone to fluvial and marine inundation.

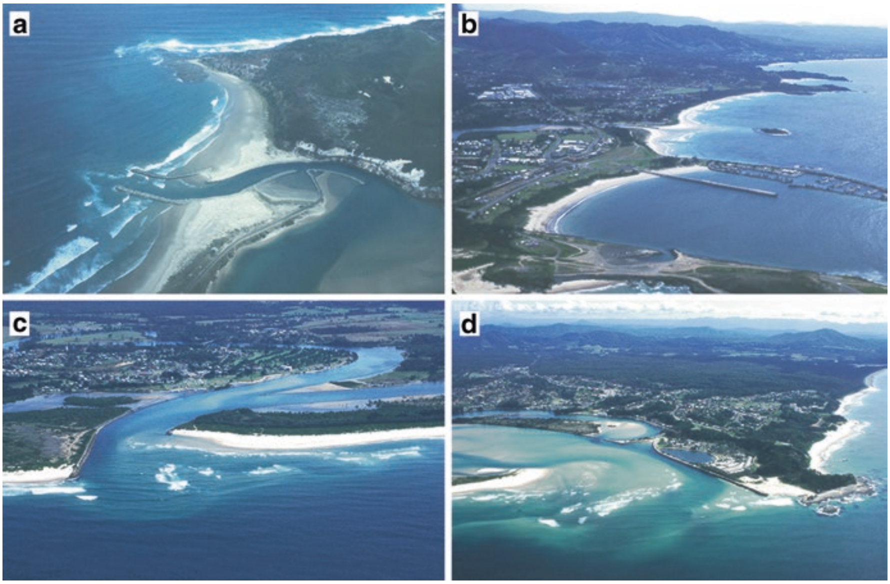

Fig. 18.29 (**a**) The trained Wooli River mouth (NSW 73-74); (**b**) Coffs Harbour (NSW 109-111); (**c**) the partly trained Bellinger River mouth (NSW116) (note the offset caused by the trapping of sand against the training wall where the shoreline has prograded 400 m); and (**d**) the partly trained Nambucca Heads and river mouth (NSW 127-129). (Photos: AD Short)

18.8.2 SC:NSW01.02.02 Wooli/Barcoongere–Bare Bluff

SC:NSW01.02.02 continues south of the Wooli for 35 km to Bare Bluff (Fig. 18.28b). It consists of a northern rocky section with short embayed beaches between Wooli and Red Rock and contained within Yuraygir National Park, south of which is the 15 km straight long Corindi-Arrawarra beach and then the rocky embayed section down to Bare Bluff. This is a moderately developed section of coast with nodal development at Red Rock (300), Corindi (1200), Arrawarra (600), Mullaway (600), Safety Beach (800), the larger Woolgoolga (5500) and Sandy Beach (1000), most separated by reserves, headlands and/or coastal lagoons.

While there have been no studies of sand transport in this SC, sandy beaches occupy 28 km (80%) of the shore. However, apart from the longer Corindi-Arrawarra beach, most are embayed between headlands and reefs, and consequently longshore transport will be at best interrupted by the northern rocky section and Woolgoolga Head, as suggested by Chapman et al. (1982). Rates are expected to be on the order of tens of thousands of cubic metres. Figure 18.30 shows rips extending off both Sandy Beach headlands, with the southern rip moving past Bare Bluff and into the Sandy Beach embayment, indicating that even under moderate conditions, headland sand bypassing is occurring.

18.8.3 SC:NSW01.02.03 Bare Bluff–Coffs Harbour/Corambirra Point

SC:NSW01.02.03 is bordered by the protruding Bare Bluff in the north and in the south Corambirra Point and its 550 m long attached breakwater, which forms the southern entrance to Coffs Harbour (Fig. 18.29b). In between is 27 km of coast containing 19 generally short beaches (mean = 0.9 km) which occupy 18 km (67%) of the coast, the remainder made up of headlands and rocky sections. This is a moderately well-developed section of coast with nodal communities at Emerald Beach (4500) and Moonee Beach (2100) in the north and then near continuous development south from Sapphire Beach (4800) to the large Coffs Harbour (70,000). Most of the development is located on high ground and/or back from the beach resulting in little property at risk, except at Campbells Beach (NSW 101) where there are a few houses and parts of a resort located within the hazard zone.

Sand transport along this section is interrupted by the rocky sections and several headlands including the two attached harbour breakwaters, though a number of studies suggest the episodic headland bypassing is occurring (Roy and Stephens 1980a, b; RDM 1998; BMT WBM 2010). Lord and Van Kerkvoort (1981a; b) conducted a sand tracing experiment at Diggers Beach and found sand was bypassing the prominent Diggers Headland and reaching beaches to the north within 1–2 days and still detectable up to 3 months.

Fig. 18.30 Two headland rips (arrows) located at either end of Sandy Beach (NSW 93), with the southern Bare Bluff rip continuing north into the Sandy Beach embayment, indicating it can bypass sand past the headland. Red line is SC boundary. (Source: Google Earth)

At Coffs Harbour (282 km), Roy and Stephens (1980a; b), Lord and Van Kerkvoort (1981a, b) and Gordon (1987) estimated rates of ~75,000 m^3 year^{-1}, equivalent to that at the Clarence. RDM (1998) found that sand was bypassing Macauleys Head, at the northern end of Park Beach, at a rate of between 11,000 and 18,000 m^3 year^{-1}, the shortfall made up by recession of Park Beach (NSW 109). Carley et al. (2006) concluded the harbour was acting as a major obstacle with the northern end of Boambee Beach accumulating at a rate of ~30,000 m^3 year^{-1}, with 37,500 m^3 year^{-1} bypassing Corambirra Point and ~50,000 m^3 year^{-1} lost into the harbour. As a result of the sand trapping by the harbour, they found that Park Beach (NSW 109) was receding at a rate of 0.5 m year^{-1} and the downdrift beaches including Campbells, Pelican, Riecks Point and Sapphire (NSW 98–100) were all receding and had lost ~75,000 m^3 $year^{-1}$, an amount equivalent to the longshore transport, while the beaches from Moonee Beach (NSW 97) northwards were more stable. BMT WBM (2010) modelled longshore transport along the Coffs Harbour coast and found that rates tended to increase northwards along the beaches peaking at 75,000 m^3 $year^{-1}$ for Boambee. They predicted by 2050 and 2100 the rates would generally increase with the harbour acting as a major sediment sink and obstacle leading to ongoing beach recession to the north, in addition to any sea-level rise-induced recession. BMT WBM (2010) provides a summary of beach behaviour for beaches between Pebbly Beach (NSW 78) and Sawtell (NSW 114) which includes beaches in this and the adjoining SCs.

18.8.4 SC:NSW01.02.04 Coffs Harbour–Nambucca Heads

SC:NSW01.02.04 continues south of Coffs Harbour along a sand-dominated coast to Nambucca Heads, 35 km to the south (Fig. 18.31a). Apart from Sawtell (3500), the small Mylestom (350) and larger Nambucca Heads (18,000), this is a largely

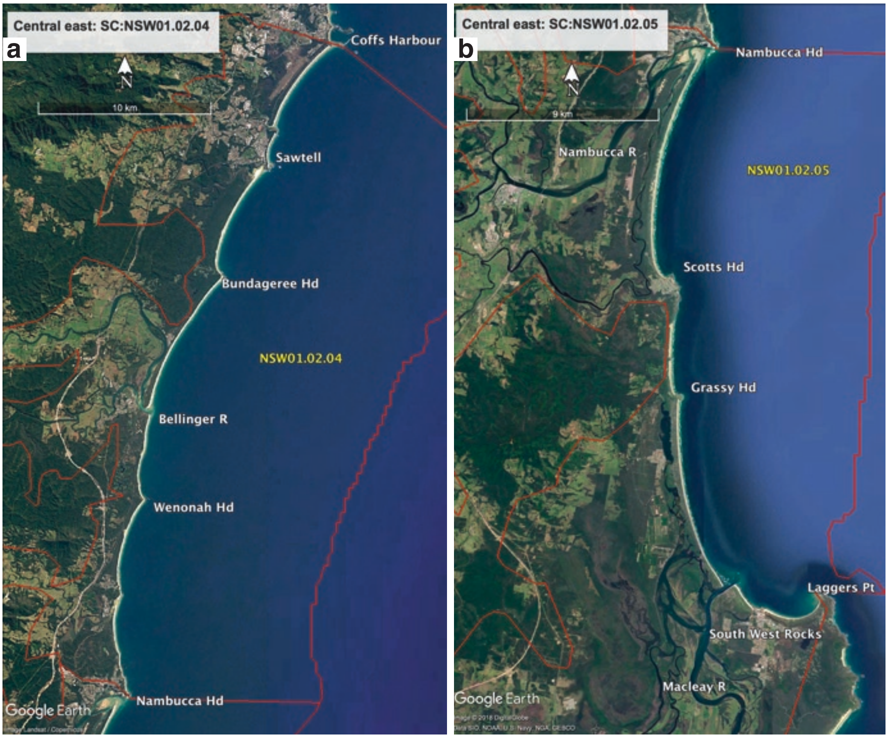

Fig. 18.31 (**a**) SC:NSW01.02.04 and (**b**) SC:NSW01.02005. (Source: Google Earth)

undeveloped section of coast with no property presently at risk. The SC has 15 beaches averaging 2.7 km in length that occupy 40 km (93%) and dominate the SC. The longer beaches are near continuous extending around some of the subdued headlands and rocky points with the only prominent headlands located at Sawtell. In addition, there are tidal creeks at Boambee and Deep Creek (Sawtell) and the small partly trained Bellinger River (Fig. 18.29c). The river had a very dynamic and migratory entrance prior to training between 1890 and 1905. The shoreline subsequently prograded to the tip of the training wall, and sand is now bypassing the entrance (316 km) at a rate estimated at 60,000 m^3 $year^{-1}$, with a rate at of 70,000 m^3 $year^{-1}$ at Nambucca (333 km) 15 km to the south (BMT WBM 2014). A similar rate of 65,000 m^3 $year^{-1}$ has been calculated for Scotts Head (346 km) and Trial Bay (364 km) (BMT WBM 2013c). It can therefore be assumed that sand is being transported into along and out of this SC at a rate of ~60–70,000 m^3 $year^{-1}$.

18.8.5 SC:NSW01.02.05 Nambucca Head–Laggers Head

SC:NSW01.02.05 commences at the partly trained Nambucca River mouth (Fig. 18.29d) and extends south to the Macleay River mouth where its curves round to the east in lee of the PC boundary at Laggers Head (Fig. 18.31b). The only development is at Scotts Head (850) and South West Rocks (5000) both located on high ground with no property at risk. This SC contains three longer beaches at Scotts Head, Stuart Point and Trial Bay, separated by rocky headlands at Scotts-Grassy heads, and the Macleay River training walls and South West Rocks. The 10 beaches occupy 30 km (86%) of the shore, with double-bar systems along the longer east-facing beaches.

The single-northern Nambucca training wall was built in 1890, and the Macleay River training walls were built between 1895 and 1902, the latter stabilising the river entrance that had previously migrated up to 11 km between South West Rocks and Grassy Head. The eastern wall protrudes 500 m further seawards than the western wall and has filled with trapped sand leading to an offset in the beach alignment. This offset is now stable, and sand is bypassing the river mouth via the ebb tidal shoals and onto the now stable Stuarts Point beach. Some marine sand extends into the river mouth building a small flood tide delta. This fact plus the presence of fluvial sand within a few kilometre of the river mouth and an efficient tidal channel suggests that small volumes of fluvial sand may be episodically delivered to the coast (BMT WBM 2013c).

Headland bypassing around the large Smoky Cape section of coast is evident from the sand waves and spits that form regularly at Laggers Head, the downdrift end of the 6 km long rocky section and the PC boundary. This sand moves into Trial Bay and along the beach at a rate estimated at 60,000 m^3 $year^{-1}$ (BMT WBM 2013c). It is likely this sand continues west bypassing South West Rocks and the Macleay River mouth and then moves northwards along the more energetic double-barred Stuart Point and Scotts Head beaches to reach the next SC at Nambucca Heads, where a similar rate of transport has been proposed.

18.8.6 PC Overview

PC:NSW01.02 has a predominately sandy shoreline (82%) that faces east into the prevailing southerly swell with its 94 beaches averaging 1.8 km in length and most bounded by rocky headlands, together with 20 generally small creek and river and mouths, including the trained Bellinger, Nambucca and Macleay river mouths. This is a moderately developed section of coast including the extensive Coffs Harbour region, Nambucca Heads, Sawtell, Scotts Head and South West Rocks, all located on high ground, while the remainder of the coast is undeveloped largely consisting of beaches backed by vegetated foredunes. There are however erosion hotspots at Brooms Head and Wooli where houses have been constructed in the beach hazard zone. Most of the beaches are well exposed to wave attack, and all are part of the northerly longshore sand transport. Rising sea levels are likely to initiate shoreline recession and movement of sand into the deeper creek and river mouths and into Coffs Harbour, all of which will aggravate the recession. Modulation in wave climate will also impact the rates of sand transport which will impact all the beach systems.

18.9 PC:NSW01.03 Laggers Point to Cape Hawke

The southern PC:NSW01.03 trends south-southwest (orientation 110°) for 192 km to the prominent 224 m high Cape Hawke, one of the highest headlands on the coast. The cape lies towards the southern end of the New England Fold belt, and a mix of sedimentary, metasedimentary and igneous rock types outcrop along the coast forming the numerous headlands and in places rock reefs. There are 63 beaches which occupy 144 km (72%) of the coast, with an average length of 2.3 km, most bounded by rock headlands. The more prominent headlands form about ten curving embayments containing the longer beaches (Hat Head 6 km, Killicks 15 km, North Shore 13 km, Lighthouse 10 km, Dunbogan 9 km, Harrington-Diamond 30 km, Nine Mile 12 km) with smaller beaches dotting the rocky sections. The entire coast is well exposed to the southerly swell and northerly longshore transport prevailing throughout, though not without interruption at the larger headland and creek and river mouths. The longer beaches are double-barred with usually a LBT outer and TBR-RBB (77%) inner bar, with lower energy LTT (22%) and R (1%) associated with sheltering by the headlands (Table 18.21). They face on average 110° and are slightly embayed (0.76) with wide beaches and low swash gradient (3.2°) and usually wide (93 m) double-barred surf zone, together with 445 beach rips crossing the inner bar (Table 18.7).

The PC has two rivers, the trained Hastings at Port Macquarie and Manning at Harrington, together with its southern distributary at Farquhar Inlet, trained inlet entrances at Tuncurry (Wallis Lake) and Camden Haven and small Khappinghat Creek at Saltwater. Each of these is acting as sink for marine sands with substantial flood tide deltas in the Manning and Farquhar.

Table 18.21 PC:NSW01.03 beach types and states

BS	BS	n	% no	Total km	Mean (km)	σ (km)	% (km)
3	RBB[a]	3	4.8	13.8	6.9	6.3	10.3
4	TBR[a]	34	54.0	88.7	2.6	3.9	66.4
5	LTT	17	27.0	29.8	2.3	4.1	22.3
6	R	9	14.3	1.25	0.14	0.1	0.9
		63	100	133.6	2.1	–	100

[a]These are predominately inner bar states on a double-bar system, with LBT outer bar

The coast has limited nodal development at Hat Head (350), Crescent Head (1600), the large Port Macquarie (46,000), Lake Cathie-Bonny Hills (6500), Camden Haven (7500), the small Crowdy Head (250), Harrington (2500), Manning Point (250), Old Bar (4000), Black Head (750) and in the south the larger Tuncurry-Forster (19,000). In between are undeveloped reserves and Hat Head and Crowdy Head national parks. While most of these communities are located on high ground and/or back from the shoreline, Lake Cathie and Old Bar are coastal hotspot with beachfront properties risk. This PC contains four SCs (Table 18.19) which are discussed below.

18.9.1 SC:NSW01.03.01 Laggers Head–Tacking Point

SC:NSW01.03.01 (Fig. 18.32) contains five curving beach systems bounded by Smoky Cape, Hat Head (Fig. 18.33b), Crescent Head, Racecourse Head, Point Plomer and Hastings River mouth (Fig. 18.33c), with smaller beaches located around the headlands and between Racecourse and Point Plomer. All of the beaches are in a natural condition with most located in Hat Head National Park and reserves extending south of Crescent Head. The 33 beaches occupy 53 km (65%) of the shore, the remainder rocky headlands. Sediment is moving northwards along the beaches and bypassing the headlands, including the large Smoky Cape in the north. Sand movement around Hat Head causes the small headland beaches to come and go (Short 2007) depending on the phase in the transport. BMT WBM (2013c) assumes an average northerly transport of 65,000 m^3 $year^{-1}$ for the Kempsey region (Grassy Head to Point Plomer). It is likely some sand is also lost offshore, as well as into the Killick and Hat Head beach dunes (Fig. 18.33a) and the Manning-Farquhar flood tide deltas (Fig. 18.33d).

BMT WBM (2013c) also found that the beaches in the Kempsey region (NSW 132-156) were stable at least between 1967 and 2009. Without sea-level rise, they predicted the beaches to remain stable to 2100. However, with sea rise they predict an interruption to longshore sand transport and consequently recession to occur particularly at the southern end of the longer beaches, with less recession towards the northern ends which will be receiving sand eroded from the southern sections. At Port Macquarie (445 km), PWD (2014) estimated the longshore transport through

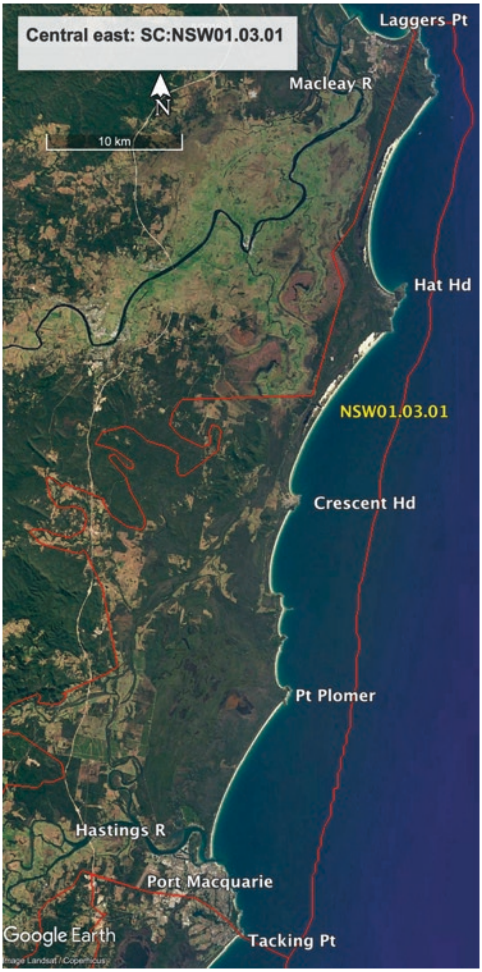

Fig. 18.32 SCs NSW01.03.01. (Source: Google Earth)

the rocky section at Flynn's beach (NSW 164) to be between 20,000 and 50,000 m^3 year^{-1}. PWD also noted it moved in pulses causing fluctuations in beach width though there was no evidence of recession over the past 40 years.

18.9.2 SC:NSW01.03.02 Tacking Point–Crowdy Head

SC:NSW01.03.02 is a 58 km long section containing four longer embayed beaches separated by the bedrock Tacking Point, Bonny Hills, Camden Haven, Diamond Head and Crowdy Head (Fig. 18.34). The beaches occupy 45 km (78%) of the coast and are backed by narrow Holocene barriers abutting wider regressive Pleistocene barriers. The narrowness of the Holocene barriers and exposure of Pleistocene

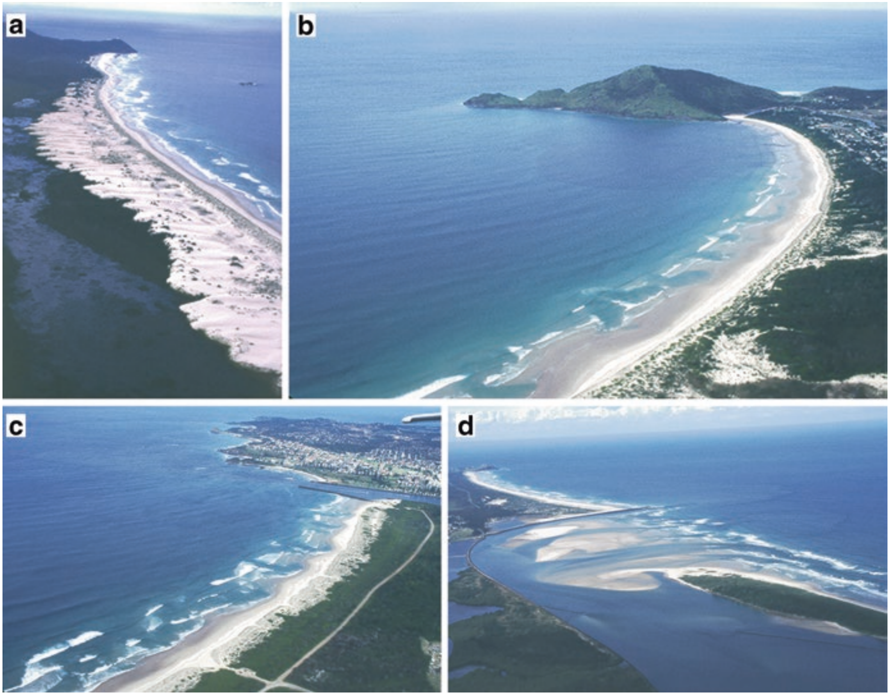

Fig. 18.33 (**a**) Transgressive dune south of Smoky Cape (NSW 144a), (**b**) Hat Head (NSW 144c with a series of well-developed rip channels), (**c**) North Shore rip-dominated beach and Port Macquarie (NSW 159) and (**d**) the Manning River mouth at Harrington (NSW 185-186). (Photos: AD Short)

coffeerock at several locations indicate that the coast is receding, which at Lake Cathie estimated is on the order of 0.1–0.3 m year^{-1} (SMEC 2013). Sand is expected to be transported along the longer beaches and around the headlands probably at rates on the order of 50,000 m^3 year^{-1}. Some of the headlands may result in loss of sand offshore, particularly Crowdy Head, which would also contribute to the general shoreline recession. The only area at risk is along the Lake Cathie foreshore where about 15 houses and a road are at immediate risk to wave impact and slope adjustment (SMEC 2013) and classified as a hotspot. The risk is somewhat ameliorated by the presence of coffeerock along the foreshore; however they remain a coastal hotspot.

18.9.3 SC:NSW01.03.03 Crowdy Head–Black Head

SC:NSW01.03.03 is essentially one 32 km long embayment bordered by Crowdy Head and Black Head (Fig. 18.34), with eight near continuous beaches occupying 31 km (97%) of the shore, together bedrock headlands at Saltwater-Wallabi Point

Fig. 18.34 SCs:NSW01.02.02-03. (Source: Google Earth)

and Red Head, and the Manning (Fig. 18.33d), Farquhar and Khappinghat inlets. This is a receding shore with Worley Parsons (2010) estimating recession rates of −1.4 m year^{-1} at Old Bar, −0.2 m year^{-1} at Saltwater and −0.1–0.2 m year^{-1} at Diamond and Black Head beaches, while Harrington Beach is presently stable. The recession is due to a shortfall in the longshore transport, estimated to be on the order of 50,000 m^3 year^{-1}, with the more rapid recession at the protruding Old Bar probably due to a readjustment in the nearshore bathymetry. Worley Parsons (2010) proposed a rather complex model of sand transport between Black Head and Crowdy

Head. They predict that ~10,000 m^3 $year^{-1}$is bypassing Black Head from Nine Mile Beach, with just 2000 m^3 $year^{-1}$ bypassing Diamond Head, with no significant bypassing of Saltwater Point, while just to the north, they estimated 4000 m^3 $year^{-1}$ is bypassing Wallabi Point. However, to the north of Wallabi Point, they calculated rates of 70,000 m^3 $year^{-1}$ at Urana Bombora and along Old Bar beach, the shortfall the cause of the ongoing beach recession which is placing houses at immediate risk at Old Bar, a coastal hotspot, and future risk at Diamond beach. The recession at Old Bar has resulted in a number of protective measures including geotextile bags and the demolition of one property that was in danger of collapse. At Farquhar Inlet they found a net loss to the inlet of 70,000 m^3 $year^{-1}$, with the short fall in sediment causing recession of Mitchell Island (Manning Point) beach equivalent to 130,000 m^3 $year^{-1}$ which is exposing Pleistocene coffeerock along the shore. This recession together with a low foredune and backing Manning River exposes the small Manning Point community to shoreline recession, marine inundation and river flooding, with a risk of being cut off in an extreme event. At the Manning River mouth (Fig. 18.33d), they predicted 100,000 m^3 $year^{-1}$ is being lost to the river with 30,000 m^3 $year^{-1}$ bypassing the inlet. Finally, they found Harrington Beach is accreting at 20000 m^3 $year^{-1}$, while at the northern end of the system, 10,000 m^3 $year^{-1}$ is bypassing around Crowdy Head.

18.9.4 SC:NSW01.03.04 Black Head–Cape Hawke

SC:NSW01.03.04 is the southernmost SC in the central east region and a relatively small compartment extending for 20 km between Black Head and Cape Hawke (Fig. 18.35). It contains eight beaches, which occupy 15 km (75%) of the shore, the remainder bedrock headlands and the trained Wallis Lake inlet at Tuncurry. This compartment has acted as a major sediment sink throughout the late Pleistocene. Roy et al. (1997) investigate the 9 km wide Tuncurry barrier system and found it contained three inner barriers dating back to 260 ka, 145 ka and 95 ka, with the Holocene outer barrier regressing 2.5 km seawards between 8 and 1 ka (see P and H Fig. 18.35). They propose the source of this sand has been the shelf sand bodies located between Cape Hawke and Seal Rocks, with this sand ultimately derived from the Hunter River and possibly further south. At the southern PC boundary at Cape Hawke (560 km), a bypassing rate of 30,000 m^3 $year^{-1}$ was suggested by Chapman et al. (1982), upgraded to 200,000 m^3 $year^{-1}$ in a more detailed investigation by Roy et al. (1997). Of this they calculated an annual rate of sediment supply to the embayment of about 46,000 m^3 $year^{-1}$, which is in agreement with the general rate of longshore transport on this section of coast. The cessation of barrier regression may be related to the filling of the embayment and its accommodation space, as the sand is now clearly leaking around the northern Diamond Reef boundary and likely to be bypassing around Red Head and onto Black Head beach. Kinsela et al. (2016a) modelled the development of the Tuncurry strandplain which involves a shoreface supply from a disequilibrium shoreface morphology, estimated at 6 ka to lie between 15 and 35 m

Fig. 18.35 SCs NSW01.03.03-04. (Source: Google Earth). P and H indicated the Tuncurry Pleistocene and Holocene barriers, respectively

water depth with a maximum thickness of 6 m and a volume of 21,000 $m^3\ m^{-1}$. This supplied the prograding barrier, complemented with 20% contributed from longshore transport which increased from 3 ka when the headland-attached SSB was established and updrift sediment sinks were stabilised. In addition, a late Holocene fall in sea level may have contributed half the secondary sand supply. They further concluded that ongoing relaxation of disequilibrium shoreface morphology may be supplying 1–2 $m^3m^{-1}yr^{-1}$ on some southeast Australian beaches.

At Tuncurry the Wallis Lake entrance was trained in 1966 and has since led to a significant increase in tidal prism and tide range leading to increased salinity and increase penetration of marine sands (flood tide delta) into estuary (Nielsen and Gordon 1980), sand which is lost from the coastal system.

18.9.5 PC Overview

PCNSW01.03 contains a series of longer curving embayed beaches bordered by a range of headland and rocky sections, all of which appear to be allowing some sand bypassing. The longer beaches are rip-dominated and double-barred with sand moving longshore in the surf zone to and around most, if not all, of the headlands. The estimated rates of longshore transport range from about 50,000 m^3 in the south (Cape Hawke) to 70,000 m^3 in the north at South West Rocks. A number of factors modulate this transport causing spatial and temporal fluctuations in transport rates. Spatial variation is caused by change in beach orientation and the impact of the headland and inlets-river mouths, such as between Diamond and Crowdy heads, while seasonal and decadal temporal variation is driven by the highly variable though predominately southerly wave climate. In addition, the headland bypassing results in pulses of sand with associated downdrift impacts (Short and Masselink 1999). The headlands are also a potential source of offshore losses via megarips (Fig. 18.30) and as proposed at Bare Point by Skene (1988). Other losses are to dunes, inlets and the river mouths. Sources include possible minor fluvial supply, from at least the Macleay, and from offshore. Overall however, there is a deficit in sand as evidenced by the long-term recession of a number of the beaches, the narrowness of the Holocene barriers and the exposure of Pleistocene dunes and coffeerock at the shore. Future climate-induced changes in sea level will to exacerbate all these impacts leading to greater shoreline recession and inundation of the many estuaries, while changes in wave climate will impact transport rates.

18.10 Northern NSW Regional Overview (PC:NSW01-03)

This northern NSW coast (PCs:NSW01–03) is experiencing northerly longshore transport from at least Coffs Harbour and probably as far south as Cape Hawke. The rate of transport increases northwards from around 50,000 m^3 $year^{-1}$ up to 600,000 m^3 $year^{-1}$, with the increase accommodated by beach and dune recession, limited river sand supply (e.g. the Clarence and Macleay) and sand from the nearshore. It is unlikely that this transport is continuous along the entire PC at the present high sea-level stand. Chapman et al. (1982) identified major or complete obstacles to longshore sand transport at Wooli (230 km), Woolgoolga (255 km), Crescent Head (412 km), Camden Haven (470 km) and Crowdy Head (505 km). Based on all of the above, it appears there is probably continuous longshore transport from at least Wooli to the Tweed and beyond, involving the bypassing of several headlands, with some sand being lost offshore and onshore, while some is contributed from rivers, beach erosion and the offshore. Further south there appear to be a number of transport subsystems, each transporting sand northwards until it is blocked by major obstacles, where some may be transported offshore. Roy and Stephens (1980a) suggested that this region went through a phase of shoreline regression in the mid-Holocene, which was followed by shoreline stability or recession. They saw the present slow recession superimposed on shoreline oscillations and the impact of major structures. On a local scale, they identified variable rates of longshore transport resulting in more severe erosion in the southern end of embayed beaches as more sand moves out of their higher energy central-northern sectors. However, given the wide range in transport rates, not to mention the somewhat variable coastal topography, together with open, closed and leaky boundaries, and input of onshore and offshore sources, more work is required to obtain more accurate rates of transport in the numerous compartments along this subregion and the degree of bypassing of the many headlands.

Vieira da Silva et al. (2016a, 2016b) investigated and modelled headland bypassing on the Santa Catarina coast of Brazil. This coast lies at a similar latitude (27°S) to the central east region and has a similar wave climate and tide range, a fact they used to compare bypassing at Santa Catarina and at Point Danger in Vieira da Silva et al. (2017). They found that Santa Caterina experienced reversals in transport which lowered the net northerly rate, while the transport rate was higher and more unidirectional at Point Danger.

The impact of sea-level rise on the open coast and estuaries in northern NSW was investigated by Kinsela et al. (2017) and Hanslow et al. (2018), respectively. Kinsela et al. used the NSW SCs to identify 137 TCs, with the TC delineation based on (1) dimensions and average orientation of coastal sectors and embayments; (2) prominence and alongshore extent of coastal headlands, cliffs and visible nearshore reefs; (3) extent of tidal inlets and training walls (where present); and (4) shoreface geometry depicted in regional-scale bathymetry data. They then applied a shoreline encroachment model (Kinsela et al. 2016) to predict cumulative beach erosion by 2100 in each PC, which ranged on average between 100 and 150 m. They also assessed the number of properties potentially affected by the erosion at the 1% exceedance level within the six NSW PCs. They found the greatest exposure was in northern NSW (PCs:NSW01.01-02) with 300 properties presently at risk increasing to ~1900 properties by 2100 in NSW01.01 and 500 increasing to 2300 in NSW01.02.

Hanslow et al. (2018) used the same compartment approach to assess the impact of sea-level rise in all 184 major NSW estuaries. They also found the greatest impact in terms of properties and land at risk to inundation will occur in PCs:NSW02.01-02, where they found there are presently 1200 exposed properties that will increase to 3100 by 2050 and 4800 by 2100. Likewise, they found that at present, there is 70 km of roadway exposure to erosion (1% level) which will increase to 196 km (2050) and 311 km (2100).

In NSW the NSW SeaBed mapping program was initiated in 2017 by the NSW Office of Environment and Heritage (OEH) as a 4-year program to map NSW secondary sediment compartments on a priority basis with multibeam and marine lidar. The aims were to (1) determine the distribution and variability in nearshore sediment types so as to better understand alongshore-across shore sediment transport and (2) further develop a state-wide coastal digital elevation model. Linklater et al. (2018) describe the program and the seabed classification procedure with examples of mapping from the Coffs Harbour SC (NSW01.02.03) and Wollongong SC (NSW02.04.02) and applications to coastal management.

18.11 Central East Overview (QLD05 and NSW01)

The central east region occupies 1260 km of the east Australian coast and contains two subregions, southeast Queensland (QLD05) and northern NSW (NSW01). The region is exposed to a predominately southerly wave climate which drives a northerly transport of uniform fine-medium, well-sorted, quartz-rich sand ultimately sourced from rivers draining the eastern highlands and deposited across the shelf at lower sea levels. Throughout the Quaternary the sand has been transported onshore and longshore and deposited as embayed Pleistocene barriers, flood tide deltas and SSB's in NSW, while once across the Queensland border, it has been deposited as massive barrier islands extending out across the inner to mid to finally outer shelf and ultimately down the continental slope to the abyssal plain north of Fraser Island, together with massive tidal deltas between the islands, and transported via Great Sandy Strait and Hervey Bay northwards to at least Rodds Bay. A number of factors influence the nature and stability of the present coastline. First, the northerly transport is continually interrupted by the many headlands, trained and natural river mouths, and tidal inlets resulting in a continuous but very temporally and spatially disjointed supply; second, there is a general increase in the rate of transport northwards from ~50,000 to ~500,000 m^3 $year^{-1}$, an increase that has to be made up from local sources; third, the local sources include beach-dune recession, very limited river supply and probably shelf supply all of an unknown quantity, with BMT WBM (2013b) providing some estimates. This transport is dependent on prevailing wave conditions with Tasman-origin southerly waves improving connectivity and bypassing, while east to tropical-origin northeast waves reduce transport rates and bypassing and can generate reversals. Goodwin et al. (2016) predict that global warming will result in an 'expansion of the latitudinal extent of the tropics in the south-west Pacific region … and… a poleward shift of the storm wave climate' which will result in 'a significant reduction in net northward longshore sand transport and the efficiency of headland bypassing events'. On the north and central coasts of NSW, they 'project a 30% reduction in longshore sand transport for the dominant extra-tropical-origin storm events, together with a 5% increase in reversed (net southward) longshore sand transport for tropical-origin storm events'. Similarly, Mortlock and Goodwin (2015a; b) predict an 'increase in the total wave energy flux in winter for the central NSW shelf and a reduction of similar magnitude during summer', together with 'an anti-clockwise rotation of wave power towards the east and southeast at the expense of southerly waves'. The 'reduced obliquity of constructive wave power would promote a general disruption to northward alongshore sediment transport, with the cross-shore component becoming increasingly prevalent'. The reduction of longshore transport should not in itself generate beach recession, while an increase in cross-shore transport could increase the supply of shelf sand to the coast. Mortlock and Goodwin (2016) also detected a second-order response of embayed beaches to changes in eastern (EO) versus central Pacific (CP) ENSO, with CP ENSO leading to higher coastal erosion potential and slower post-storm recovery than EP ENSO during an El Niño/La Niña cycle.

In addition to the present and future vagaries in sediment transport, this region has a very vulnerable shoreline with 508 km (72.5%) consisting of sandy beaches in southeast Queensland and 454 km (81%) in northern NSW. Much of this shoreline is either stable or receding, with no naturally prograding sections. It is susceptible to the spatial and temporal variations in longshore transport; in addition, the pulsatile nature of the headland bypassing leads to episodes on erosion and accretion on downdrift beaches (Fig. 18.22b), and in the longer term, Goodwin et al. (2006) have demonstrated how slight change in wave climate direction can have major impacts on both sediment transport and beach alignment. Further Goodwin et al. (2014) predict that such fluctuations in sand transport will remain the primary control on shoreline behaviour until 2050, following which sea-level rise will become an increasingly significant driver of shoreline change. Finally, the coast is exposed to periodic extreme events associated with tropical, east coast and midlatitude cyclones (Shand et al. 2010; Glatz et al. 2017) which result in severe beach erosion and place property at risk, with six coastal hotspots located in the NSW section. A return to periods of intensified and clustered east coast cyclones, not seen since 1976 (Browning and Goodwin 2016), would have a devastating impact on the coast, like the 1974 cluster and glimpsed in the June 2016 event (Harley et al. 2016).

As discussed in Chap. 17, DERM (2011) predicts a range of climate-related impacts that will generate increased coastal erosion, storm damage and inundation along the QLD coast, while in NSW, (as discussed above) Kinsela et al. (2017) and Hanslow et al. (2018) have mapped and quantified the erosion and inundation impacts for the entire coast and found they are greatest in northern NSW (NSW01.01–03). This highly developed and in places a highly vulnerable coast that will need to be managed so as to minimise these adverse impacts. At the same time, OEH's NSW SeaBed mapping program (Linklater et al. 2018, 2019) is obtaining the type of information required to undertake an assessment of the nature of each compartment's seabed including its sediment type, distribution, volume and transport pathways (https://www.environment.nsw.gov.au/research-and-publications/our-science-and-research/our-research/water/offshore-mapping).

The Gold Coast provides a working example of how some of these impacts are already being managed and points to what will be required in the future if we are to minimise these impacts. The Gold Coast contains a very valuable 30 km of beaches, property and infrastructure, and since the 1970s, the council and State have worked to protect these assets and beach amenity (Jackson and Tomlinson 2017; Strauss et al. 2017). The entire backbeach has been protected by a terminal seawall, usually buried under a managed foredune (Stuart and McGrath 2003). Sand is pumped into the southern end of the system at the Tweed (Dyson et al. 2001) and out of the northern end at the Seaway (Polglase 1987; Coughlan and Robinson 1988) in order to maintain the natural throughput of sand. Erosional hotpots are topped up with beach nourishment (Jackson 1989; Andrews et al. 1995) sourced either from the Tweed River and other smaller flood tide deltas and from offshore, and in one case protected by a surfing reef, with plans for a second surfing reef at Palm Beach and sand back-passing at Surfers Paradise. All this is done at considerable expense, an expense that can be afforded owing to the massive tourism industry which is ultimately based on the Gold Coast beaches. While most locations in the central east region will not be able to afford such levels of protection, it is an indication of what is required to maintain a section of receding coast exposed to fluctuations in sediment supply coupled with periodic cyclone erosion, which is typical of this entire region. Fortunately, many of the region beaches are located in national parks and reserves and are undeveloped, with erosional hotspots only located along the Gold Coast and at Amity, Kingscliff, Belongil, Lennox Head, Brooms Head, Wooli, Lake Cathie and Old Bar, which, apart from the Gold Coast, total only several kilometres in length, though this length is expected to increase as sea level rises and more hotspots emerge.

The best way to manage this coast into the future with the added impact of climate change is to leave the presently undeveloped beaches undeveloped, backed by a natural foredune and a suitable buffer zone and setback. Where they are developed, buyback should be seriously considered, together with beach nourishment in suitable areas. Seawall and hard protection should only be used in very-high-priority infrastructure areas and not normally for housing, as private property will be ultimately protected at the expense of the public, of public beaches and beach amenity, something that has already happened at Belongil and Lennox Head. In this way future coastal development is kept well clear of present and future hazards, the beaches and beach amenity are maintained at a high standard, and the coast can continue to be buffered by the vagaries of its sand transport and storm systems without endangering property and life.

References[1]

Ackworth C, Lawson S (2012) The Tweed River entrance sand bypassing project ten years of managing operations in a highly variable coastal system. NSW Coastal Conference, Tweed Heads NSW

Allen M, Callaghan J (1999) Extreme wave conditions for the South Queensland coastal region. In: 14th Australasian conference on coastal and ocean engineering, Institution of Engineers Australia

[1] The NSW open coast is divided into 23 coastal LGAs that are required to develop coastal zone management plans. To this end they also undertake coastal hazard and process studies, which from 2018 are required to use a sediment compartment approach, examining whole SCs and their sediment sources, transport and sinks, rather than individual beaches or parts of the coast. All past reports are usually available online from the council websites and provide a detail assessment of each LGAs coastline and in many cases individual beaches. They provide a wealth of information on the NSW coast its geology, geomorphology, processes, hazards and management and are updated on a recurring basis, with future reports adopting the compartment approach. Some of the existing reports are referenced in this and the following chapter.

Andrews MJ, Zwar MK, Irwin CN (1995) Monitoring of the southern Gold Coast beach nourishment project – 1995 update report. In: 11th Australasian conference on coastal and ocean engineering, Townsville, Institution of Engineers Australia, pp 1–6

Andrews M, Chalmers R, Swartz R (2001) Maroochy River entrance natural pressures and anthropogenic responses. In: 15th Australasian conference on coastal and ocean engineering, Gold Coast, Institution of Engineers Australia, pp 464–468

Baird (2017) NSW coastal wave model. State wide nearshore wave transformation tool. Prepared for OEH, Sydney, 47 p plus appendices

Barnes M, Matthew P, Andrews M, Fisk G (2011) Managing the sunshine coast shoreline erosion threat. In: 20th Australasian conference on coastal and ocean engineering, Institution of Engineers Australia, pp 24–29

BMT WBM (2010) Coffs Harbour coastal processes and hazards definition study. BMT WBM, Newcastle

BMT WBM (2013a) Sunshine coast regional council: coastal processes study for sunshine coast. BMT WBM, Brisbane

BMT WBM (2013b) Byron Shire coastline hazards assessment update. Prepared for Byron Shire Council by BMT WBM, Brisbane

BMT WBM (2013c) Kempsey coastal processes and hazard definition study. BMT WBM Pty Ltd, Newcastle, 70 p plus appendices

BMT WBM (2014) Bellingen coastal zone management study. BMT WBM Pty Ltd, Newcastle, 116 p plus appendices

BMT WBM (2015) Tweed River entrance sand bypassing reassessment of long term average annual net sand transport rate 2015. Prepared for NSW Land Property Mgt Auth. BMT WBM, Brisbane

Boyd R, Ruming K, Goodwin I, Sandstrom M, Schroder-Adams C (2008) Highstand transport of coastal sand to the deep ocean: a case study from Fraser Island, southeast Australia. Geology 36:15–18

Brooke B, Lee R, Cox M, Olley J, Pietsch T (2008a) Rates of shoreline progradation during the last 1700 years at Beachmere, southeastern Queensland, Australia, based on optically stimulated luminescence dating of beach ridges. J Coast Res 24:640–648

Brooke BO, Preda M, Lee R, Cox M, Olley J, Pietsch T, Price A (2008b) Development, composition and age of indurated sand layers in late Quaternary coastal deposits of northern Moreton Bay, Queensland. Aust J Earth Sci 55:141–157

Brooke BP, Pietsch TJ, Olle JM, Sloss CR, Cox ME (2015) A preliminary OSL chronology for coastal dunes on Moreton Island, Queensland, Australia–marginal deposits of a large-scale Quaternary shelf sediment system. Cont Shelf Res 105:79–94

Browning SA, Goodwin ID (2016) Large-scale drivers of Australian east coast cyclones since 1851. J South Hemis Earth Syst Sci 66:1250151

Bryan WW, Coaldrake JF (1976) The coastal lowlands of southeast Queensland (The Wallum). In: Holmes JH (ed) Man and the environment: regional perspectives. Brisbane, pp 10–23

Bryant D, Tomlinson R (1995) Coastal erosion on Cloherty's peninsula Moreton island – a case study. In: 12th Australasian conference on coastal and ocean engineering, Melbourne, Institution of Engineers Australia, pp 85–90

Carley JT, Wyllie SJ, Lord DB, Cox RJ (2006) Coastal processes in the Coffs Harbour region. In: Proceedings of 15th NSW coastal conference

Carley JT, Coghlan IR, Anning D (2017) Coastal processes and management in Byron Bay, Australia. Aust Coasts Ports 2017:212–218

Castelle B, Turner IL, Bertin M, Tomlinson R (2009) Beach nourishment at Coolongatta Bay over the period 1987–2005: impacts and lessons. Coast Eng 56:940–950

CERC (1984) Shore protection manual, vol 2. Coastal Engineering Research Center, US Corps Engineers, Department of Army, Waterway Experiment Station

Chamberlain S, Tomlinson R (2006) Noosa River entrance channel dynamics. CRC Coastal Zone Estuary Waterway Mgt, Indooroopilly, 76 p

Chapman DM (1978) Management of sand budget, Kirra Beach, Gold Coast. In: 4th Australian conference on coastal and ocean engineering, Adelaide, Institution of Engineers Australia, pp 19–24

Chapman DM, Geary M, Roy PS, Thom BG (1982) Coastal evolution and coastal Erosion in New South Wales. Coastal Council New South Wales, Sydney, 341 pp

Coaldrake JE (1960) Quaternary history of the coastal lowlands of southern Queensland. In Hill D, Denmead AK (eds) The geology of Queensland. J Geol Soc Qld Brisbane 7:403–408

Coaldrake JE (1962) The coastal sand dunes of southern Queensland. Proc Royal Soc Qld 72:101–116

Coghlan I, Carley J, Cox R, Blacka M, Loftghouse J (2013) Concept designs for a groyne field on the far north NSW coast. NSW Coastal Confernce, Port Macquarie, 18 p

Coltheart L (1997) Between wind and water: a history of the ports and coastal waterways of New South Wales. Hale Ironmonger, Sydney, 208 p

Coughlan PM (1989) Nossa beach – coastal engineering works to mitigate the erosion problem. In: 9th Australasian conference on coastal and ocean engineering, Adelaide, pp 198–203

Coughlan PM, Robinson DA (1988) Gold Coast seaway – its impact on the adjacent coast. In: 2nd Australasian Port, Harbour and offshore engineering conferecnce, Brisbane, pp 1–6

Cowell PJ, Stive MJF, Roy PS, Kaminsky GM, Buijsman MC, Thom BG, Wright LD (2001) Shoreface sand supply to beaches. In: Proceedings of 27th international conference on coastal engineering. American Society Engineers, pp 2495–2508

D'Agara M, Tomlinson R (2001) Discussion of the dredging of the internal Delta of Currumbin estuary and its impact on adjacent beaches. In: 15th Australasian conference on coastal and ocean engineering, Gold Coast, pp 459–463

Delft (1970) Coastal erosion and related problems Gold Coast Queensland Australia, vol 1. Delft Hydraulics Laboratory, The Netherlands. http://www.goldcoast.qld.gov.au/documents/bf/coastal-erosion-related-problems-vol1.pdf

Dennison WC, Abal EG (1999) Moreton Bay study: a scientific basis for the Healthy Waterways campaign. Brisbane, South East Queensland Regional Water Quality Management Strategy Team, pp 23–25

DERM (2011) Queensland coastal processes and climate change. Queensland Climate Change Centre of Excellence, Department of Environment Resource Mangt, Brisbane, 49 p

Dowling RM (1979) The mangrove communities of Moreton Bay. In Bailey A, Stevens AC (eds) Northern Moreton Bay symposium: Brisbane, Royal Society Queensland, Special Publication, pp 54–62

Doyle T (2018) Foredune morphodynamics in southeast Australia: the role of humans and vegetation. PhD thesis, University of Wollongong, Wollongong, 267 p

Dyson A, Victory S, Connor T (2001) Sand bypassing the Tweed River entrance: an overview. Proc Coast Ports Conf:310–315

Ellerton D, Rottenour T, Miot da Silva G, Gontz A, Shulmesiter J, Hesp P, Santini T, Welsh KJ (2018) Late-Holocene cliff-top blowout activation and evolution in the cooloola sand mass, southeast Queensland, Australia The Holocene, pp 1–16. https://doi.org/10.1177/09596836187886579

Evans KG, Stephens AW, Shorten GG (1992) Quaternary sequence stratigraphy of the Brisbane River delta, Moreton Bay, Australia. Mar Geol 107:61–79

Flood P (1979) Tidal flat sedimentation along the shores of Deception Bay, South-Eastern Queensland – a preliminary account. Proc Royal Soc Qld 91:77–84

Flood PG, Grant BP (1984) Eighteen Mile Swamp: a modern back-barrier peat forming environment, North Stradbroke Island. In Coleman, Covacevich, Davies (eds) Focus on Stradbroke. Boolarong Publications, Brisbane

Flood PG, Grant BP, Frankel E (1986) The origin of Eighteen Mile Swamp: a modern back-barrier pear forming environment, North Stradbroke Island, southeast Queensland. In Frankel E, Keene JB, Waltho AE (eds) (1986) Recent sediments in eastern Australia: marine through terrestrial. Publications – Geological Society. Australia, NSW Div. No 2, pp 131–140

Floyd CD, Druery BM (1976) Results of river mouth training on the Clarence bar, NSW, Australia. In: 15th international coastal engineering conference, Honolulu, American Society of Civil Engineers

Ford AR (1963) River entrances of New South Wales. J Inst Eng Aust 35:313–320

GCCC (2017) Gold Coast City Council http://www.goldcoast.qld.gov.au/gold-coast-beach-nourishment-38539.html

GHD (2011) Shoreline erosion management plan for Bongaree, Bellara, Banksia Beach and Sandstone Point. Report prepared for Moreton Bay Regional Council

Glatz M, Ftizhenry M, Kulmar M (2017) It's time for an update – extreme waves and directional distributions along the New South Wales coastline. NSW coastal conference, Port Stephens 22 p. http://www.coastalconference.com/papers.php

Gontz AM, Moss PT, Wangenknecht EK (2014) Stratigraphic architecture of a regressive strand plain, Flinders Beach, North Stradbroke Island, Queensland, Australia. J Coas Res 30:575–585

Goodwin ID, Stables MA, Olley JM (2006) Wave climate, sand budget and shoreline alignment evolution of the Iluka–Woody Bay sand barrier, northern New South Wales, Australia, since 3000 yr BP. Mar Geol 226:127–144. https://doi.org/10.1016/j.margeo.2005.09.013

Goodwin ID, Freeman R, Blackmore K (2013) An insight into headland sand bypassing and wave climate variability from shoreface bathymetric change at Byron Bay, New South Wales, Australia. Mar Geol 341:29–45

Goodwin ID, Freeman R, Mortlock T (2014) A centennial – scale view of wave climate change impacts on shoreface and shoreline stability along drift-aligned coast. American Geophysical Union, Ocean Sciences Confernce, Honolulu, abstract

Goodwin I, Mortlock T, Browning S (2016) Tropical and extratropical-origin storm wave types and their influence on the East Australian longshore sand transport system under a changing climate. J Geophys Res Oceans. https://doi.org/10.1002/2016JC011769

Gordon AD (1987) Beach fluctuations and shoreline change, NSW. In: 8th Australasian conference on coastal and ocean engineering, Launceston, Institution of Engineers Australia, pp 103–107

Gordon AD, Lord DB, Nolan MW (1978) Byron Bay–Hastings point erosion study. New South Wales Department of Public Works, Sydney

Gourlay MR (1975) Wave climate and design waves at Moffat Beach – a specific analysis with some general implications. In: 2nd Australian conference on coastal and ocean engineering, Gold Coast, Institution of Engineers Australia, pp 159–166

Gourlay MR, Hacker JF (1983) Sedimentation investigations for the kedron brook floodway: redevelopment of Brisbane International Airport. In: 6th Australian conference on coastal and ocean engineering, Brisbane, Institution of Engineers Australia, pp 175–181

Grimstone LR (1975) A model for the sediment budget of Gold Coast beaches during the last 100,000 years. In: 2nd Australasian conference on coastal and ocean engineering, Gold Coast, Institution of Engineers Australia, pp 128–135

Hails JR (1967) Significance of statistical parameters for distinguishing sedimentary environments in New South Wales, Australia. J Sediment Petrol 37:1059–1069

Halligan GH (1906) Sand movement on the New South Wales coast. Proc Linnean Soc NSW 31:619–640

Hanslow DJ, Morris BD, Foulsham E, Kinsela MA (2018) A regional scale approach to assessing current and potential future exposure to tidal inundation in different types of estuaries. Sci Rep (Published online) 8:7065. https://doi.org/10.1038/s41598-018-25410-y

Harley MD, Turner IL, Splinter KD, Phillips MS, Simmons JA (2016) Beach response to Australian East Coast lows: a comparison between the 2007 and 2015 events, Narrabeen-Collaroy Beach. J Coastal Res, SI 75:388–392

Harris PT, Jones MR (1988) Bedform movement in a marine tidal delta; air photo interpretations. Geol Mag 125:31–49

Harris PT, Pattiaratchi CB, Cole AR, Keene JB (1992) Evolution of subtidal sandbanks in Moreton Bay, Eastern Australia. Mar Geol 103:225–257

Harris PT, Tsuji Y, Marshall JF, Davies PJ, Honda N, Matsuda H (1996) Sand entrainment on the mid- to outer-shelf under a western boundary current: Fraser Island continental shelf, eastern Australia. Mar Geol 129:313–330

Harrison J (2013) The Queensland coastal plan 2012: coastal adaptation challenges for local governments. In: 21st Australasian conference on coastal and ocean engineering, Institution of Engineers Australia, pp 358–363

Hekel H, Day RW (1976) Quaternary geology of the Sunshine Coast, southeast Queensland. Queensland Department of Mines, Record 1976/16

Hekel H, Ward WT, Jones M, Searle DE (1979) Geological development of northern Moreton Bay. In Bailey A, Stevens AC (eds) Northern Moreton Bay symposium, Brisbane, Royal Society Queensland, Special Publications, pp 7–18

Helyer Z, Acworth C, Nielsen K (2012) Acoustic doppler current profiling from Kirra beach to Cook Island – field exercises undertaken by the tweed river entrance sand bypassing project. NSW Coastral Conf, Tweed Heads, 22 p

Heron ML, Prytz A, Bathgate J (2001) Currents off Tweed Heads monitored by HF ocean surface radar. In: 15th Australasian conference on coastal and ocean engineering, Gold Coast, Institution of Engineers Australia, pp 49–54

Huang Hai-jun, Short AD, Zeng T, Hanslow D (1999) Impact of river training wall on adjacent beach, Ballina, New South Wales, Australia. Chin J Oceanol Limonol 1

Jackson LA (1989) Implementation and monitoring of 1.5 × 10^6 m^3 nearshore nourishment at Kirra/Bilinga Gold Coast. In: 9th Australasian conference on coastal and ocean engineering, Adelaide, pp 188–192

Jackson LA, Tomlinson R (2017) Fifty years of seawall and nourishment strategy evolution on the Gold Coast. Aust Coast Ports 2017:640–645

Jones MR (1992) Quaternary evolution of the Woorim-Point Cartwright coastline, vols 1 & 2. Department of Minerals and Energy, Marine Coastal Investigations Project Report MA49/2

Kinsela MA, Daley MJA, Cowell PJ (2016a) Origins of Holocene coastal strandplains in Southeast Australia: Shoreface sand supply driven by disequilibrium morphology. Mar Geol 374:14–30. https://doi.org/10.1016/j.margeo.2016.01.010

Kinsela MA, Morris BD, Daley MJA, Hanslow DJ (2016b) A flexible approach to forecasting coastline change on wave-dominated beaches. J Coast Res SI 75:952–956

Kinsela MA, Morris BAS, Linklater M, Hanslow DJ (2017) Second-pass assessment of potential exposure to shoreline change in New South Wales, Australia, using a sediment compartments framework. J Mar Sci Eng 5:61. https://doi.org/10.3390/jmse5040061

Lees B (2006) Timing and formation of coastal dunes in northern and eastern Australia. J Coast Res 22:78–89

Lewis SE, Wüst RAJ, Webster JK, Collins J, Wright SA, Jacobsen G (2015) Rapid sea-level fall along north-eastern Australia between 100 and 800 cal. yr BP: an appraisal of the oyster evidence. Mar Geol 370:20–30

Linklater M, Ingleton T, Kinsela M, Morris B, Allen K, Sutherland M, Hanslow D (2018) Seabed classification approach for SeaBed NSW coastal seafloor mapping program. In: HYDRO18 confence, Australian Hydrographic Society, Sydney, 14 p

Linklater M, Ingleton T, Kinsela M, Morris B, Allen K, Sutherland M, Hanslow D (2019) Seabed feature classification along a subtropical-temperate continental shelf. Geosciences 9:141. https://doi.org/10.3390/geosciences9030141

Lloyd RJ (1980) Beach restoration scheme. In: Proceedings of 17th international coastal engineering conference, Sydney. Institution of Engineers Australia, pp 1619–1635

Lord DB, Van Kerkvoort A (1981a) The effects of a major harbour construction on longshore sediment movement – Coffs Harbour, New South Wales. Conf. Environmental Engineering

Lord DB, Van Kerkvoort A (1981b) A coastal process investigation, Coffs Harbour, NSW. In: Proceedings of 5th Australian conference on coastal and ocean engineering, Perth, Institution of Engineers Australia, pp 147–151

Lord DB, Nieslen AF, Moratti M (1993) Coastal management: Lennox Head New South Wales. In: 11th Australasian conference on coastal and ocean engineering, Townsville, Institution of Engineers Australia, pp 547–552

Lovell ER (1975) Evidence for a higher sea level in sea level in Moreton Bay, Queensland. Mar Geol 18:M87–M94

Macdonald HV, Patterson DC (1984) Beach response to coastal works, Gold Coast, Australia. In: 19th international conference on coastal engineering, Houston, 17 p

Mariani A, Flocard F, Carley JT, Drummond C, Guerry N, Gordon AD, Cox RJ, Turner IL (2013) East Coast study project – national geomorphic framework for the management and prediction of coastal erosion, Water Research Laboratory, WRL Research Report. School Civil Environmental Engr, UNSW, Manly Vale

Maxwell WGH (1970) The sedimentary framework of Moreton bay, Queensland. Aust J Mar Freshw Res 21:71–88

McCauley E, Tomlinson R (2006) The evolution of Jumpinpin Inlet. Cooperative Res Centre Coastal Zone Estuary Waterway Mgt, Indroopilly

McGrath BL, Patterson DC (1973) Wave climate at Gold Coast, Queensland. In: Proceedings of 1st Australian conference on coastal engineering, Sydney, pp 8–15

McKellar JB (1975) The eastern Australian rutile province. In: Knight CL (ed) Economic geology of Australia and Papua New Guinea, vol 1. Metals

McPhee D (2017) Environmental history and ecology of Moreton Bay. CSIRO, Clayton, 208 p

McSweeney S, Shulmeister J (2018) Variations in wave climate as a driver of decadal scale shoreline change at the Inskip Peninsula, southeast Queensland, Australia. Estuar Coast Shelf Sci 209:56–69

Miot da Silva G, Shulmeister J (2016) A review of coastal dunefield evolution in southeastern Queensland. J Coast Res SI 75:308–312

Morim J, Cartwright N, Etemad-Shahidi A, Strauss D, Hemer M (2016) Wave energy resources along the Southeast coast of Australia on the basis of a 31-year hindcast. Appl Energy 184:276–297

Mortensen SB, Hibberd WJ, Kaergaard KK, Sten E, Deigaard R, Hunt S (2015) Concept design of a multipurpose submerged control structure for Palm Beach, Gold Coast Australia. In: 22nd Australasian conference on coastal and ocean engineering, Institution of Engineers Australia, pp 594–600

Mortlock TR, Goodwin ID (2015a) Wave climate change associated with ENSO Modoki and tropical expansion in Southeast Australia and implications for coastal stability. Coastal Sediments 2015, San Diego, 13 p. https://doi.org/10.1142/9789814689977_0198

Mortlock TR, Goodwin ID (2015b) Directional wave climate and power variability along the Southeast Australian shelf. Cont Shelf Res 98:36–53. https://doi.org/10.1016/j.csr.2015.02.007

Mortlock TR, Goodwin ID (2016) Impacts of enhanced central Pacific ENSO on wave climate and headland-bay beach morphology. Cont Shelf Res 120:14–25

Nielsen AF, Gordon AD (1980) The impact of breakwater construction on estuary stability – a case study. In: 17th international conference on coastal engineering, Sydney, pp 445–448 (abstract)

Nielsen AF, Gordon AD (2016) Breakwaters and training walls – the good the bad and the ugly. Coast Conference, Melbourne 12 p

Passosa T, Webster JM, Volker D, Clarke S, Kinsela MA, Hubble TCT (2019) Paleo-shorelines and lowstand sedimentation on subtropical shelves: a case study from the Fraser shelf. Aust J Earth Sci. https://doi.org/10.1080/08120099.2018.1558417

Pattearson CC, Patterson DC (1983) Gold Coast longshore transport. In: 6th Australian conference on coastal and ocean engineering, Brisbane, Institution of Engineers Australia, pp 251–256

Patterson DC (2007a) Sand transport and shoreline evolution, northern Gold Coast, Australia. J Coast Res SI50:147–151

Patterson DC (2007b) Comparison of recorded Brisbane and Byron wave climates and implications for calculation of longshore sand transport in the region. In: Coasts and ports 2007, proceedings of 18th Australasian conference on coastal and ocean engineering, Melbourne, Institution of Engineers Australia

Patterson DC (2009) Modelling the shoreline impacts of Richmond River training walls. In: Proceedings of the 18th NSW coastal conference, Ballina

Patterson DC (2010) Modelling short to geological time-scale coastline response to climate change along the central east Coast of Australia. In: Proceedings of 1st practical responses climate change, National Conference, Melbourne

Patterson DC (2012) Shoreward sand transport outside the surfzone, northern Gold Coast, Australia. In: Proceedings of 33rd international conference on coastal engineering, Santander, Spain

Patterson D, Boswood P, Elias G (2012) Tweed River entrance sand bypassing long term average sand transport rate. NSW Coastal Conference, Tweed Heads, 16 p

Pattiaratchi CB, Harris PT (2002) Hydrodynamic and sand transport controls on en echelon sandbank formation: an example from Moreton Bay, eastern Australia. J Mar Res 53:1

Pickett JW. Thompson CH, Martin HA, Kelley RA (1984) Late Pleistocene fossils from beneath a high dune near Amity, North Stradbroke Island, Queensland. In Coleman RJ, Covacevich J, Davie P (eds) Focus on Stradbroke. Boolong Publications, Brisbane, pp 167–176

Polglase RH (1987) The Nerang River entrance sand bypassing system. In: 8th Australasian conference on coastal and ocean engineering, Launceston, Institution of Engineers Australia, pp 196–200

PPATF (2009) Northern Bribie Island: what are the potential risks for a tidal breakthrough? Pumicestone passage Advisory Task Force, Erosion fact sheet 3. Sunshine Coast Regional Council

PWD (2014) Flynn's Beach seawall. Report No. DC13220. Prepared for Port Macquarie-Hastings Shire, Public Works Dept, Sydney, 82 p plus appendices

RDM (1998) Park Beach Coastline Hazard Definition and Management Study prepared by Resource Design & Management [RDM] for Coffs Harbour City Council and Department of Land Water Conservation

RH DHV (2016) Draft Wooli coastal zone management plan. Royal Haskoning DHV, North Sydney, prepared for Clarence Valley Council, 23 p plus appendices

Robinson DA, Patterson DC (1975) The Kirra Point groyne – a case history. In: 2nd Australian conference on coastal and ocean engineering, Gold Coast, Inst Engrs, pp 45–52

Roy PS (1975) Coastal geology of the Cudgen area – north coast of NSW. Geol Survey NSW, Department of Mines Geol Survey Report No. GS 1973/286, 52 p plus maps

Roy PS (1984) New South Wales estuaries: their origin and evolution. In: Thom BG (ed) Coastal geomorphology in Australia. Academic Press, Sydney, pp 9–122

Roy PS, Crawford EA (1977) Significance of sediment distribution in major coast rivers, northern NSW. In: 3rd Australian conference on coastal and ocean engineering, Institution of Engineers Australia, pp 177–184

Roy PS, Stephens AW (1980a) Regional geological studies of the N.S.W. Inner continental shelf. Geological Survey Report No GS 1980/028. Geological Survey New South Wales, Department of Mines

Roy PS, Stephens AW (1980b) Geological controls on process-response, S.E. Australia. In: 17th international coastal engineering conference, Sydney, pp 913–933

Roy PS, Thom BG (1981) Late Quaternary marine deposition in New South Wales and southern Queensland – an evolutionary model. J Geol Soc Aust 28:471–4898

Roy PS, Thom BG, Wright LD (1980) Holocene evolution on an embayed high-energy coast: an evolutionary model. Sediment Geol 26:1–19

Roy PS, Zhuang W-Y, Birch GF, Cowell PJ, Congxian L (1997) Quaternary geology of the Forster-Tuncurry coast and shelf, southeast Australia. Geological Survey NSW, Department of Mines Research, Sydney, 405 p

Roy PS, Williams RJ, Jones AR, Yassini I, Gibbs PJ, Coates B, West RJ, Scanes PR, Hudson JP, Nichol S (2001) Structure and function of south-east Australian estuaries. Estuar Coast Shelf Sci 53:351–384

Royal Haskoning DHV (2017) Surfers paradise sand backpassing: forward planning report. Prepared for Gold Coast City Council, M&APA102R001F04, Royal Haskoning DHV, Burleigt Heads, 84 p plus appendices

Saeede S, Strauss D, Etemad-Shahidi A, Tomlinson R (2018) Hydrosedimentological modelling of a small, trained tidal inlet system, Currumbin Creek, southeast Queensland, Australia. J Coast Res 34:341–359

Sedigh M, Tomlinson R, Cartright N, Etemad-Shahidi A (2016) Morphological evolution of the Nerang River entrance ebb-tidal delta. J Coast Res SI 75:238–242

Shand TD, Goodwin ID, Mole MA, Carley JT, Browning S, Coghlan IR, Harley MD, Pierson WL, Kulmar MA (2010) NSW coastal storms and extreme waves. In: 19th NSW coastal conference, Batemans Bay, 14 p. http://www.coastalconference.com/2010/papers2010/Tom%20Shand%20full%20paper.pdf

Short AD (1999) Wave-dominated beaches. In: Short AD (ed) Beach and shoreface morphodynamics. Wiley, Chichester, pp 173–203

Short AD (2000) Beaches of the Queensland coast: Cooktown to Coolangatta. Sydney University Press, Sydney, 360 p

Short AD (2007) Beaches of the New South Wales coast, 2nd edn. Sydney University Press, Sydney, 398 p

Short AD, Masselink G (1999) Embayed and structurally controlled beaches. In: Short AD (ed) Beach and shoreface morphodynamics. Wiley, Chichester, pp 230–250

Sircombe KN (1999) Tracing provenance through the isotope ages of littoral and sedimentary detrital zircon, eastern Australia: Sedimentary Geol, 124:47–67. https://doi.org/10.1016/S0037–0738(98)00120–1

Skene DL (1988) The Quaternary geology and evolution of the coast and inner continental shelf at Wooli, northern New South Wales, M.Sc., Dept of Geog, Univ Sydney, 213 pp

Skene DL, PS Roy (1985), The Quaternary geology of the coast and inner shelf At Wooli, northern NSW. Prepared for the Geol Survey New South Wales, Department of Mineral Resources Geol Survey Report No 1986/216

Sloss CR, Murray-Wallace CV, Jones BG (2007) Holocene sea-level change on the southeast Australian coast: a review. The Holocene 17:999–1014

SMEC (2013) Lake Cathie coastal zone management plan. SMEC, Newcastle, 32 p plus appendices

Stephens AW (1982) Quaternary coastal sediments of southeast Queensland. Geologisches Jahrbuch Reihe D Heft 56:37–47

Stephens AW, Roy PS, Jones MR (1981) Geological model of erosion on a littoral drift coast. 5th Australian Conf Coastal Ocean Engr, Perth, Inst Engr Austr, 171–182

Strauss D, Murray T, Harry M, Todd D (2017) Coastal data collection and profile surveys on the Gold Coast: 50 years on. Aust Coast Ports 2017:1030–1036

Stuart G, McGrath J (2003) Management of urban coastal dunes – three decades since major storms – Gold Coast Australia. Coast and Ports Australasian Conference, Auckland, 8 p

Switzer AS, Sloss CR, Jones BG, Bristow CS (2010) Geomorphic evidence for mid-late Holocene higher sea level from southeastern Australia. Quat Int 221:13022

Tejan-Kella MS, Chittleborough DJ, Fitzpatrick RW, Thompson CH, Prescott JR, Hutton JT (1990) Thermoluminescence dating of coastal sand dunes at Cooloola and North Stradbroke Island. Aust J Soil Res 28:465–481. https://doi.org/10.1071/SR9900465

Thom BG, Roy PS (1983) Sea level change in New South Wales over the past 15 000 years. In: Hopley D (ed) Australian sea levels in the last 15 000 years. Deparment of Geography, James Cook University, Townsville, Monograph Series, pp 64–84

Thom BG, Eliot I, Eliot M, Harvey N, Rissik C, Sharples C, Short AD, Woodroffe CD (2018) National sediment compartment framework for Australian coastal management. Ocean Coast Manag, 154:103–120

Thompson CH (1981) Podzol chronosequences on coastal dunes of eastern Australia. Nature 291:59–61

Thompson CH (1992) Genesis of podzols on coastal dunes in southern Queensland. I. Field relationships and profile morphology. Aust J Soil Res 30:593–613

Thompson CH, Moore AW (1984) Studies in landscape dynamics in the Cooloola-Noosa river area, Queensland. 1. Introduction, general description and research approach. Divisional Report No., 73. CSIRO Division of Soil, 93 p

Tomlinson R (2008) Golf Coast reef: 10-year anniversary. International Conference on Coastal Engineering, Hamburg, 20 p

Tomlinson R, 2017, Evolution of the Broadwater. Gold Coast Waterways Authority, Gold Coast. https://www.gcwa.qld.gov.au/wp-content/uploads/2017/05/MTB_RodgerTomlinson-171016.pdf

Tomlinson RB, Foster DN (1987) Sand bypassing at the Tweed River entrance. In: 8th Australasian conference on coastal and ocean engineering, Sydney, Institution of Engineers Australia, pp 85–89

Van Senden D, Howells L, Lord D (1997) Evans head coastal processes study. In: 13th Australasian conference on coastal and ocean engineering, Christchurch, Institution of Engineers Australia, pp 901–906

Veevers JJ (2015) Beach sand of SE Australia traced by zircon ages through Ordovician turbidites and S-type granites of the Lachlan orogen to Africa/Antarctica: a review. Aust J Earth Sci 62:385–408

Vieira da Silva G, Muler M, Prado MFV, Short AD, Klein AHF, Toldo Jr EE (2016a) Shoreline change analysis and insight into the sediment transport path along Santa Catarina Island North Shore, Brazil. J Coast Res 34:863–874. https://doi.org/10.2112/JCOASTRES-D-15-00164.1

Vieira da Silva G, Toldo EE Jr, Klein AHF, Short AD, Woodroffe CD (2016b) Headland sand bypassing – quantification of net sediment transport in embayed beaches, Santa Catarina Island north shore, southern Brazil. Mar Geol 379:13–27. https://doi.org/10.1016/j.margo.2016.05.008

Vieira da Silva G, Toldo Jr EE, Klein AHF, Short AD, Tomlinson R, Strauss D (2017) Headland sand bypassing – processes and driving forces contributions. Coast and Ports 2017, IEA, Cairns

Walker J, Lees B, Olley J, Thompson C (2018) Dating the Cooloola coast dunes of south-eastern Queensland. Aust Mar Geol 398:73–85

Ward WT (1978) Notes on the origin of Stradbroke Island. Papers Department of Geology, University of Queensland, vol 8, pp 97–104

Ward WT, Little IP, Thompson CM (1979) Stratigraphy of two sandrocks at Rainbow Beach, Queensland and a note on humate composition. Paleogeogr Paleoclimatol Paleoecol 26:305–316

Ware D (2016) Tweed River entrance sand bypass project. Case study for CoastAdapt, National Climate Change Adaptation Res Facility, Gold Coast, 8 p

Whitlow R (2000a) Geology and geomorphology of the Ibis Mine lease; an investigation into the nature, morphology and origins of dune landforms and associated water features on north Stradbroke Island and the Ibis Mine lease area. Report by TriMap Pty ltd, Nerang, 225 p

Whitlow R (2000b) The geology of the Gold Coast region. Report for Gold Coast City Council, Gold Coast, 47 p

Whitlow R (2005) A geomorphological outline of the Spit and the southern Broadwater, Gold Coast, Queensland: their environmental history and modifications. Report prepared for Gold Coast city Council, 16 p

Witt CL, Hill PC (1987), Gold Coast Seaway: an overview of the project's design and construction and it's subsequent performance. In: 8th Australian conference on coastal and ocean engineering, Launceston, pp 259–266

Worley Parsons (2010) Black Head to Crowdy Head: coastline hazards definition study, vols.1 & 2. Worley Parsons, Newcastle, 89 p plus appendices

Worley Parsons (2012 Evans Head Coastline hazard and Estuarine water level definition study. Worley Parsons, Newcastle, prepared for Richmond Valley Council

Wyllie SJ, Tomlinson RB (1989) Coastal processes data collection and interpretation – tweed heads NSW. In: 9th Australasian conference on coastal and ocean engineering, Adelaide, pp 250–255

Whyte D, Turner IL, Ranasinghe R (2005) Rip Characterisation on the Gold Coast, Australia: an analysis using coastal imaging techniques. In: 17th Australasian conference on coastal and ocean engineering, Adelaide, pp 233–238

You Z-J, Laine R, Hanslow DJ, Baldock T, Wiecek D (2014) Field measurements of beach-dune dynamic profiles to assess erosion hazard on the coast of NSW, Australia. Coastal Engineering Proceedings, 11 p. https://doi.org/10.9753/icce.v34.management.23

Young S, Lewis G, Couriel E, Hartley A, Clarke G (2017) NSW entrance bar management – bar crossing safety and bar to beach: linking dredging operations with coastal hazard mitigation and beach amenity improvements. NSW Coastal Conferenece, 13 p

Websites

MHL http://new.mhl.nsw.gov.au/data/realtime/wave/

Breakwaters http://www.advisian.com/en/global-perspectives/breakwaters-and-training-walls%2D%2D-the-good-the-bad-the-ugly

Hotspots http://www.environment.nsw.gov.au/coasts/coasthotspots.htm

GCCC http://www.goldcoast.qld.gov.au/gold-coast-beach-nourishment-38539.html

Tweed http://www.tweedsandbypass.nsw.gov.au/

NSW SeaBed mapping: https://www.environment.nsw.gov.au/research-and-publications/our-science-and-research/our-research/water/offshore-mapping

Seaway https://www.gcwa.qld.gov.au/sand-bypass-system/

Chapter 19
Southern NSW Region

Abstract The southern NSW region extends for 1000 km between Cape Hawke and the border at Cape Howe. The coast has a humid sub-tropical to temperate climate and several small- to moderate-sized rivers and numerous streams draining the Eastern Highland which flow into estuaries at the coast. The coast is a mix of rocky shore and headlands and short embayed beaches, together with numerous estuaries and a few river mouths. It is exposed to moderate to occasionally high southerly swell and micro-tides. These maintain wave-dominated beaches and northerly sand transport which is interrupted and/or stopped by the numerous headlands and structures. Sediments are quartz-rich apart from some rocky carbonate-enriched sections. Barrier are limited in extent and dominated by small regressive to stable systems, together with a few large transgressive dune systems including clifftop dunes, with the estuaries and shelf sand bodies also acting as major sediment sinks. This chapter describes the regions' beaches, barriers, sediment transport and sediment compartments.

Keywords Southern NSW · Wave-dominated · Micro-tide · Beaches · Barriers · Estuaries · Sediment transport · Sediment compartments

19.1 Introduction

The southern NSW coastal region (Fig. 17.1) begins at Cape Hawke where the southeast-trending ridges of folded Carboniferous rocks form major headlands bordering large south-facing embayments that extend south into the Myall Lake region. At Port Stephens the fold belt borders the horizontally bedded shales and sandstones of the Sydney Basin which extends south for 380 km to Wasp Head, together with occasional igneous outcrops. South of Wasp Head the rugged, folded Lachlan Fold Belt extends another 210 km to the regional and state border and major change in coastal orientation at Cape Howe. In total, there is 1032 km of open coastline (including Jervis Bay), together with five major bays, Port Stephens, Broken Bay, Sydney Harbour, Botany Bay and Port Hacking, which contain an additional 202 km of outer bay shoreline.

A. D. Short, *Australian Coastal Systems*, Coastal Research Library 32,
https://doi.org/10.1007/978-3-030-14294-0_19

This is also the most populated part of the Australian coast containing the massive Sydney and the regional cities of Newcastle and Wollongong, as well as many regional towns and communities. It also contains a number of reserves and extensive national parks, in part owing to the rugged and/or sandy nature of the coast and its immediate hinterland.

In marked contrast to the central east region where beaches occupy 80% of the coast, this region is dominated by its geology, with rocky bluffs and cliffs forming 56% of the coast, the remainder occupied by usually short embayed beaches averaging 0.86 km in length on the open coast and 0.47 km in the bays, both well below the national average. In addition, there are several large drowned river valleys and many generally small barrier estuaries and lagoons. The region contains six PCs which are listed in Table 19.1 and shown in Fig. 19.1.

19.1.1 Rivers and Creeks

The central-southern NSW coast is paralleled along its entire length by the Eastern Highlands, which in places extend close to the coast. The highlands are drained by 7 small- to moderate-sized rivers and over 130 creeks, all of which drain to estuaries. The largest rivers are the Hunter and Nepean-Hawkesbury (catchments ~20,000 km^2),

Table 19.1 Southern NSW PCs

PC No.[a]	Name	Boundaries	Beach ID[b]	No. of beaches	km[c]	Total km
Southeast NSW02						
NSW02.01		Cape Hawke-Nobbys Head	NSW 201-240	40	560–704	144
			Port Stephens	15	40	40
NSW02.02	Central coast	Nobbys Hd-Cape Three Points	NSW 241-289	49	704–800	96
NSW02.03	Sydney	Cape Three Points-Hacking Pt	NSW 290-340	51	800–926	126
			4 Sydney bays	104		162
NSW02.04	Illawarra	Hacking Pt-Beecroft Hd	NSW 341-408	68	926–1084	158
NSW02.05		Beecroft Hd-Wasp Hd	NSW 409-514	106	1084–1264	180
NSW02.06		Wasp Hd-Cape Howe	NSW 515-721	207	1264–1592	328
NSW02		*Cape Hawke-Cape Howe*	*NSW 201-721*	*521*	*560–1592*	*1032*
			+bays	*119*		*202*
		Region sub-total		*640*		*1234*

[a]NCCARF compartment number
[b]ABSAMP beach ID
[b]Distance from QLD/NSW border

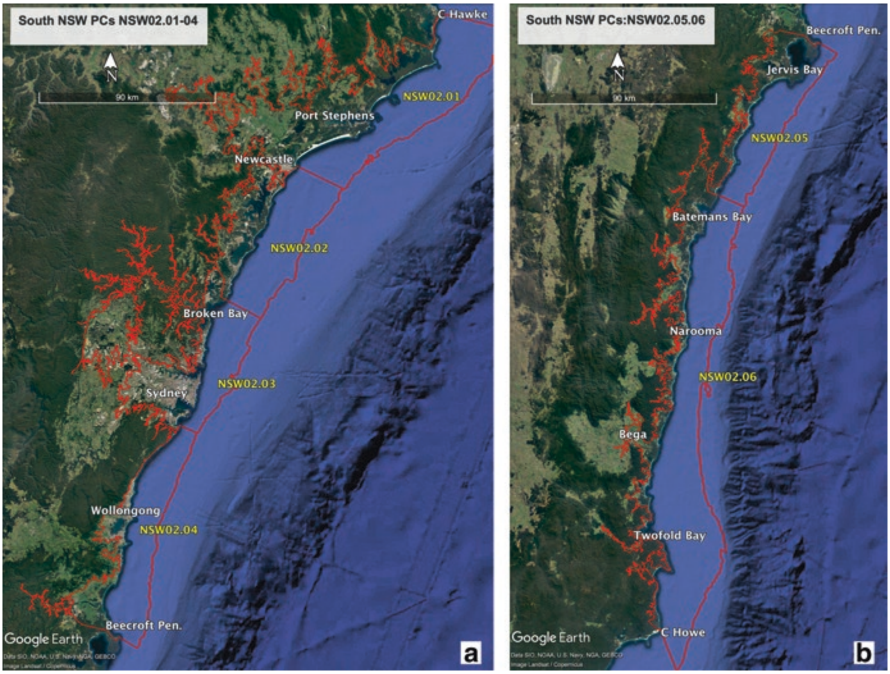

Fig. 19.1 The southern NSW region and its six PCs, (**a**) NSW02.01–04 Cape Hawke to Beecroft Peninsula and (**b**) NSW02.05-06 Beecroft Peninsula to Cape Howe. (Source: Google Earth)

both of which drain to estuaries, with the moderate-sized Shoalhaven (7300 km^2) developing the only substantial delta on the coast (Table 17.3). The southern rivers are all small (<2000 km^2) and drain to estuaries or small deltas like the Moruya and Towamba. All the rivers and streams however have delivered bedload to the coast and shelf at low sea levels and to their estuaries and deltas at highstands. The bedload is derived from the New England Fold Belt, the Sydney Basin sandstones and the rugged Lachlan Fold Belt including its granite batholiths. As discussed in Sect. 18.1, the southern rivers have been supplying quartz-rich sand to the coast and shelf throughout the Tertiary, sand that is mobilised and transported onshore during sea-level transgressions and longshore by the predominately southerly waves which drive the transport system that extends northwards for up to 2000 km to Fraser Island and beyond (Fig. 18.2).

Many of the rivers have been trained and a few harbours constructed on the open coast (see list Table 19.2). The 28 proclaimed ports and their history and development are reviewed by Coltheart (1997) and Strachan et al. (1997). All of these structures impact both the open coast and the river-estuarine circulation and tidal prism. The trained river mouths usually develop shallow ebb tide deltas which makes entrance navigation a hazard (Young et al. 2017). They can also impede longshore sand transport and if they increase the tidal prism can lead to a loss of sand into the river/estuary, an increase in estuarine salinity and modification in estuarine ecology.

Table 19.2 Southern New South Wales training walls and breakwaters

River/inlet	Structure	Date constructed[a]	Impact[b]
Newcastle	2 training walls	1846	Major[c]
Swansea	1 training wall	1877	Major [a, b, c]
Botany Bay	Port and airport runway	1980s	Major
Silver Beach	Groyne field	1976	Major
Wollongong	Harbour breakwaters	1844	Minor
Port Kembla	Harbour breakwaters	1900	Major
Lake Illawarra	2 training walls	2000	Major
Shellharbour	Harbour breakwaters	1950s	Minor
Shell Cove	2 training walls	2015	Minor
Bass Point	Jetty	19??	Minor
Kiama	Breakwater	1871	Minor
Crookhaven	1 training wall	1902–1908	Moderate
Captain's Point	Harbour breakwaters	1910??	Minor
Ulladulla	Harbour breakwaters	1960	Minor
Batemans Bay	1 training wall	1905, 1990	Major
Moruya	2 training walls	1898–1946	Major
Narooma	2 training walls	1976–1980	Major[a, b, c]
Bermagui	2 training walls	1958	Moderate
Eden	Harbour breakwater	1862, 1987	Minor
Twofold Bay	Jetty	1990s?	Minor

[a]Coltheart (1997)
[b]Nielsen and Gordon 2017 (a = good, b = bad, c = ugly)

Table 19.3 PC:NSW02 sand size and % carbonate

No.	281
Size (mm)	0.31
σ (mm)	0.11
Sorting	0.34
Carbonate (%)	19.2
σ carbonate (%)	21.7
Range (%)	0–93

19.1.2 Sediments and Processes

The beach sands along the central-southern NSW coast are dominated by well- to very-well-sorted, fine to medium quartz grains (mean = 0.31 mm) derived from erosion of the eastern highlands (Table 19.3). Most of the sand is between 0.2 and 0.4 mm in size, a little coarser than the northern NSW and southeast Queensland sands. Carbonate averages 19% but ranges from 0 to 93%, with the areas of higher carbonate associated with the more rocky sections of the coast, with the highest carbonate between the Central Coast and Beecroft Peninsula (750–1090 km) and

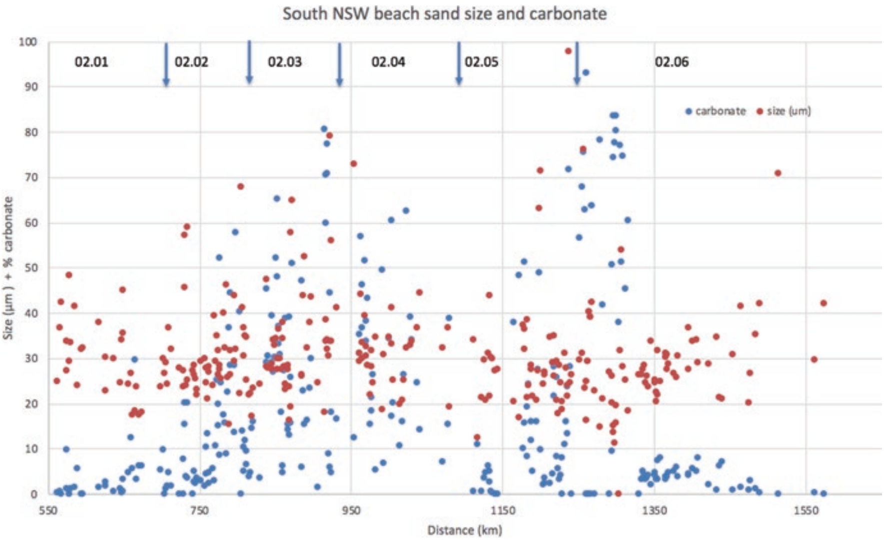

Fig. 19.2 Southern NSW region sand characteristics. Size = red, μm; % carbonate = blue. Distance from QLD/NSW border. Arrows indicate boundaries of the six PCs NSW02.01-02.06

between Caves Beach and Broulee Island (1160–1325 km). Bird (1967) likewise found the southern NSW sand predominately well-sorted subangular to rounded medium quartz sand, with generally <6% carbonate and low feldspar, and colour white to iron-stained yellow. He also found carbonate increased around rocky shoreline and at estuarine mouths.

Figure 19.2 illustrates the longshore trend in the regions' sand size and carbonate. It is primarily fine to medium in size (0.2–0.4 mm), increasing in size in the areas of higher carbonate. The size distribution is in agreement with You et al. (2014). This implies there is an underlying uniform population of fine-medium quartz-rich sand, similar though slightly coarser to the downdrift central east region (Fig. 18.3) which it feeds. This population is locally enriched and coarsened by the injection of carbonate detritus which decreases in occurrence downdrift of the source regions. The lack of downdrift carbonate can be explained by a diminution in carbonate by abrasion and solution and the removal of carbonate from Pleistocene deposits which act as sources in northern NSW. The fine-medium quartz-rich sand also continues south into Gippsland, as will be discussed in Chap. 20.

There are a number of boulder beaches along the coast stretching from Boulder and Rocky beaches (NSW 22–3) at Lennox Head to Merrica Beach (NSW 713) in Disaster Bay. Oak (1984) investigated boulder beach characteristics on the central-southern NSW coast and found that they fined up-beach with slopes between 6 and 10° and that the boulders were mobilised during storms. Bishop and Hughes (1989) found the boulder beach at Terrigal was imbricated and fitted and dated to 4.8 ka, while at Bondi a 240 tonne boulder was deposited on the rock platform during a storm in 1912. There have been some suggestions that boulder beaches are deposited by tsunami; however, Courtney et al. (2012) examined all the proposed southern NSW sites and concluded 'Critical evaluation of geomorphic and chronological evidence revealed a number of concerns, specifically regarding the erroneous interpretation of evidence. Alternative interpretations of evidence were offered with particular reference to the context of the sites and geomorphic influences throughout the Holocene. Ongoing coastal processes of weathering and deposition under both normal and storm conditions are noted as likely interpretations of most features'.

As discussed in Sects. 17.3 and 17.4, the entire region is micro-tidal with a mean spring range of 1.3 m. Waves arrive predominately as moderate to occasionally high southerly swell with an $H_s = 1.6$ m and T = 10 s from the southeast at Sydney (Table 17.2), with wave height decreasing slightly to the south. Storm waves are generated by tropical, east coast and midlatitude cyclones and can arrive from the east through south (Figs. 16.2 and 17.2; Shand et al. 2010; Glatz et al. 2017), with southerly storm waves dominating (Table 18.13). Waverider buoys are maintained along the central and southern NSW coast at Newcastle, Sydney, Port Kembla, Batemans Bay and Eden (see real-time data and wave exceedance tables at http://new.mhl.nsw.gov.au/data/realtime/wave/). Assessment of regional wave climates is contained in coastal process studies prepared for NSW coastal councils (e.g. BMT WBM 2014), while Morim et al. (2016) examined the level and distribution of wave energy along the coast.

19.1.3 Beaches

There are 521 beaches along this region which have an average length of 0.86 km and occupy 448 km (43%) of the coast (Table 19.4a). The combination of fine to medium sand, micro-tides, numerous embayed beaches and a moderate to occasionally high wave climate produces a range of low to moderate energy WD beaches ranging from R to RBB, with the rip-dominated TBR dominating (45% by length), with usually 1450 beach rips operating along the coast. Given the uniform wave climate, the beach type is to some degree controlled by beach length and degree of embaymentisation, with the shorter more embayed beaches receiving lower breaker waves and being dominated by R (mean length = 0.34 km) and LTT (0.53 km). As beach length and exposure increases, so too does beach state with TBR (1.12 km) and RBB (2.53 km) in length (Short 1978). Also, unlike the northern NSW and southeast Queensland beaches, most of the southern beaches are single-bar systems. Of the 551 beaches, 178 (34%) are R and have no bar, 317 (61%) 1 bar and only 26 (5%) double barred, with the 6 PCs averaging between 0.75 and 1.1 bars (Table 19.5), compared to 27% double-barred in northern NSW and 44% in southeast Queensland. In contrast the five main bays (Port Stephens, Broken Bay, Sydney Harbour, Botany Bay and Port Hacking) are a mix of WD R (48%) in the outer bay areas exposed to low refracted ocean swell, while the inner and more sheltered parts

Table 19.4 (a) Southern NSW region (NSW02) open coast WD beach states. (b) NSW bay beach types and states

(a)

BS	BS	No.	%	km	% (km)	Mean length (km)
3	RBB	49	9.4	124	27.7	2.53
4	TBR	181	34.7	203.1	45.4	1.12
5	LTT	113	21.7	60.4	13.5	0.53
6	R	178	34.2	60.16	13.4	0.34
		521	100.0	447.7	100.0	0.86

(b)

BS	BS	No.	%
5	LTT	2	1.7
6	R	56	47.5
11	B + SF	45	38.1
12	B + TSF	12	10.2
14	R + RF	3	2.5
		118	100

Table 19.5 Southern NSW open coast PC beach characteristics

PC:NSW	02.01	02.02	02.03	02.04	02.06	02.06
n	43	50	51	68	106	207
Beach length (km)	106	55	34	77	84	149
Mean length (km)	1.9	1.1	0.7	1.1	0.8	0.7
Orientation (deg)	121	114	128	101	130	111
Embaymentisation	0.68	0.73	0.67	0.7	0.65	0.68
Gradient (deg)	4.2	4.6	5.6	5.2	4.8	5.1
Beach width (m)	90	56	64	66	61	47
Surf zone width (m)	80	75	65	84	40	46
Number bars	1.1	1.1	0.75	0.9	0.7	0.8
Number rips	287	156	116	258	173	460

are predominately TD B + SF (38%) and B + TSF (10%) (Table 19.4b). The bay beaches average just 0.47 km in length and occupy only 28% of the predominately rocky outer bay shores.

Compared to the central east beaches, the southern NSW beaches are shorter (0.86 km), more embayed (0.65–0.73), face east-southeast (101–130°) and have steeper gradients (4.2°–5.6 °) owing to the slightly coarser sand and lower energy beach states, with narrower usually single-bar surf zones (40–80 m) (Table 19.5). For a description of all NSW beaches, see Short (2007).

19.1.4 Barriers

There are 148 barrier systems along the central-southern NSW coast which occupy 409 km (40%) of the coast, the remainder dominated by the rocky shore. While most of the barriers are small, narrow and stable, there are a few larger systems in exposed south-facing locations backed by major transgressive dunes and a few in larger embayments that have infilled with extensive regressive systems. Figure 17.4 illustrates the distribution of these barriers along the coast and the dominance of smaller and receding barriers and mainland beaches along this southern section, which will be discussed in the relevant SCs below. By comparison with northern NSW, the southern barriers are shorter (mean length = 2.8 km), but there are twice as many and occupy a similar length of coast (409 km compared to 453 km). While most are relatively small, the few large transgressive and regressive barriers substantially increase the total barrier volume. The larger barriers are a result of three factors: first, the coast south of Newcastle lacks extensive Pleistocene barriers, leaving considerable accommodation space for Holocene barriers (e.g. Woy Woy, Broulee-Bengello, Disaster Bay); second is the presence of a few large exposed south-facing embayments that have acted as major sediment traps (e.g. Myall Lakes, Stockton Bight, Kurnell, Wreck Bay); and third is the dominant onshore wind swings to a more southerly orientation (Fig. 18.21) exposing south- to southeast-facing barriers to strong onshore winds. As a result, the southern barriers have twice the volume of the northern barriers (6829 M m^3 compared to 3185 M m^3) and more importantly more than twice the volume per metre of the beach (14,436 m^3 m^{-1} compared to 7034 m^3 m^{-1}) (Table 19.6). They are however an order of magnitude smaller than the massive southeast Queensland barriers which average 116,051 m^3 m^{-1} (Table 18.15).

Table 19.6 South NSW region and PCs: NSW02.01-06 barrier dimensions

PC:NSW	02.01	02.02	02.03	02.04	02.05	02.06	NSW02
No.	15	15	24	30	46	69	199
Total length (km)	104	46	29	70	91	133	473
Mean min width	400	120	210	120	240	120	200
Mean max width	1390	5120	440	300	540	315	1350
Mean height (m)	17	16	9	9	15	5	12
Area (ha)	17,753	1902	1596	23,278	2690	3539	50,758
Unstable (ha)	3477	577	442	172	192	214	5074
Total volume (M m^3)	4472	360	203	1204	406	184	6829
Unit volume (m^3 m^{-1})	42,867	7818	7082	17,115	5437	1380	14,436

19.1.5 Sand Transport

The number and size of the barriers (Table 19.6) indicates there are considerable volumes of sand available along the entire region. However, the nature of the coast has placed major obstacles in the way of longshore and onshore sand transport, in the form of long sections of rocky shore and nearshore, major headlands, numerous estuaries and in places steep and deep shorefaces. On the open coast, the beaches tend to be shorter, embayed and swash aligned, all of which inhibit longshore sand transport. As a consequence, most of the transport has been onshore rather than longshore, with limited longshore transport occurring at present. Table 19.7 lists the known estimates of longshore sand transport on the southern coast. The highest estimates are on the order of 20–30,000 m^3 $year^{-1}$, an order of magnitude lower than the north coast (Table 18.17), with the remainder a few thousand at most, while the

Table 19.7 Estimated rates of longshore sand transport in the southern NSW region

km[a]	Location	Rate (m^3 $year^{-1}$)	References
578	Boomerang	30,000	Gordon (1987)
580	Blueys	30,000	Gordon (1987)
690	Stockton Bight	0	Gordon and Roy (1977) and Gordon 1987
704	Nobbys Head	90,000	Boleyn and Campbell (1968)
704	Nobbys Head	20–30,000	DHI (2006)
710	Newcastle	30,000	Lucas and Anderson (1973) and WBM 2000
764	Soldiers Beach	5000	Gordon (1987)
786	Wamberal Beach	12,000	Gordon (1987)
792	Avoca Beach	9000	Gordon (1987)
839	Palm Beach	11,000	Gordon 1987
857	Narrabeen-Collaroy	0	Gordon (1987)
886	Bondi	0	
918	Bate Bay	0	Gordon (1987)
987	Port Kembla	35–98,000	Healy and Lee (1975)
1001	Warilla	25,000	Gordon (1987)
1280	Long Beach	0	Coghlan et al. (2017)
1286	Surfside	100 s	Coghlan et al. (2017)
1317	Barlings-Tomakin	0	Coghlan et al. (2017)
1322	Broulee	0	Coghlan et al. (2017)
1323	Broulee spit (when open)	100 s	Coghlan et al. (2017)
1327	Bengello (via Moruya Heads)	1000s	Oliver et al. (2017)
1333	Moruya-Pedro	1000s	Oliver et al. (2018)
1440	Tathra	0	Geary and Lord (1981)
1560	Disaster Bay	0	
1590	Cape Howe	100 s	Dune overpassing

[a]Distance from QLD-NSW border

majority are expected to be zero. The nature of the coastal sediments and their texture and their low, interrupted and disjointed modes of transport will be discussed in each of the SCs below.

The 130 southern NSW estuaries have also been a major sink for shelf sand. Roy (1992) found that all NSW estuaries trapped large quantities of shelf sand during the PMT, but only a few, such as Port Hacking, have continued to infill after sea level stabilised. He concluded that in barrier estuaries the growth of flood tide deltas is retarded, owing not to undersupply of shelf sand, but low sand-transporting capacity of the restricted tidal flows in their inlet channels, whereas the drowned valley estuaries have larger flood tide deltas built during PMT and have continued to grow throughout the stillstand so long as accommodation space is available in the central basin. At the Pedro barrier and adjacent Congo inlet (SC:NSW02.06.03), Oliver et al. (2018) found that during the initial phase of barrier accretion, the Congo flood tide delta accreted sediment at the same rate as the adjacent barrier, with the delta now holding a substantial portion of the Holocene sediment infill. This is likely to be the case at most barrier lagoons and estuaries along the NSW coast. The volumes listed in Table 19.6 are therefore conservative and should only be used as a guide to potential total barrier volumes.

Thom (1974), in a farsighted paper which focused on the causes of beach erosion along the southeast coast, examined the role played in beach recession by a range of processes including the clustering of storm events; the role of sediment size; changes in beach plan (alignment) in response to changing wave direction (i.e. beach rotation); foredune instability; mobile dune migration; and finally the role of sea-level rise, increased storminess and diminished sand supply to nearshore (sediment) 'cells'. In terms of sediment supply, he proposed that there was an initial abundant sand supply to build the barrier systems, but as the supply was exhausted, this ceased, and some sand might be lost offshore during 'heavy' storms, leading to either shoreline stability or retreat. He also discusses the longshore sand transport which, while caught in 'sediment traps' along the embayed central-southern NSW coast, is more continuous along the 'broad' northern NSW and southeast Queensland embayments including 'in transit' around headlands (headland bypassing). He finished by presenting a model of the five barrier types that occur along the eastern coast: prograding, stationary, receding, episodic transgressive and mainland beach. Many of these ideas were further examined and expanded on by Chapman et al. (1982).

More recently Kinsela et al. (2016a) reviewed what we know about the barrier systems along the NSW coast and examined the potential sources of sand to supply these barriers and concluded that the dominant source and driver of sand supply were the shoreface disequilibrium during the Holocene sea-level transgression, with a convex shoreface sand body providing the necessary conditions for onshore-directed sand supply by wave processes. They also found that additional sources were contributed in places by longshore sand supply, particularly from 3 ka onwards. This initiation of transport followed the infilling and stabilisation of updrift sediment sinks which lead to leakage out of some sinks and to the formation of headland-attached sand bodies. They also suggested that remnant shoreface disequilibrium may continue to be supplying sand at imperceptible rates to some beaches and thereby potentially moderating the initial beach response to sea-level rise. As will be seen in this chapter, all three modes are evident along the southern NSW coast. Massive shelf-supplied onshore transport accompanied the PMT, particularly in exposed higher energy locations; limited and interrupted longshore transport occurs in suitable locations; and ongoing stability and perhaps progradation continues on some beaches, suggesting ongoing shelf supply.

As discussed in Sect. 18.6, Kinsela et al. (2017) applied a shoreline encroachment model to all NSW PCs to predict shoreline recession at present and in 2050 and 2100 as well as the number of properties and amount of infrastructure exposed to erosion. The results of this study are reviewed in Sect. 19.8.

The southern NSW region contains six PCs and a total of 34 SCs (Table 19.8). The nature of each of these PCs and SCs is discussed in the following sections.

Table 19.8 The Southern NSW region, PCs (NSW02.01-06) and SCs

PC/SC[a]	Name	Boundaries	Beach ID[b]	No. of beaches	km[c]	Total km
NSW02.01.01		C Hawke-Seal Rocks	201-217	17	560–594	34
NSW02.01.02	Myall Lakes	Seal Rocks-Yacaaba	218-223	6	594–648	54
NSW02.01.03	Port Stephens	Yacaaba-Zenith Pt	PS 1-15	15	0–25	25
NSW02.01.04		Zenith Pt-Birubi Pt	224-237	14	648–671	23
NSW02.01.05	Stockton Bight	Birubi Pt-Nobbys Hd	238-240	3	671–704	33
NSW 02.01		*C. Hawke-Hunter River*	*NSW 201-240*	*55*	*560–704*	*169*
NSW02.02.01	Newcastle	Nobbys Hd-Norah Hd	241-272	32	704–762	58
NSW02.02.02	Central coast	Norah Hd-Cape Three Points	273-289	27	762–800	38
NSW 02.02		*Hunter R-Cape Three Points*	*NSW 241-289*	*49*	*704–800*	*96*
NSW02.03.01	N Broken Bay	Cape Three Points-Barrenjoey	290-299	10	800–838	38
			Broken Bay 1-21	21	39	39
NSW02.03.02	Northern beaches	Barrenjoey-North Hd	300-319	20	838–876	38
NSW02.03.03	Sydney harbour	North Hd-South Hd	Sydney Hbr 1-52	52	64	64
NSW02.03.04	Eastern beaches	South Hd-C Banks	320-330	11	876–905	29
NSW02.03.05	Bate Bay	C Banks-Hacking Pt	331-340	10	905–926	21

(continued)

Table 19.8 (continued)

PC/SC[a]	Name	Boundaries	Beach ID[b]	No. of beaches	km[c]	Total km
			Botany Bay 1-23	23	49	49
			Port hacking 1-8	8	10	10
NSW 02.03		*C. Three Points-Pt Hacking*	*NSW 290-340*	*155*	*800–926*	*288*
NSW02.04.01		Hacking Pt-Bellambi Pt	341-367	27	926–974	48
NSW02.04.02	Illawarra	Bellambi Pt-Red Pt	368-378	11	974–992	18
NSW02.04.03		Red Pt-Bass Pt	379-385	7	992–1010	18
NSW02.04.04		Bass Pt-Black Hd	386-399S	14	1010–1044	34
NSW02.04.05		Black Hd-Beecroft Pt	400-408	9	1044–1084	40
NSW 02.04		*Hacking Pt-Beecroft Pens.*	*NSW 341-408*	*68*	*936–1084*	*158*
NSW02.05.01	Sydney Basin	Beecroft Hd-Pt Perpendicular	0	0	1084–1093	9
NSW02.05.02	Jervis Bay	Pt Perpendicular-Bowen Is	409-438	30	1093–1146	53
NSW02.05.03		Bowen Is-St Georges Hd	439	1	1146–1159	13
NSW02.05.04	Wreck Bay	St Georges Hd-Red Hd	440-460	21	1159–1185	27
NSW02.05.05		Red Hd-Warden Hd	461-471	11	1185–1203	17
NSW02.05.06		Warden Hd-Wasp Hd	472-514	43	1203–1264	61
NSW 02.05		*Beecroft Hd-Wasp Hd*	*NSW 409-514*	*106*	*1084–1264*	*180*
NSW02.06.01		Wasp Hd-Three Islet Pt	515-522	8	1264–1276	12
NSW02.06.02	Batemans Bay	Three Islet Pt-Mosquito Bay Pt	523-540	18	1276–1302	26
NSW02.06.03		Mosquito Bay Pt-Bingie Bingie Pt	541-577	37	1302–1346	44
NSW02.06.04		Bingie Bingie Pt-Mystery Bay	578-611	34	1346–1383	37
NSW02.06.05		Mystery Bay-Goalen Hd	612-637	26	1383–1418	35
NSW02.06.06		Goalen Hd-Tathra Hd	638-659	22	1418–1444	26

(continued)

Table 19.8 (continued)

PC/SC[a]	Name	Boundaries	Beach ID[b]	No. of beaches	km[c]	Total km
NSW02.06.07		Tathra Hd-Worang Pt	660-678	19	1444–1497	53
NSW02.06.08	Twofold Bay	Worang Pt-Red Rock	679-703	25	1497–1521	24
NSW02.06.09		Red Rock-Green Cape	704-709	6	1521–1548	27
NSW02.06.10	Disaster Bay	Green Cape-Jane Spiers	710-713	4	1548–1570	22
NSW02.06.11	Nadgee Nature Reserve	Jane Spiers-Cape Howe	714-721	8	1570–1592	22
NSW 02.06		*Wasp Hd-Cape Howe*	*NSW 515-721*	*207*	*1264–1592*	*328*
	SE NSW region					

[a]NCCARF compartment number
[b]ABSAMP beach ID
[c]Distance from QLD/NSW border

19.2 PC:NSW02.01 Cape Hawke to Seal Rocks

19.2.1 Introduction

PC:NSW02.01 occupies the southern section of the New England Fold Belt where it reaches the coast between Cape Hawke and Birubi Point (Fig. 19.1a) and beyond which lies the Sydney Basin. Much of this coast north of Port Stephens is occupied by the Myall Lakes National Park, with Tomaree National Park and Worimi Conservation Lands to the south. There are however several large and rapidly growing towns and villages located between the parks and around Port Stephens; from the north these are Pacific Palms-Blueys Beach (3500), Smith Lake (1100), Hawks Nest Tea Gardens (4200), the large Port Stephens (65,000) and Stockton (30,000), a suburb of Newcastle City.

The PC contains five SCs located in either side of Port Stephens and includes the port (Table 19.8) and 169 km of open coast and 43 beaches which occupy 108 km (75%) of the coast, together with 25 km of outer Port Stephens shore which contains 15 beaches occupying 17.2 km (69%) of the bay shoreline (Tables 19.9a and 19.9b). The open coast beaches are predominately well exposed and dominated by the higher energy TBR and RBB (91%), both part of extensive double-bar systems, with only 9% more sheltered LTT-R. The beaches are composed of fine to medium quartz-rich sand, with size averaging 0.3 mm ($\sigma = 1$ mm) and carbonate as low as 4% ($\sigma = 6\%$) (Fig. 19.2). These characteristics suggest a predominately fluvial-shelf source and a degree of longshore transport, which is discussed below.

Table 19.9a PC:NSW02.01 open coast beach types and states

	BS	No.	% no	Total km	% km	Mean km	Sd km
3	RBB	6	14.0	33.8	31.2	5.6	5.6
4	TBR	15	34.9	65	60.0	4.3	7.1
5	LTT	13	30.2	7.6	7.0	0.3	0.35
6	R	9	20.9	1.9	1.8	0.2	0.15
		43	100	108.3	100	2.5	–

Table 19.9b Port Stephens (SC:NSW02.01.03) beach types and states

BS	BS	No.	%	Length (km)	%	Mean (km)	σ (km)
6	R	7	47	9.3	54	1.3	1.4
11	B + SF	8	53	7.9	46	1	0.6
		15	100	17.2	100	1.1	–

A series of major faults have aligned the ranges and valleys of the fold belt to the southeast (150°), facing them directly into the prevailing southerly waves and dominant onshore winds. The long deep valleys were drowned by the sea-level transgressions providing considerable accommodation space that was only partially filled by Pleistocene barriers and have been subsequently filled by massive Holocene barriers. In Port Stephens, the ridges and valleys form the northern bay shore, with the southern shore is a combination of barriers and tied-islands together with a permanent opening in the east between two prominent headlands.

19.2.2 SC:NSW02.01.01 Cape Hawke–Seal Rocks

SC:NSW02.01.01 is a 34 km long section of east-facing coast bordered by the equally prominent Cape Hawke and Seal Rocks and contains two curving embayments linked by Charlotte Head in the centre (Fig. 19.3). The northern 13 km wide embayment contains 10 km long Seven Mile Beach (Fig. 19.4a) and its narrow stable barrier and six small embayed beaches.The 12 km wide southern embayment has a series of nine small embayed beaches some backed by narrow barriers including beachfront property along the Blueys and Boomerang beaches and the dynamic 3 km long Sandbar beach and barrier impounding Smith Lake, which breaches the beach when flooding (Fig. 19.4b). Roy and Boyd (1996) and Roy et al. (1997) undertook a major study of the coast and shelf between Seal Rocks and the Tuncurry barrier. They proposed a model where sand is bypassing, and in the past overpassing, Seal Rocks and moving northwards to and around Charlotte Head at a rate up to ~200,000 m^3 $year^{-1}$ driven by the southerly waves. The rate decreases significantly past Charlotte Head resulting in sand accumulating along this SC in a headland-attached sand body that parallels the coast out to depth of 50 m, with the greatest accumulation and thickness of sediment off Seal Rocks, Charlotte Head and Cape Hawke. The Nine Mile Beach-Wallis Lake barrier is a thin, narrow

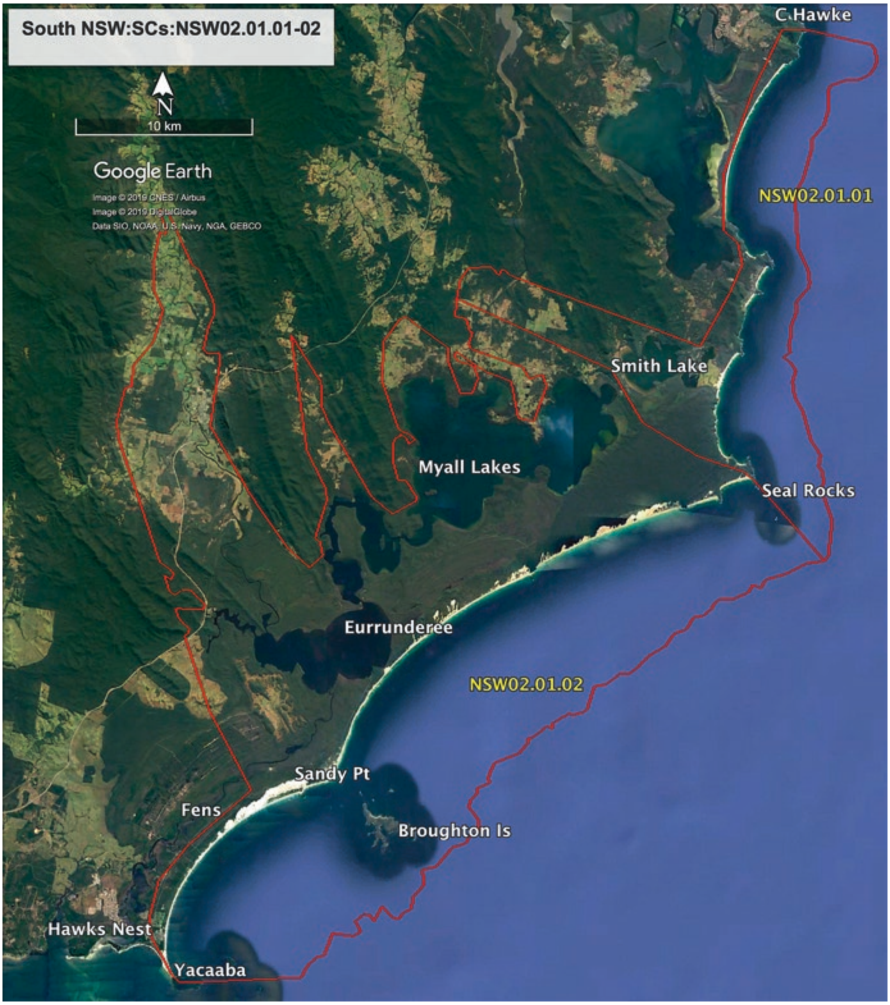

Fig. 19.3 SCs:NSW02.01.01 and 02 extends from Cape Hawke to Yacaaba. (Source: Google Earth)

Holocene barrier that transgressed over a Pleistocene barrier, together with Pleistocene clifftop (~300 ka) and 'glacial' dunes backing and bordering the barrier. A major sink for the sediment has been the larger Tuncurry barrier, located in the adjoining SC (NSW01.02.05), which contains inner Pleistocene regressive barriers dating at ~217–228 ka, 145 ka and 80–94 ka and the 2.5 ka wide regressive Holocene barrier deposited between 8 and 1 ka (see Sect. 18.9.4; Fig. 18.35).

This SC and the adjoining SC are therefore acting as a major sediment trap for the sand that makes it over and around Seal Rocks, the trap due in large part to the abrupt change in orientation of the coast at Seal Rocks as it swings from the

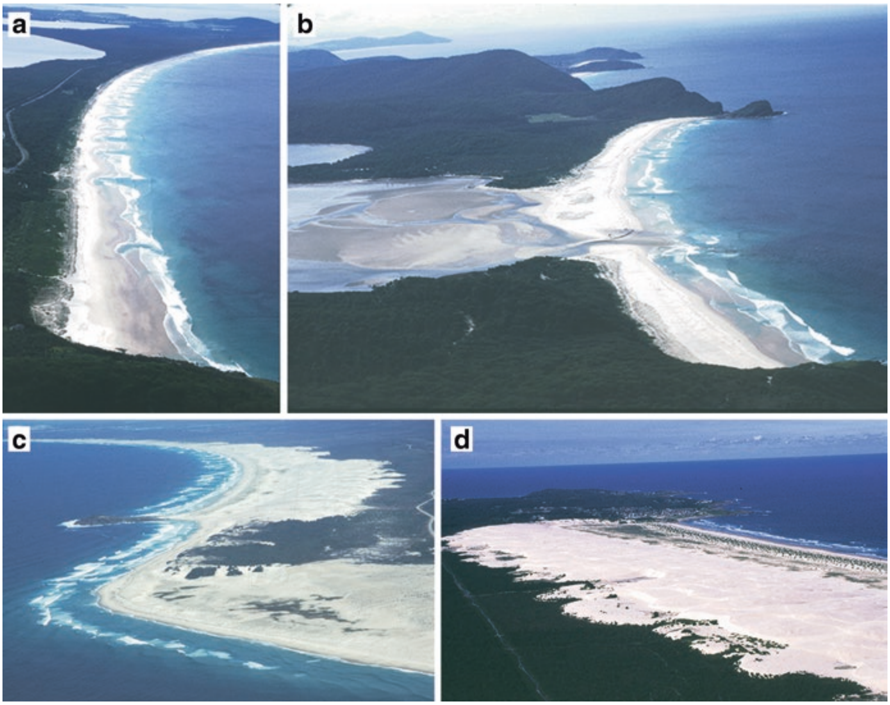

Fig. 19.4 (**a**) Nine Mile Beach and barrier (NSW 201); (**b**) Smith Lake and barrier with the entrance open and flood tide delta exposed (NSW210); (**c**) transgressive dunes at Sandy Point (NSW 221-223); and (**d**) transgressive dunes at the northern end of Stockton Bight (NSW 239). (Photos: AD Short)

southeast to the east (Fig. 19.3) and the associated decrease in wave energy and transport rates. Also, at the protruding Seal Rocks, Roy et al. (1997) found the EAC impinges on the shoreface and transports some sand south depositing it as a large SSB (Fig. 17.4) located immediate east and south of the rocks.

19.2.3 SC:NSW02.01.02 Seal Rocks–Yacaaba

SC:NSW02.01.02 contains the Myall Lakes, a series of barrier-impounded lakes. The barriers range from regressive to transgressive and are the largest barrier systems by length and volume in NSW. The lakes occupy a series of south-facing drowned bedrock-aligned valleys that contain inner Pleistocene regressive and transgressive barriers and the Holocene outer barriers that appear to have largely filled the accommodation space, resulting in a predominately sandy shoreline that curves almost unbroken for 47 km to Seal Rocks which sand is now bypassing. The system faces southeast into the prevailing swell and has some of the longest and highest energy double-barred beaches in the region with wave energy and beach state only decreasing in the south where Bennetts Beach faces east in lee of Yacaaba. Thom et al. (1992) reviewed decades of field investigation in this region (which commenced with Thom 1965) and provide a very detailed overview of the Quaternary evolution of the entire Port Stephens-Myall Lakes region, which was also reviewed by Roy and Boyd (1996). The 54 km long SC contains two large embayments bordered by Seal Rocks and Yacaaba Head and separated by the Sandy Point (Fig. 19.4c), a cuspate foreland formed in lee of Broughton Island. The embayment contains three distinct barrier systems which increase in volume to the north. The northern Seal Rocks, a large Pleistocene and Holocene transgressive barrier, extends up to 6 km inland and reaches heights of 120 m, the highest in NSW. The dunes were active between 4.0 and 1.2 ka and are now vegetated. It has a total volume of 1663 M m^3 and the highest per metre volume in the region at 118,714 m^3 m^{-1}. The central Eurunderee barrier has an inner regressive Pleistocene barrier and outer transgressive Holocene barrier that extends up to 1.5 km inland and to heights of 80 m. This barrier has experienced four episodes of dune transgression at 7 ka, 3.5 ka, 2.3 ka and since 0.9 ka and has a volume of 1140 M m^3 (59,400 m^3 m^{-1}). In the south is the Fens barrier, which contains an up to 7 km wide regressive Pleistocene barrier and 1.5 km wide regressive Holocene barrier that regressed between 6.5 and 3.5 ka and which is now experiencing dune transgression along its northern Dark Point sector for the past few hundred years (volume = 240 M m^3; 14,545 m^3 m^{-1}). Overall however 95% of the three barriers are now stable and vegetated.

The positive transition in wave height, beach state (LTT-RBB), foredune height, volume and stability and dune type and volume along this SC was used by Short and Hesp (1982) in the development of their wave-beach-dune interaction model, which helps explain the diversity of barrier types and their order of magnitude increase in volume between the southern and northern end of the system.

19.2.4 SC:NSW02.01.03 Port Stephens

SC:NSW02.01.03 contains Port Stephens a drowned river valley-barrier estuary (Fig. 19.5). It is partly bordered by south-trending bedrock ridges and valleys along its northern shore and a mix of Pleistocene and Holocene barriers and tied bedrock islands in the south, with 1.3 km opening between the prominent Yacaaba and Zenith Point heads in the east. The small Karuah River enters the western end of the bay and has built a bay head delta extending into the inner bay; however, it does not supply sand to the outer bay or the coast. The 12 km long outer bay contains 15 WD and TD beach systems which occupy 67% of the bay shore, most associated with the flood tide delta. The outer bay has acted as a major sediment sink with a large shallow flood tide delta extending 6 km to the bay and responsible for the name of Shoal Bay. The delta has an area of 30 km^2 and a volume on the order of 10 M m^3. Its nature and dynamics was investigated by Austin et al. (2018). Thom et al. (1992)

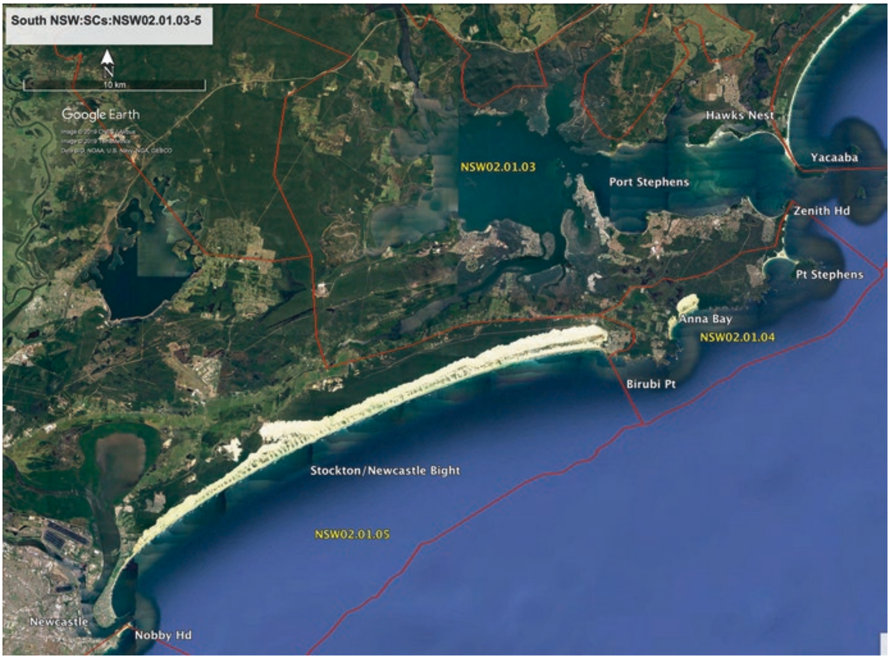

Fig. 19.5 SCs NSW02.01.03-05 includes Port Stephens and the large Stockton Bight barrier. (Source: Google Earth)

describe the nature and stratigraphy of the bay, while there have been several investigations of the nature and dynamics of the tidal delta and its impact on the adjacent shorelines. Gordon (1982), Watson (1997, 2000) and SMEC (2014) modelled sand transport along the northern Jimmys Beach and concluded that local wind waves drive easterly longshore transport, while Wenping et al. (2009), Austin et al. (2009, 2018) and Vila-Concejo et al. (2007, 2009, 2010) all support westerly swell-driven transport. The latter monitored sand waves moving westward from the northern entrance along Jimmys Beach to Winda Woppa Spit, which combined with exposure of the south-facing spit to southerly storm waves has led to erosion of the spit and placed a road and houses located in the immediate hazard zone at risk (SMEC 2014), making it one of the NSW coastal hotspots. BMT WBM (2012) concluded that sand is moving westerly along Jimmys Beach, where it meets some easterly transport, but with overall net westerly movement along the beach and adjoining Winda Woppa Spit. They recommended placement of ~10,000 m^3 on the beach every 6 months to match the erosion rate of 20,000 m^3 $year^{-1}$, which was essentially adopted in the coastal zone management plan (SMEC 2014). Between 1988 and 2012, 569,000 m^3 was placed on the beach averaging 20,000 m^3 $year^{-1}$ (Blumberg et al. 2009; SMEC 2014). There has since been considerable additional nourishment of the beach to protect the road and backing houses. On the southern side of the bay, nourishment has also taken place along the Shoal Bay beach (Lord et al. 1995).

19.2.5 SC:NSW02.01.04 Zenith Point–Birubi Point

SC:NSW02.01.04 extends south from Zenith Point for 23 km to Birubi Point (Fig. 19.5) and consists of 3 embayments which contain 14 beaches that occupy 8.5 km (37%) of the predominately rocky shore. The northern embayment between Zenith Point and Point Stephens has a series of small pocket beaches linked to Point Stephens by a tombolo that is breached by major storms. The semi-circular Fingal Bay on the southern side of the tombolo forms the next embayment, with the Fingal barrier slowly receding deep into the bay eroding into Pleistocene Tomaree dune deposits. This is followed by several kilometres of rocky shore before the southern Anna Bay embayment is reached. The bay is backed by active transgressive dunes extending up to 800 m inland and vegetated dunes to 1.5 km, the sand derived from the Tomaree dune sand exposed on the seabed (Roy and Boyd 1996). The barrier has a volume of 48 M m^3 (11,860 m^3 m^{-1}). While sand has moved into these embayments, it is unlikely there is any substantial longshore transport owing to the prominent headlands and rocky shore. Sand may however be bypassing the headlands via the high energy shoreface and moving from Stockton Bight into Port Stephens and around Yacaaba and beyond. This remains to be investigated. During the last glacial, strong westerly winds mobilised sand from the Stockton Bight inner barrier and blanketed all of the bedrock between the coast and Port Stephens.

19.2.6 SC:NSW02.01.05 Birubi Point–Nobbys Head

SC:NSW02.01.05 contains the 33 km long Stockton Bight barrier, the longest single barrier in NSW. This is an exposed southeast-facing beach-barrier, with the beach containing a high energy rip-dominated double-bar system. The barrier consists of an inner Pleistocene barrier and outer Holocene barrier which was initiated 6.5 ka following the PMT and subsequently prograded 1.5 km seaward. This was followed by three episodes of dune transgression at 5–4 ka, 2 ka and since 0.5 ka (Thom et al. 1992; Roy and Boyd 1996), with the present dunes very active the length of the barrier and 44% of the barrier presently bare and unstable and the largest unstable dune system in NSW. The Holocene barrier has a volume of 1400 M m^3 (46,300 m^3 m^{-1}), second only to the Seal Rocks barrier in regional barrier size. The barrier was investigated in detail by Thom et al. (1992) who describe the evolution of the inner and outer barrier system. They found that grain size was coarser in the west (0.4 mm), finer to the centre (0.3 m) and finest in the east (0.25 mm), a trend also found in the backing dunes and inner barrier. Whether this trend reflects the winnowing due to longshore sand transport or proximity to the Hunter River was not discussed. Gordon and Roy (1977) concluded there was gross drift to north and south but no net drift within the bight, with Gordon and Lord (1980) estimating 0.3 M m^3 $year^{-1}$ was lost into the dunes and Roy and Crawford (1979a) finding that owing to a deficiency in the sediment budget, the beach was receding at between 1 and 2 m year^{-1}. DHI (2006) investigated longshore transport in the bight and found that between 1866 and 2000, it ranged from 20,000 to 30,000 m^3 year^{-1}. They also predicted that sand was bypassing Nobbys Head and contributing 33,000 ^{3} year^{-1} to the beach. Roy and Boyd (1996) also provide an evolutionary model for the Hunter River barrier and entrance.

Stockton Bight is an exposed, high wave energy system with extensive mobile dunes which are transgressing inland at rates up to 7 m year^{-1}, as well as northwards at up to 3 m year^{-1}. Sand is continuing to move from the beach into the dunes owing to the degraded foredune, a result of human and vehicle impacts. In the south Stockton Beach has experienced shoreline recession since at least 1886 (Moratti 1997), probably due to a combination of the Hunter River training walls and sand loss to the dunes and possibly longshore. The Hunter River training walls were initially constructed in 1846 leading to the formation of Nobbys Beach and interruption to the movement of sand past the river mouth. While sand may be bypassing the Nobbys, the 1.5 km of the beach immediately downdrift has receded and is now armoured to protect the road, infrastructure and property, with plans to enhance this seawall (NCC 2016).

19.2.7 PC Overview

PC:NSW02.01 contains the two largest barrier systems in NSW, the Myall Lakes and Stockton Bight, separated by the large Port Stephens and its extensive flood tide delta. Combined these represent the largest sediment sink on the NSW coast containing on the order of 4.5 km^3 of marine sand, which represents 42,900 m^3 m^{-1} of beach. The Quaternary evolution of this entire system has been studied by Thom et al. (1992), and the transport of sediment through this system has been modelled in the south by DHI (2006) and inferred from stratigraphic records by Roy et al. (1997) in the north. The sediment is estimated to be moving through the system on the order of 20–30,000 m^3 year^{-1} around Nobbys Head and possibly up to 200,000 m^3 year^{-1} at Seal Rocks. However, sand is also being lost to the mobile dunes in Stockton Bight, Eurunderee and Seal Rocks embayments and into the large Port Stephens flood tide delta, as well as possibly offshore at Seal Rocks, and in the north around Cape Hawke into the next PC. This is the highest energy and most dynamic system on the NSW coast which already contains the erosional hotspot of Jimmys Beach and property at risk at Blueys, Boomerang and Stockton beaches. While the risk is high, the vulnerability is substantially reduced owing to the presence of national parks and reserves which back most of the open shoreline. This area will however feel the impacts of climate change, with potential impacts including ongoing shoreline recession due to sea-level rise; changes in longshore transport rates due to change in wave climate; increased loss of sand into Port Stephens as the flood tide delta is reactivated; changes in rates of beach-dune transfer and dune migration due to change in wind climate; marine inundation of low-lying areas particularly in Port Stephens and Fullerton Cove; and overwashing in areas of foredune instability, as occurs along Stockton Bight.

19.3 PC:NSW02.02 Newcastle-Central Coast

19.3.1 Introduction

PC:NSW02.02 includes the Newcastle-Central Coast region of NSW, extending for 96 km between Nobbys Head at the entrance to the Hunter River and Newcastle Harbour, south-southwest to Cape Three Points on the northern side of Broken Bay (Fig. 19.1a, Table 19.1). This is a reasonably developed section of coast with the city of Newcastle (450,000) in the north and its suburbs spreading south to Swansea, which is followed by the coastal towns at Toukley, The Entrance, Wamberal-Terrigal, Avoca and Copacabana-Macmasters which are all part of the larger Gosford region which has a population of 170,000 and is considered a satellite suburb of both Newcastle and Sydney. Amongst this development are Wyrrabalong and Bouddi national parks, Wamberal Nature Reserve and Munmorah State Conservation Area, all largely located on rugged rocky sections of the coast.

Nobbys Head marks the beginning of the appearance of the horizontally bedded Sydney Basin sedimentary rocks at the coast, with the head containing the first coal measures mined by convicts in the early days of settlement (from 1804), when it was known as Coal Head. The 96 km of coast south to Cape Three Points is dominated by steep cliffs composed of Newcastle Coal Measures down to Wybung Head and then the sandstone and shale of the Narrabeen Group down to Cape Three Points. In between are a few longer beaches formed across the mouth of drowned valleys and impounding barrier estuaries including the large Lake Macquarie and Tuggerah Lakes. Roy (1992) found the Lake Macquarie flood tide delta formed between 6 and 3 ka and is now stable, while the adjacent barrier is receding. Just over half the PC consist of sandy beaches (55.5 km, 57%). The longer more exposed beaches range from WD TBR to RBB (83% by length), while the shorter more embayed and sheltered beaches tend to be R (11%) and LTT (6%) (Table 19.10). The beaches are composed of carbonate-enriched fine to medium sand, with size averaging 0.3 mm ($\sigma = 1$ mm) and carbonate 13% ($\sigma = 14\%$) but ranging up to 65% (Fig. 19.2). The increase in carbonate which begins in this SC continues south to Broulee Island in PC:NSW02.06, and it is typically of the carbonate-enriched and more variable Sydney Basin beach material.

There are 15 barriers located along the PC with a total length of 46 km. They occupy the valley mouths and most impound coastal lagoons and ICOLs, with per-

Table 19.10 PC:NSW02.02 beach types and states

BS	BS	No.	%	Length (km)	% (km)	Mean (km)	σ (km)
3	RBB	5	10	22	39.6	4.4	4.1
4	TBR	16	32	24.1	43.4	1.5	1.8
5	LTT	10	20	3.2	5.8	0.3	0.3
6	R	19	38	6.2	11.2	0.3	0.4
		50	100	55.5	100	1.11	–

manent entrances at Swansea Heads and The Entrance, the others periodically open as at Glenrock, Wamberal, Terrigal, Avoca and Copacabana. The barriers tend to be narrow 100–500 m wide, consisting of foredune/s of low to moderate height (mean = 16 m), with a total area of 1900 ha, 30% of which is unstable transgressive dunes most located on Nine Mile Beach barrier. They have a total volume of 360 M m^3, which represents a reasonably low 7818 m^3 m^{-1} of beach (Table 19.6). The PC contains two SCs which are discussed below.

19.3.2 SC:NSW02.02.01 Nobbys Head–Norah Head

SC:NSW02.02.01 extends 58 km from Nobbys Head to the prominent Norah Head (Table 19.8; Fig. 19.6) and is a mix of rocky shore with 30 embayed beaches and 2 longer beaches at 10 km long Nine Mile and 9 km long Birdie-The Lakes fronting Lake Macquarie and lakes Munmorah and Budgewoi, respectively, with the 32 beaches occupying 33 km (58%) of the coast. This is a rock-dominated coast, with considerable interruption to any longshore transport by the rocky sections, headlands and inlets. Then only substantial accommodation space is located in the two larger estuarine flood tide deltas and the Nine Mile Beach dunes. In the north along the rocky Newcastle section, WBM (2000) calculated alongshore transport at 30,000 m^3 $year^{-1}$, the sand going on to bypass Nobbys Head (Fig. 19.7a) and reaches Stockton Bight. If sand is bypassing Nobbys, it has to be sourced from the narrow beaches that extend south to Dudley and/or from the shoreface. BMT WBM (2014) reported that these beaches can be completely eroded during major storm events indicating both their small size yet ability to recover. Roy (2001) proposed that south of the Hunter River the steep rocky nature of the shelf indicates there is a relatively limited supply of shelf sand, with barriers typically stationary or receding. Sand may be moving along the longer Nine Mile and Birdie beaches, but whether it is reaching the downdrift beaches or being lost offshore is unknown. This is an exposed SC with dynamic beaches. Fortunately, the longer most exposed beaches are largely undeveloped, and most development is set back and/or on high ground, resulting in a generally low level of vulnerability on the open coast. The limited barrier development in this SC is indicated by the relatively low volume of its nine barriers which total 147 M m^3, with a per metre volume of 5244 m^3 m^{-1}.

19.3.3 SC:NSW02.02.02 Norah Head-Cape Three Points

SC:NSW02.02.02 continues southwest for 38 km to the prominent Cape Three Points (Fig. 19.8), so named by Cook in 1770. This SC contains a few longer embayed beaches which occupy 22 km (57%) of the coast each separated by rocky sections with high sandstone cliffs, some capped by Pleistocene clifftop dunes, with rock platforms at their base and rock reefs extending offshore. The northern 8 km

Fig. 19.6 SC:NSW02.02.01 Nobbys Head to Norah Head. (Source: Google Earth)

long Tuggerah Beach (Fig. 19.7c) is the largest barrier in the SC and formed across Tuggerah Lake with an inlet in the south at The Entrance. South of The Entrance is a 5 km long series of rock- and reef-bound beaches down to Shelly and Bateau Bay, while further south Spoon Bay-Wamberal-Terrigal, Avoca and Copacabana are separated by protruding headlands and reefs (Figs. 19.7 b and d) and classified as closed TCs by Thom et al. (2018). Each also blocks coastal lagoons with usually closed inlets (ICOLs). The six barriers are largely vegetated and have a volume of 360 M m^3 with a higher unit volume of 20,000 m^3 m^{-1} largely owing to the larger east- to southeast-facing Tuggerah barrier. Mariani et al. (2013) conducted a detailed investigation of Avoca Beach and concluded it is a closed TC, with no linkages to adjoining beaches and only cross-shore transport, including a megarip that forms at the northern end of the beach. Likewise, Coutts-Smith (2004) in a field investigation of

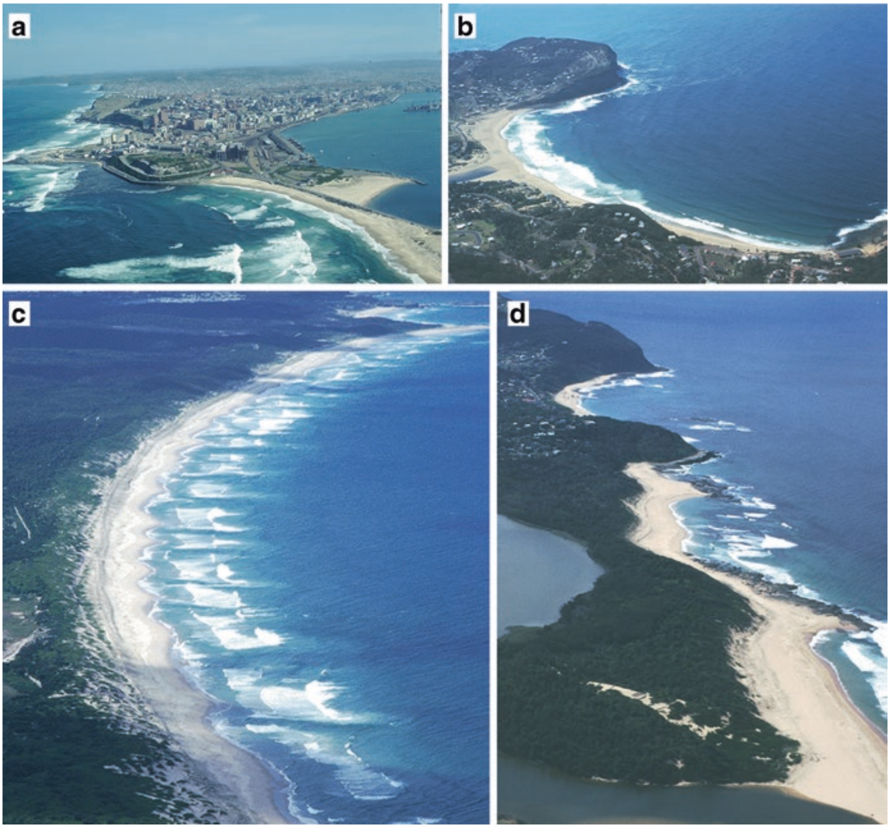

Fig. 19.7 (**a**) Newcastle and Nobbys Beach with Hunter River on the right (NSW242); (**b**) Copacabana-Macmasters Beach (NSW 288); (**c**) the rip-dominated Tuggerah Beach (NSW 275); and (**d**) the rock-dominated Spoon Bay (NSW 284). (Photos: AD Short)

adjoining Copacabana Beach found the surface velocities in the northern megarip reached 1.3 m s^{-1} and at depth reached 0.9 m s^{-1}. In one event, the rip deposited 60,000 m^3 of sand up to 900 m offshore and in 15 m water depth, with smaller volumes, deposited as deep as 25 m with photographic evidence suggesting the sediment reached 1 km offshore and depths of 35 m, a depth from which it would be unlikely to return.

This SC has four coastal hotspots at North Entrance, Norahville, Norah Head where periodic beach erosion is threatening the backing houses and Wamberal when houses were washed into the sea in 1978 and the rebuilt beachfront houses remain very vulnerable. In all of these locations, the risk is more a result of construction of property being permitted within the beach hazard zone, rather than shoreline recession. Kinsela et al. (2017) used Wamberal Beach to model shoreline recession to 2050 and found at the 50% exceedance level it will erode the beach and part of the foredune, while at 10% all the beachfront properties would become exposed to erosion, and at 1% the barrier could be breached.

19.3.4 PC Overview

The Newcastle-Central Coast (PC:NSW02.02) represents the beginning of the more rock-dominated, embayed coast of the Sydney Basin, which severely constrains longshore transport. Rather there is a dominance of embayment confined on-offshore transport leading to closed SCs and even closed TCs like Avoca and Copacabana. As a consequence, the response of the beaches to prevailing and coastal process also transforms. Whereas to the north shoreline stability is

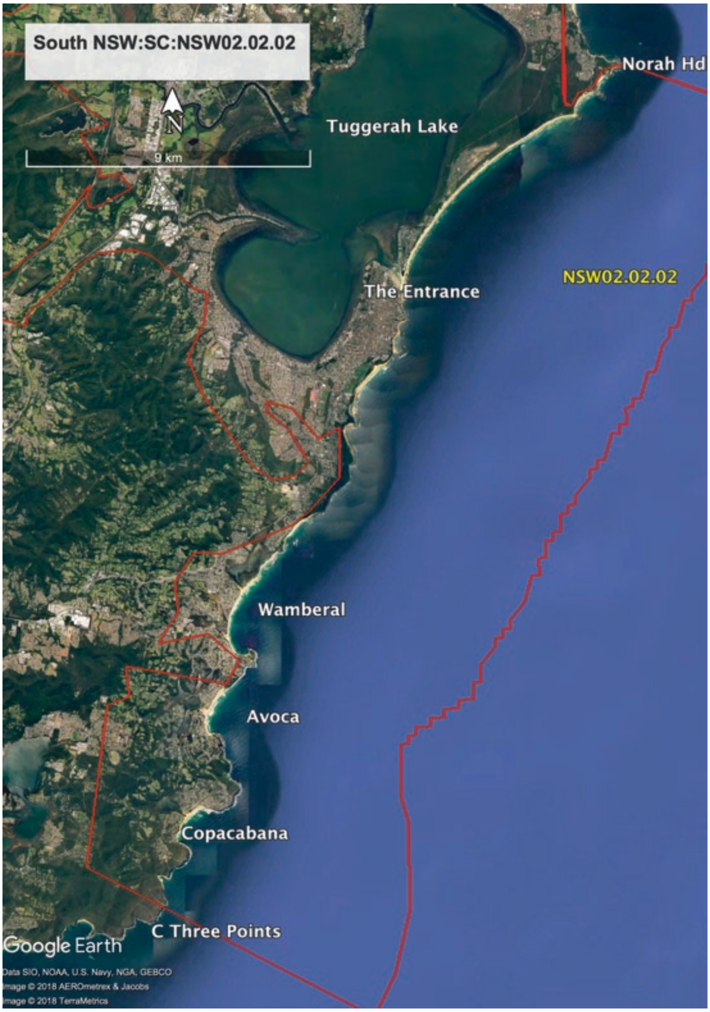

Fig. 19.8 SC:NSW02.02.02 extends from Norah Head to Cape Three Points. (Source: Google Earth)

dependent on storm events, as well as the volume of sand transported into, along and out of each system, a rate that is spatially and temporally variable, to the south the longshore transport is usually irrelevant and only storm-induced cross-shore transport is the major concern, particularly when megarips prevail. Additionally, beach rotation becomes more prominent in the shorter embayed beaches and can induce severe localised short-term erosion while the sediment budget remains balanced. Rising sea level and changing wave climate will impact this coast through loss of sand to storm-induced net offshore transport; shoreline recession owing to sea-level rise; sand loss to the reactivated flood tide deltas and lagoons; inundation of the extensive estuarine and lagoon shores; and possible shoreline realignment owing to a shift in wave climate.

19.4 PC:NSW02.03 Sydney Coast

19.4.1 Introduction

Sydney with a population of four million is the most densely populated and most developed section of the Australian coast. However, while Sydney is renowned for its beaches and bays, the open coast is predominately rocky with steep cliffs of sandstone and shale occupying 73% of the shore, which contains 51 open coast beaches in amongst the cliffs together with 4 drowned river valleys (Broken Bay, Sydney Harbour, Botany Bay and Port Hacking; Figs. 19.1a, and 19.9). The beaches total 34 km (27%) and tend to be short (mean = 0.67 km), embayed and bordered by prominent sandstone and shale headlands up to 100 m high with rock reefs extending offshore, which either separate the beaches or in some cases completely enclose the beaches with rock terrain, forming separate TCs. The coast and shoreface are also steep and deep, with the edge of the continental shelf located just 20–50 km offshore (Fig. 19.9a), the narrowest in Australia and one of the narrowest in the world. These factors combined with its easterly orientation and close proximity to east coast cyclones produce the highest energy section of the east coast, with H_s averaging 1.6 m and storm H_{max} reaching a mean of 4 m and maximum waves to 8.5 m (Short and Trenaman 1992; Shand et al. 2010).

Sydney has micro-tides and is exposed to moderate to occasionally high waves and receives the greatest number of storm waves for the NSW coast (Fig. 17.2; Glatz et al. 2017). The PCs beaches are composed of carbonate-enriched quartz sand, with size averaging 0.33 mm ($\sigma = 0.1$ mm) and carbonate 27% ($\sigma = 21\%$). The beach sand is however amongst the most variable on the NSW coast with size ranging from fine to medium and carbonate ranging from low to high even on adjacent beaches. As Fig. 19.2 illustrates, there is considerable variation in both size and carbonate indicative of local sources, especially carbonate and closed SCs and TCs with little if any sediment exchange. The beaches range from sheltered to fully exposed to southerly waves and consequently from lower energy R (14%) to LTT

(15%), to the dominant TBR (44%) and the most exposed RBB (27%) (Table 19.11). The R beaches tend to be sheltered and short (mean = 0.2 km) like Fishermans, Shelly and Jibbon. The LTT often occur at the sheltered end of longer beaches like south Newport, Collaroy and North Bondi. The TBR and RBB are the more fully exposed (e.g. North Palm, Dee Why, Curl Curl, South Bondi, Maroubra, North Cronulla), with the coarser sands on the northern beaches maintaining TBR beaches and the finer sand south from Long Reef down to Maroubra producing a

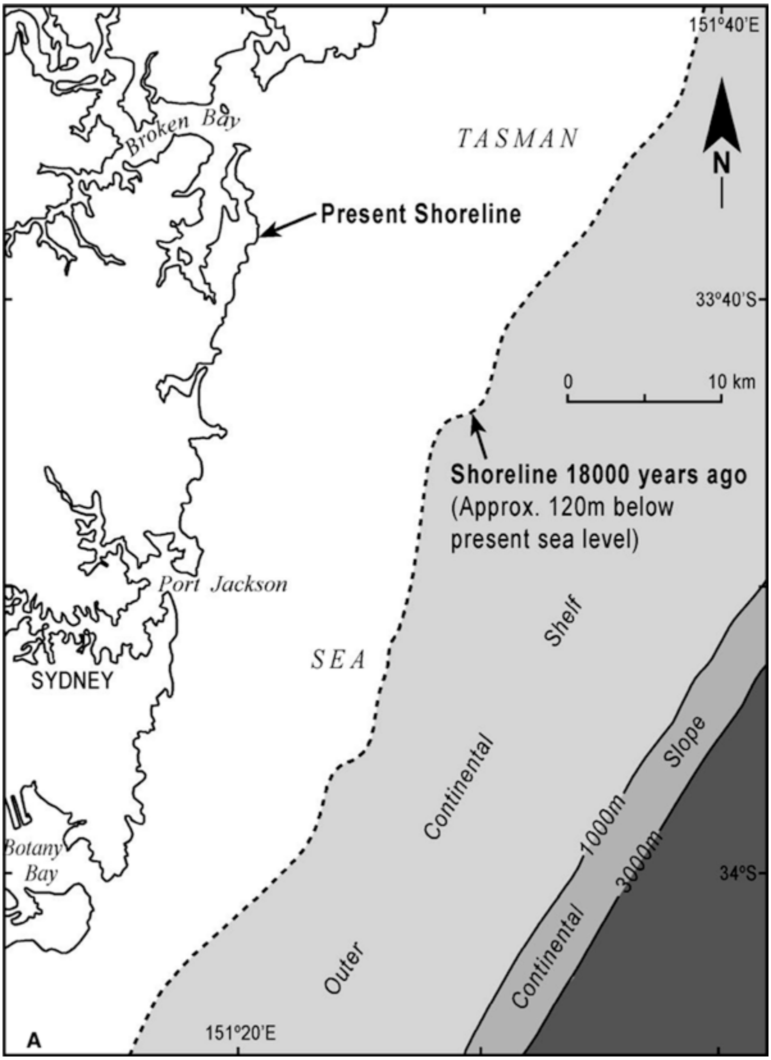

Fig. 19.9 (**a**) The Sydney coast and shelf showing the shoreline 18 ka and today (Source: Short 2007); and (**b**) the coast, shelf and sediments between Sydney Harbour and Providential Head. (Source: Metromix 1993)

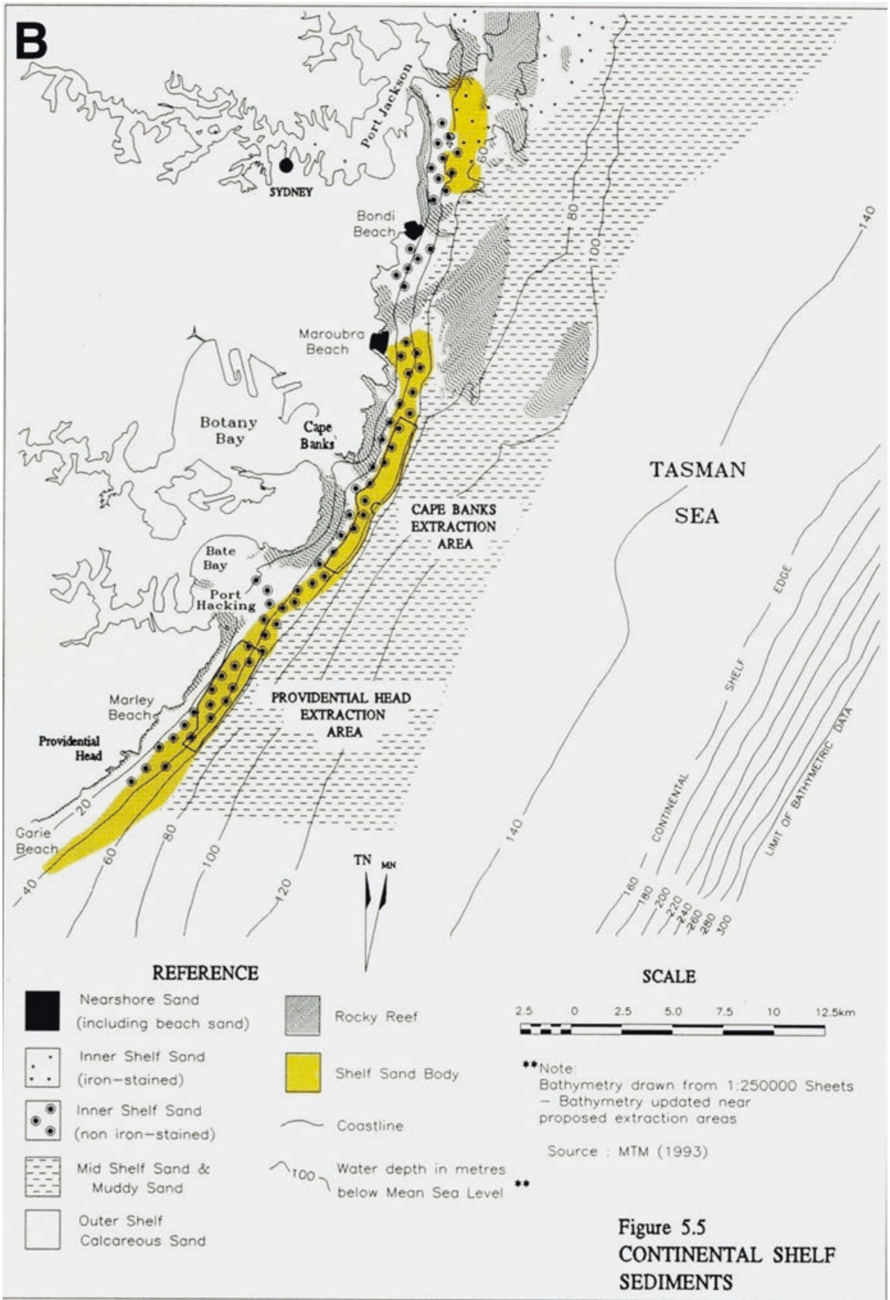

Fig. 19.9 (continued)

Table 19.11 PC:NSW02.03 the Sydney coast beach types and states

BS	BS	No.	%	Length (km)	% (km)	Mean (km)	σ (km)
3	RBB	5	9.8	9	26.5	1.8	3.6
4	TBR	17	33.3	15	44.2	0.9	1.8
5	LTT	5	9.8	5.1	15.0	1.0	2.1
6	R	24	47.1	4.8	14.2	0.2	0.5
		51	100	33.9	100	0.6	–

higher Ω and RBB beach state. Along the rip-dominated LTT-RRB beaches, there are usually 86 beach rips operating along Sydney's beaches. However, when waves exceed ~3 m, the beach rips expand and merge into a series of 36 megarips, usually 1 megarip for each embayed beach, though in some cases (e.g. Bilgola-Newport and McKenzies-Tamarama-Bronte) 1 rip can drain the entire embayment. Williams (1992) found that megarips occurred on most Sydney beaches during high waves when the surf zones average 300 m in width. The rips achieve velocities between 1.2 and 2.6 m s^{-1} and carry suspended sand between 0.35 and 1.05 km seawards. These large storm-driven megarips are a mechanism for transporting the eroded beach-barrier sand up to 1 km offshore and depositing it in the SSB's (Fig. 19.9b).

Sydney's beaches have been investigated since the 1900s when the impact of severe storms was reported by Andrew (1912). Later McKenzie (1958) conducted pioneering work on beach and headland rip currents, Short and Wright (1981) provided an overview of the beaches, and Wright and Short (1984) developed the now universal WD beach model based in part on studies of Sydney beaches. Narrabeen Beach remains the most investigated beach in Australia with monthly surveys running since 1976. A number of beaches are now monitored regularly using video cameras, periodic surveying, Lidar and public CoastSnap images (see http://ci.wrl.unsw.edu.au/current-projects/narrabeen-collaroy-beach/ and http://www.environment.nsw.gov.au/research-and-publications/your-research/citizen-science/digital-projects/coastsnap).

19.4.2 *Shelf Sand Bodies (SSBs)*

SSB's are inner shelf deposits of Holocene sand, primarily derived from erosion of adjacent beaches and barriers, with at least nine SSB's located along the NSW coast (Fig. 17.4). A major SSB is located off the Sydney coast between 45 and 70 m depth and 1 and 3 km offshore and reaches thicknesses between 10 and 30 m. These massive sand bodies extend from Broken Bay down to Long Reef and from South Head for 40 km south to Providential Head (Fig. 19.9b). They have a volume on the order of 200 M m^3 (Cowell 1986), and it has been proposed that they would make an ideal source of sand from which to nourish Sydney and Central Coast beaches when required (ACEOM 2010). The steep Sydney coast typically consists of either steep cliffs fronted by deep water or embayed beaches in the valleys between the cliffs, both of which are usually fronted by rock reefs from 20 to 40 m depth and then the SSB's out to 70 m (Fig. 19.9b).

The most detailed studies of the Sydney inner shelf and its SSB's were undertaken by Field and Roy (1984), Roy (1984a, 1985, 2004), Roy and Boyd (1996) and Metromix (1993), the latter as part of their EIS for the proposed Sydney marine aggregate mining. This report details the nature of the coast and particularly the inner shelf, its geology, morphology, sediments and ecology. The SSB's resulted from the early to mid-Holocene erosion of coastal barriers that had been deposited during the PMT between 13 and 6.5 ka. Figure 19.10 shows their evolution with shoreward reworking of shelf deposits (13 ka), construction of sand ramps against the cliffs during the transgression (10 ka), erosion of the ramps commencing once sea level stabilised (6.5–4 ka) and subsequently surficial reworking (4 ka–present). The transgressive phase built sand ramps and deposited clifftop dunes at Kurnell, from what Roy and Crawford (1979b) termed the 'proto-barrier', and also between Cape Banks and North Bondi, North Head and Long Reef, while Cape Three Points, Long Reef, North Head and Diamond Bay have remnants of Pleistocene clifftop dunes. Field and Roy (1984) proposed that offshore transport occurred during storm wave conditions which can both suspend the sand and drive an offshore bottom flow capable of seaward bed transport, the sand being transported to depths from which it cannot be returned by wave action. No doubt megarips also played a role in the offshore sand transport. Field and Roy (1984) also proposed that the predominant southeast waves are reworking the surface and transporting sand northwards, parallel to the coast. Gordon and Hoffman (1986) calculated that during intense southerly storms, SSB sand was being transported northwards at rates of 110 m^3 m^{-1} at 24 m and 3 m^3 m^{-1} at 80 m, while the remainder of time southerly shelf currents rarely induced sediment entrainment. However, Wallis and Chidgey (1989) measured the southerly EAC currents off Sydney averaging 0.38 m s^{-1} with a maximum between 0.3 and 0.5 m s^{-1}, and Nielsen et al. (1992) observed sand waves in 25–70 m water depth which were aligned perpendicular to the south moving EAC. Likewise, Griffin et al. (2008) noted that well-rounded, fine to medium predominately quartz sand extends to 60 m depth along the inner shelf. They modelled its mobility on the continental shelf between Sydney and Jervis Bay and found that significant waves can mobilise the sand on the inner shelf (0–60 m), the location of the SSB's, but only rarely the mid shelf (60–120 m), while maximum waves mobilised the sand fraction across the mid shelf. This indicates there is more than sufficient wave energy to mobilised the SSB surficial sediments. Cowell (1986) calculated that >80% of the SSB sand was eroded from the dunes and ramps and delivered by storms and downwelling. He also proposed that inshore longshore transport would have been greater when the ramps were present. The modern beaches and barriers are therefore a remnant of a larger system (equivalent in volume to the SSB's) that occupied parts of the Sydney coast during and immediately following the Holocene sea-level transgression and stillstand.

Hesp (1993) in a study of the Illawarra beach and barrier systems found the clifftop dunes at Kurnell dated from 12 to 8.5 ka, while Pye and Bowman (1984) dated

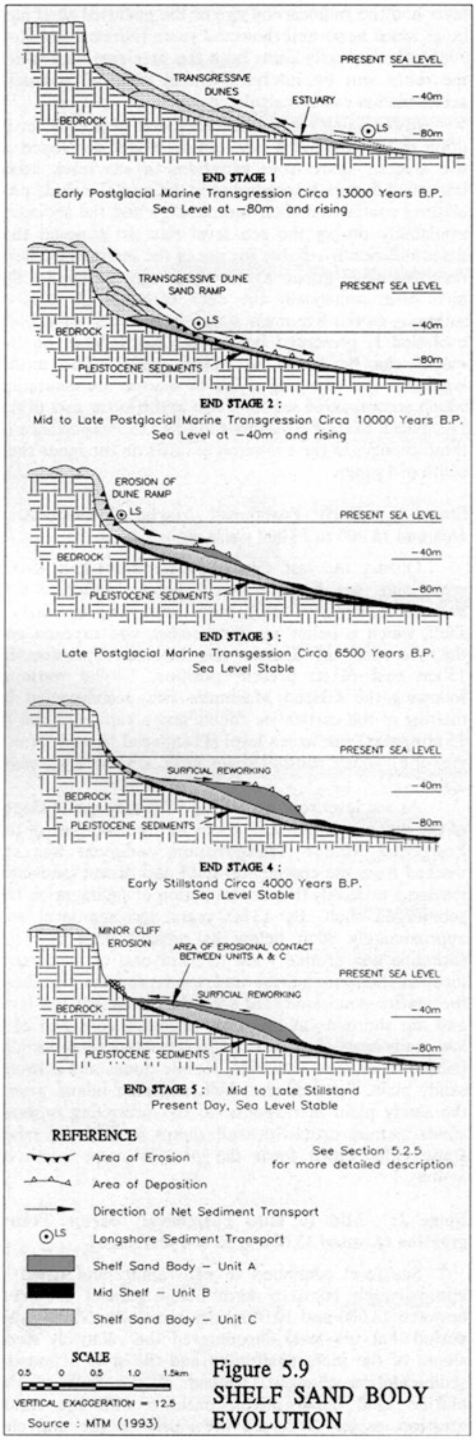

Fig. 19.10 Evolution of Sydney's shelf sand bodies at 13 ka, 10 ka, 6.5 ka, 4 ka and present. (Source: Metromix 1993)

the dunes between Marley and Jibbon from 9.7 to 5.2 ka. Hesp found that based on dune orientation, the dunes were sourced from sand ramps located right along the Marley to Hacking Point coast, a coast with cliffs up to 60 m high which would have been even higher at 12 ka. The ramps were subsequently eroded leaving the bare rocky cliffs and now stable and vegetated clifftop dunes. The presence of the Pleistocene clifftop dunes indicates that this scenario also occurred during previous highstands of sea level leaving SSB's on the shelf to be reworked shorewards during the next marine transgression, and so repeat the cycle. As will be seen in Chap. 26 to 30, clifftop dunes are found on many cliffs along the SA and WA coasts, some well over 100 m high.

19.4.3 Barriers

The Sydney coast (NSW02.03) contains 24 barrier systems which occupy just 29 km (20%) of the coast. Most are small, stable to regressive systems, like Narrabeen, while only the more exposed North Palm Beach, North Curl Curl, Bondi and Wanda-Kurnell have experienced dune transgression. The three exceptions are the large regressive Woy Woy barrier (Hails 1969; Thom et al. 1981) and the once massive dunes at Bondi and Kurnell (Roy and Crawford 1979b). All three face south into the southerly waves and winds and have acted as natural sand sinks for largely wave-deposited sand in the case of Woy Woy and wave- and wind-deposited sand at Bondi and Kurnell. The low Woy Woy barrier extends for 4 km into Broken Bay and evolved between 6.5 and 1.5 ka (Thom et al. 1981) and is now covered in houses. The Bondi dunes were levelled and are now buried under housing, while the Kurnell dunes have mined to supply Sydney's demand for construction sand, and the remnants are now being covered by houses, a sad demise for Sydney's three largest barrier systems. The 24 barriers average only 210–440 m in width and have a mean height of 9 m occupying an area of 1600 ha, with a total volume of 203 M m^3 (7080 m^3 m^{-1}) with 82% of this contained in the large Woy Woy and Kurnell barriers.

19.4.4 Sediment Transport

The Sydney coast contains a series of embayed headland-bound beaches separated by four large drowned river valleys, all of which severely impede longshore sand transport. Wright et al. (1980) suggested that sand may be moving around Barrenjoey and into Broken Bay, and Patterson and Britton (1993) also suggested sand is moving around Narrabeen headland; however, there is no evidence to support the Narrabeen transport. Rather on-offshore transport dominates, with sand being lost offshore during severe storms and then returning slowly to the shore. Forty years of monitoring Narrabeen-Collaroy Beach indicates that while the beach and shoreline are extremely dynamic, the total beach volume and mean shoreline position have remained stable (Harley et al. 2015).

The largest volume of sand along the coast is located in the four large flood tide deltas which contain on the order of 630 M m^3, with the SSB's and barriers each containing ~200 M m^3. These figures are best estimates and need more detailed surface and subsurface mapping to be accurately quantified. This implies that 75% of Sydney's marine sands are located in the bays and on the inner shelf, with only 25% remaining in the barriers. Sydney's beach systems were largely eroded between 6-4ka. Today the remnants continue to oscillate and rotate, some like Dee Why slowly recede and some like McKenzie occasionally disappeared. Today the beaches are dynamic though reasonably stable and remnants of a once substantially larger system. The Sydney coast is divided into five SCs, which include the four large bays, and are each discussed below.

19.4.5 SC:NSW02.03.01 Broken Bay

SC:NSW02.03.01 includes all of Broken Bay from its northern entrance at Cape Three Points to Barrenjoey (Fig. 19.11). The bay, a downed river valley, is a major sediment sink for the Sydney coast containing a large flood tide delta. Albani and Johnson (1974) found that the Broken Bay bedrock was as deep as 125 m below present sea level and as deep as 20 m in Pittwater. The deep drowned valley has a 10 km wide entrance that faces east-southeast into the prevailing southerly swell that has delivered Quaternary marine sand to the bay to build the deltas and barrier, as well as the 10 open coasts and 21 bay beaches. Roy (1992) and Roy and Boyd (1996) dated the initiation of the delta at 9 ka and found it is underlain by fluvial and mud basin deposits, and is now interfingering with fluvial sands. On the northern side of the bay is the Woy Woy regressive barrier which dates to 8 ka (Thom et al. 1981; Roy 1992) and adjacent Brisbane water flood tide delta (Fig. 19.12a). The open coast beaches occupy 7 km (9%) and the coast and the bay beaches 8 km (10%), the remainder predominately steep sandstone cliffs. The ocean beaches range from TBR on the outer exposed coast to R moving into the bay with Pearl Beach (NSW 298) being used as type R beach for beach studies and experiments by Bryant (1984a), Short (1984) and Masselink (1999). The sheltered bay beaches range from WD R and LTT to predominately TD B + SF (93%) (Table 19.12).

Most of the beach are small (~0.5 km) mainland beaches backed by steeply rising slopes, with Woy Woy the only large barrier with a volume of 25 M m^3 (10,000 m^3 m^{-1}). Roy and Boyd (1996) found that the 4.5 km wide barrier sits on top of flood tide delta sands and prograded between 8 and 1 ka and now appears to have stabilised. The remaining barriers Maitland, Killcare, Tallow and Pearl have a total volume of just 1.7 m^3.

The Broken Bay flood tide delta occupies the outer bay extending up to 6 km into the bay. Roy (1994) investigates the delta and found the 20–40 m thick marine sand sequence overlies estuarine shelly mud and accumulated between 11.6 and 6 ka as sea level entered the bay and stabilised. It now appears to have stabilised, and its inner reaches are being overlapped by fluvial channel sand. The tidal delta has an

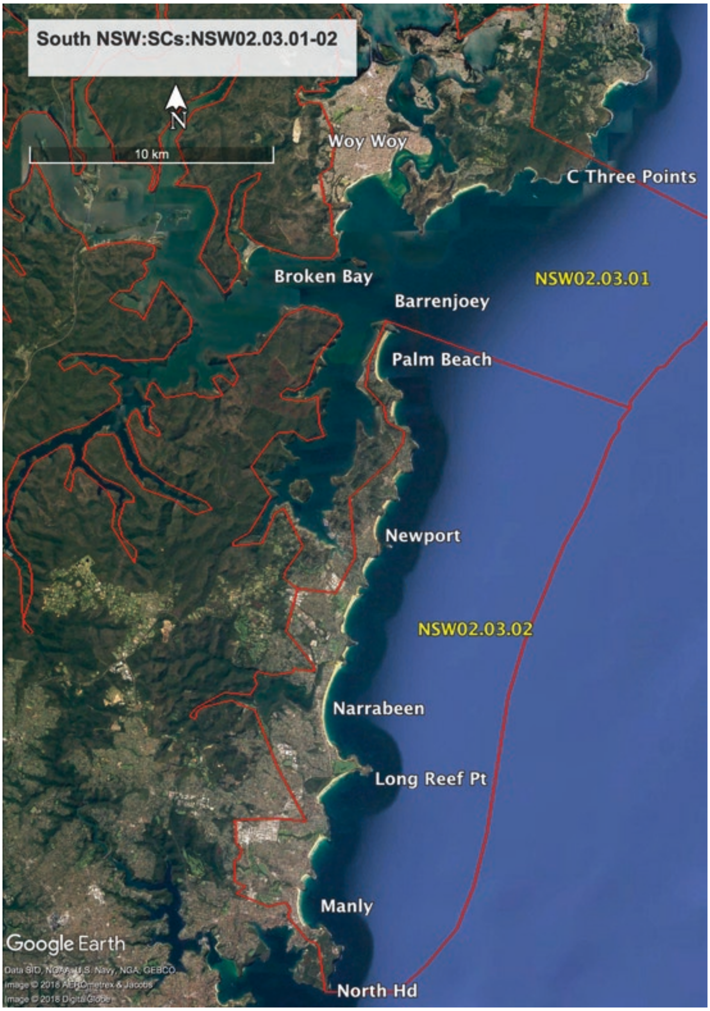

Fig. 19.11 SC:NSW03.03.01-02 Broken Bay and the northern Sydney coast. (Source: Google Earth)

area of ~30 km^2, and assuming an average sand thickness of 10 m, this would represent 300 M m^3 of sand, far exceeding the barriers. In Pittwater, the tidal delta is continuing to migrate southwards which causes shoreline instability and erosion on both sides of Pittwater. On the eastern shore at Snapperman-Sandy Beach (BB 20) a migratory cuspate foreland is placing houses are at risk and on the western shore at Mackerel Beach (BB 8) Cowell and Nielsen (1991) investigated the impact of a migratory inlet on shoreline instability. Kulmar and Gordon (1987) estimated sand is moving 3.5 km down the western shore of Pittwater at rates between 1300 and 1800 m^3 $year^{-1}$ towards a terminus at The Basin spit (BB 11).

Fig. 19.12 (**a**) Pearl Beach and Ocean Beach-Umina together with the Brisbane Water tidal delta (NSW297-298); (**b**) rip-dominated Palm Beach and its managed dunes (NSW 300); (**c**) Long Reef-Dee Why with a megarip flowing out the centre (NSW 314); and (**d**) the deeply embayed Freshwater Beach (NSW 316). (Photos: AD Short)

Table 19.12 Broken Bay (SC:NSW02.03.01) beach types and states

BS	BS	No.	%	Length (km)	%	Mean (km)	σ (km)
5	LTT	2	10	0.14	1.8	0.7	–
6	R	1	5	0.3	3.9	0.1	–
11	B + SF	15	75	7.2	93.0	0.5	0.4
12	B + TSF	1	5	0.1	1.3	0.1	–
		19	95	7.7	100	0.4	–

19.4.6 SC:NSW02.03.02 Barrenjoey-North Head

SC:NSW02.03.02 incorporates Sydney's northern beaches between Barrenjoey and North Head (Fig. 19.11). The 38 km of the coast contains 20 beaches occupying 17.3 km (45%) of the shore, with an average length of 0.86 km, including the 3.6 km long Narrabeen-Collaroy, the second longest in Sydney. The rest of the SC consists of steep headlands formed of Narrabeen sandstone and shale north from Long Reef and Hawkesbury sandstone to the south. Then headlands divide the main beaches into TCs, with rock reefs extending offshore as at Narrabeen (Fig. 19.13) and forming a closed SC (RH DHV 2014).

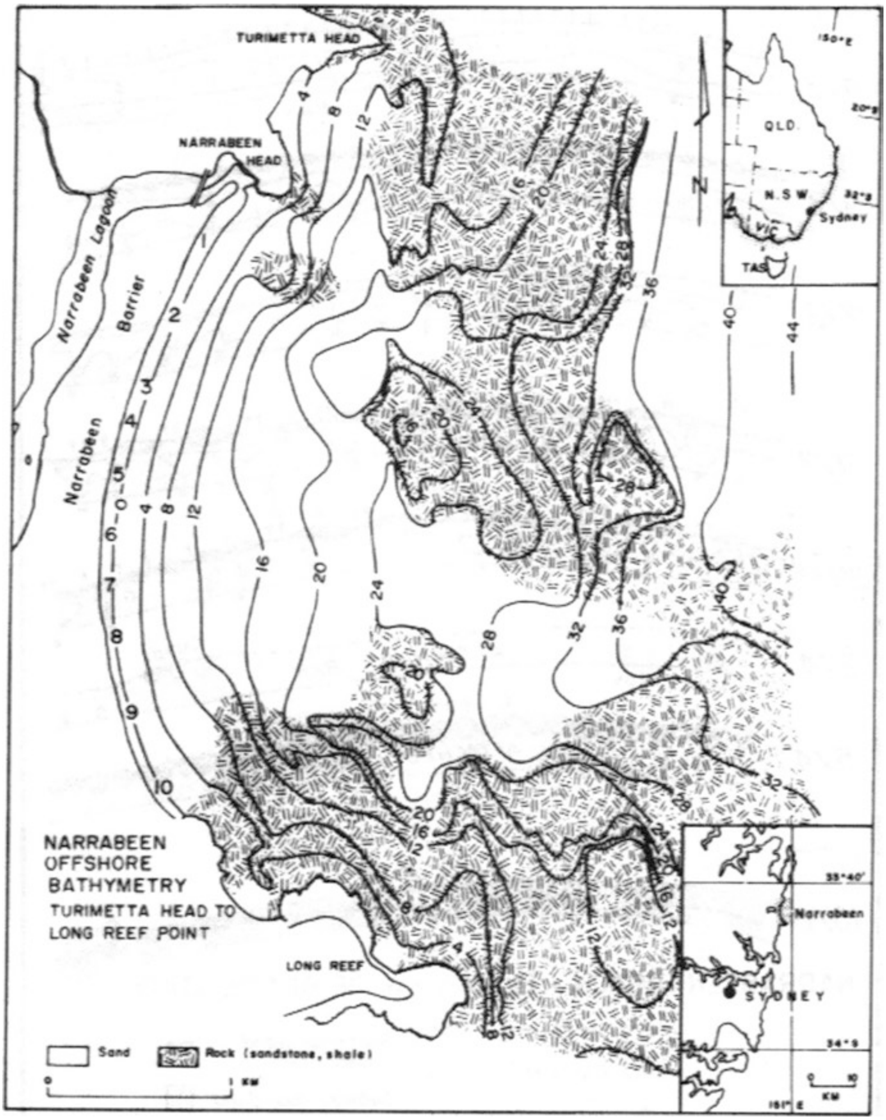

Fig. 19.13 Narrabeen Beach bathymetry and extent of rock reefs, showing how the rocks essentially enclose the compartment and its sand. (Source: Short 1979)

The Sydney beaches are generally moderately to well exposed and are predominately TBR (82%) to occasionally RBB (12%), with the only lower energy LTT and R (6%) located at the sheltered southern end of some beaches (south Newport and Collaroy) and more sheltered locations like around Long Reef and Fairy Bower-Shelly Beach. There are several studies covering a number of the beaches including rip studies by McKenzie (1958), rip experiments (Wright et al. 1982), rip and beach hazards (Short and Hogan 1994) and several Narrabeen investigations (Short 1979, 1984, 1985; Short and Trembanis 2004; Harley et al. 2011, 2014, 2015, 2016; Wainwright et al. 2015; Gallop et al. 2017), with the Narrabeen long-term survey dataset now available online (see Turner et al. 2016).

When waves exceed about 3 m, megarips develop on all the more exposed beaches (Williams 1992), with embayments like Bilgola-Newport being drained by one large rip, while two to three rips form in the longer Narrabeen-Collaroy embayment (Short 1985). During the June 2016 storm, a 1:10 year event, Harley et al. (2017) measure sand being deposited up to 400 m offshore and to depths 10 m by the central Narrabeen megarip.

There are 12 barriers in this SC, with the more exposed North Palm Beach, Avalon, Bungan, Long Reef (Fig. 12.9c) and Curl Curl being backed by small transgressive fields, the widest originally 500 m wide and 25 m high at Avalon, while Narrabeen and Manly both regressed and are capped by foredune ridges, with Manly the widest at 500 m. The others range from receding at Long Reef to a mainland beach at Turimetta to a few foredunes with an average range in width from 100–300 m and an average height of 10 m. All the barriers have been modified and developed to some extent, with the Avalon dunes quarried in the 1950–1960s with only the high foredune remaining, while the north Curl Curl dunes were used for a tip. Only the Palm Beach dunes maintain some form of natural, though managed, morphology (Fig. 12.9b). Palm Beach, Avalon, Newport, Narrabeen, Curl Curl and Manly are the largest barriers; however, all the barriers have a total volume of just 20 M m^3 and a very low per metre volume of 1300 m^3 m^{-1}, indicating the small amount of sand deposited on northern Sydney beaches.

Most of the beaches and barriers appear to be in a state of dynamic equilibrium, with the 40-year survey record of Narrabeen suggesting either slight progradation during this period at 0.5 m^3 m^{-1} $year^{-1}$ (RH DHV 2014) or dynamic stability (Harley et al. 2015), while neighbouring Long Reef-Dee Why has receded exposing lagoonal peats, the sand lost to transgressive dunes and perhaps offshore (Fig. 19.12a). Thom (1983) dated the upper Long Reef peats at ~1.4 and 1 ka, suggesting they were buried by the receding barrier about this time. It is likely all the beaches initially receded as sand was transported offshore to the SSB's before they reached a more equilibrium state.

Sydney's northern beaches do however contain three coastal hotspots at Bilgola, Mona Vale (The Basin) and Collaroy, the latter making international news in 2016 where several houses threatened to fall into the sea (Harley et al. 2016). Each of the hotspots is a result of past planning regulations which allowed property to be placed in the beach hazard zone, resulting in repeated erosion events, loss of property and destruction of several houses. As a consequence, seawalls have been built at each of these sites, while severe beach and foredune erosion has also led to the construction of seawalls at south Palm Beach, Fishermans, Dee Why, South Curl Curl and Manly. Major beach nourishment for the Sydney coast has been discussed for decades but not implemented (see ACEOM 2010). Each of these locations presents ongoing conflict between maintenance of public beach amenity and protection of private houses and infrastructure, which in Collaroy's case has been going on for more than 100 years (see, e.g. WSC 1978, WSC 1985, WC 2014) and where regrettably an initial policy of resumption of beachfront houses was followed by high rise development along this very hazardous beach.

19.4.7 SC:NSW02.03.03 Sydney Harbour

SC:NSW02.03.03 contains Sydney Harbour a drowned river valley (Fig. 19.14) that extends 19 km inland and has an area of 55 km^2 and an indented shoreline of 317 km. It is open to the Tasman Sea though its 2 km wide entrance and ocean waves

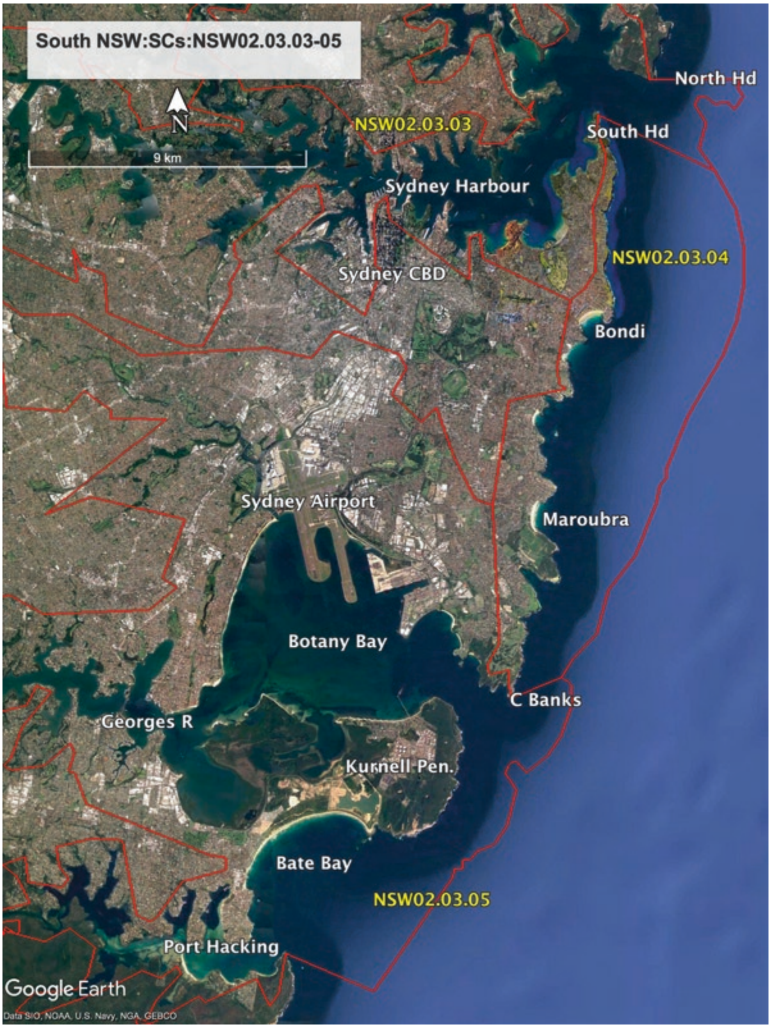

Fig. 19.14 SC:NSW02.03.03-06 Sydney Harbour and the southern Sydney coast and bays. (Source: Google Earth)

Table 19.13 SC:NSW02.03.03 Sydney Harbour beach types and states

BS	BS	No.	%	Length (km)	%	Mean (km)	σ (km)
6	R	31	59.6	6	68.6	0.19	0.18
11	B + SF	12	23.1	1.2	13.7	0.1	0.08
12	B + TSF	7	13.5	1.4	16.0	0.2	0.15
14	R + RF	2	3.8	0.15	1.7	0.07	–
		52	100	8.75	100	0.16	–

penetrate up to 6 km into the harbour, particularly during storm events. The rocky outer harbour, east of the Harbour Bridge, has 65 km of shoreline and contains 52 small beaches that occupy 8.8 km of the shore (13.5%). The more exposed outermost beaches are R, while the more sheltered beaches are a mix of TD B + SF and B + TSF (Table 19.13). Most of the beaches are backed by steeply rising slopes, with some like Washaway (SH 13) coming and going with the storms. There are small regressive barriers in Middle Harbour at Clontarf, the Spit and Balmoral. All have been heavily modified and some reclaimed by infilling and armouring for recreational and residential development.

The harbour has acted as a major sediment sink with the Middle Harbour and main harbour flood tide deltas extending up to 6 km into the harbours and covering an area of ~15 km^2, with a volume the order of 90 M m^3 (Cowell 1986), four to five times the size of the open coast barriers.

19.4.8 SC:NSW02.03.04 South Head-Cape Banks

The eastern Sydney SC (NSW02.03.04) runs from South Head for 20 km down to Cape Banks at the entrance to Botany Bay (Fig. 19.14). This is a predominately cliffed sandstone coast with the 11 beaches occupying just 3 km (10%) of the coast, all bordered by prominent headlands, while some like Gordons Bay, Coogee, Clovelly, Long Bay and Little Bay are deeply embayed. The beaches range from R on the deeply embayed beaches to TBR on the more exposed South Bondi, Tamarana-Bronte and Maroubra, with megarips forming on all the exposed beaches during higher waves, and with the McKenzies-Tamarama-Bronte embayment drained by one large rip during high waves. The hazards to bathers posed by these beaches and their rips were addressed by Short and Hogan (1989).

As mentioned above (Sect. 19.10.2), this entire SC is bordered by the large SSB which commences at South Head and extends south along the entire length of the SC. The only barriers of note are Bondi and Maroubra. Bondi originally had transgressive dunes extending 2.5 km back towards Rose Bay and an area of ~5 km^2. The dunes have been levelled and are now covered in suburbia. Clifftop dune sands also extend up to 2.5 km inland behind much of the coast between Diamond Bay and Cape Banks, the dunes derived from the sand ramps that transported sand up and over the cliffed coast. Most of this sand has been levelled and developed. Thom and Oliver (2018) date from clifftop dunes between 70 and 90 m above sea level overlying Hawkesbury sandstone at Dover heights, Vaucluse, Rose Bay and Bellevue Hill. They dated from 32 to 23.5 ka during the last glacial maxima. They hypothesise the dunes were transported by strong southeast winds up and over the abandoned sea cliffs to be deposited as a mantle of clifftop dunes.

Much of the field work on SSB's took place off these beaches with Field and Roy (1984) developing an evolutionary model for the coast and shelf, with initial transgression and barrier deposition followed by erosion as most of the sand was transported offshore to the SSB's. The SCs barriers total only about 15 M m^3 (5450 m^3 m^{-1}), while the SSB off this section total an order of magnitude greater at 200 M m^3 (Cowell 1986).

19.4.9 SC:NSW02.03.05 Cape Banks-Hacking Point

SC:NSW02.03.05 is the southern most of the Sydney coast SCs which includes three major subsystems, Botany Bay, the Kurnell Peninsula-Bate Bay and Port Hacking, each a major sediment sinks (Fig. 19.14). Both Botany Bay and Port Hacking contain large flood tide deltas (~90 and 150 M m^3 each), while Bate Bay contains the large Kurnell barrier (~140 M m^3) which includes once massive transgressive dunes and clifftop dunes. Roy and Crawford (1979b) conducted a detailed field mapping and investigation of the Kurnell Peninsula and barrier and documented its evolution. They proposed five stages in the evolution of the peninsula. Around 9 ka a transgressive marine sand entered Bate Bay and the entrance to Botany Bay. Then between 9 and 7 ka, a 'proto' barrier formed across Bate Bay attached to Kurnell Peninsula delivering clifftop dunes which have been dated at 12–8 ka (Thom et al. 1994), followed by the sea-level stillstand. Sea level stabilised around 7 ka, and a 1 km wide regressive foredune ridge plain prograded seawards till 4 ka. This was followed by shoreline stabilisation/erosion as two separate phases of dune transgression eroded the outer ridges and moved the sand landward. The first phase was initiated ~3.7 ka and migrated landward over the regressive ridges. Both these phases stabilised and were vegetated. Finally, since 1 ka a third phase was initiated about 0.6 ka and remains active today. It was however assisted by land clearing in the eighteenth century with dunes recorded to have moved 1 km inland since the 1880s. These dunes have in recent decades been quarried for the Sydney sand market and now only a few remnants remain, while housing covers much of the former quarry site. Foster and Gordon (1978) found that Cronulla Beach was receding at between 0.5 and 0.8 m $year^{-1}$ and recommended dune stabilisation to prevent further sand loss and beach nourishment, both of which have since been implemented.

Hann (1986) found that Botany Bay contained basal fluvial sediment overlain by 50 m of Pleistocene sands, mud and clay deposited in estuarine environment interspersed with periods of exposure. During low sea level, massive longshore transport

Table 19.14 (a) Botany Bay and (b) Port Hacking beach types and states

a) BS	BS	No.	%	Length (km)	%	Mean (km)	σ (km)
6	R	14	60.9	13.4	72.0	1	1.4
11	B + SF	5	21.7	3.1	16.7	0.6	0.6
12	B + TSF	4	17.4	2.1	11.3	0.5	0.9
		23	100	18.6	100	0.8	–
b) BS	BS	No.	%	Length (km)	%	Mean (km)	σ (km)
6	R	2	25	1.9	53.8	0.9	–
11	B + SF	5	62.5	1.5	42.5	0.3	0.2
14	R + RF	1	12.5	0.1	3.7	0.1	–
		8	100	3.5	100	0.4	

from as far south as Shoalhaven delivered sand to be trapped by Kurnell Peninsula. At the same time, strong southwest 'glacial' winds blew sand out of the exposed bay floor and northwards for up to 8 km blanketing much of eastern Sydney (Gale et al. 2018). The Holocene marine transgression flooded bay and formed the Lady Robinson regressive barrier between 8 and 6 ka as the shallow bay floor eroded and deepened.

While the open coast has more exposed rip-dominated beaches, within the two bays, R beaches dominate the outer more exposed parts of the bays, with TD B + SF and B + TSF dominating the more sheltered inner bays (Table 19.14).

Botany Bay: Perhaps the first description of beach and dune processes in Australia was undertaken by Andrew (1912) who monitored Botany Bay's Lady Robinson Beach shoreline between 1909 and 1912 and described the impact of the July 1912 storm which left a 4.5 m erosion scarp in the foredune. He goes on to record the recovery of the beach and foredune as well as 'trenches' (blowouts) formed in the foredune and southerly transport down the beach during northerly wind conditions. The longshore transport is visibly apparent on the 6 km long Lady Robinson Beach where a series of 11 groynes have been constructed between 1997 and 2005. The sand is moving northwards along the northerly two thirds of the beach towards the Cooks River mouth, possibly due to wave refraction around the Sydney Airport runways (Lawson and Atkinson 1978) and Port Botany, which extend up to 3 km into the bay and are completely armoured, and southwards along the southern third to accumulate on the Dolls Point sand spit. Prior to construction of the groynes, there was on the order of 150,000 m^3 of sand recycled from Dolls Point onto the beach between 1974 and 1986 (Coull and Willoughby 2003; Frost 2011). Frost also examined the impact of the groyne field and found it has had mixed results in stabilising the beach and that sand was continuing to move both northwards and southwards, with sand waves arriving at Dolls Point. Likewise, inside the southern entrance, 3 km long Silver Beach is essentially a west-trending sand spit, upon which 15 groynes were built from 1969 to 1970 to reduce sand transport estimated at 2000–3000 m^3 year^{-1} (Willoughby et al. 1995) and minimise erosion of the eastern end of the beach (Treloar et al. 1981). Transport on both these beaches indicates that sand is still moving into the bay. Willoughby et al. (1995) reviewed the impact of the port and airport on coastal processes within Botany Bay and concluded that while they have modified the natural beach processes around the bay, these changes have not always been negative and that in many cases they are only marginal.

The bay has acted as a major sediment sink and source. Sand has moved through the bay entrance to supply the large flood tide delta which occupies all the northern and central bay floor. Sand from the bay floor also supplied the Lady Robinson barrier a 700 m wide regressive barrier capped by low foredune ridges, with a subaerial volume of ~75 M m^3 (10,700 m^3 m^{-1}). During the sea-level lowstand (~18 ka), strong southerly 'glacial' wind reactivated the sandy bay floor and blew sand up to 8 km northwards as far as Moore and Centennial parks covering an area of ~25 km^2 with a volume on the order of ~100 M m^3.

Port Hacking is a narrow 9 km long west-trending drowned river valley with a 1 km wide entrance and a large flood tide delta that has moved 6 km into the bay, with deeper tributaries off to either side of the delta. The delta has been dated from at least 9 ka to the present (Roy 1984b). Roy found the 20 km^2 tidal delta has migrated into the bay and its tributary arms at an average rate of ~0.5 m $year^{-1}$ and has a volume on the order of 150 M m^3, though Druery and Geary (1985) measured a contemporary rate of 1.5 m $year^{-1}$, representing 2500 m^3 $year^{-1}$. During the same period, the smaller Hacking River fluvial bayhead delta has migrated 1.5 km into the bay. The flood tide delta is now feeding upon itself eroding the outer delta to supply the prograding inner delta and thereby deepening the outer bay causing the outer bay beaches to become more exposed, and some like Bonnie Vale are eroding, while the sandy Deeban Spit is completely overwashed by major storm events. Fortuitously no property is at risk.

19.4.10 PC Overview

The Sydney coast is a steep predominately rocky cliffed coast which only offers significant accommodation space in the four drowned river valley estuaries and on the steep inner shelf. While there is considerable sand available in the Sydney system, most is located in the estuarine flood tide deltas and on the inner shelf as SSB's, with south- to southeast-facing Woy Woy and Kurnell containing the only significant barrier systems. Rough estimates of the Sydney sand volume are on the order of 1000 M m^3, with most located in the SSB's (>200 M m^3) and four large flood tide deltas (>600 M m^3) and the remainder in the barriers, most in the larger Woy Woy (75 M m^3), Lady Robinson (75 m^3) and Kurnell (140 M m^3) systems. There is little, if any, longshore transport on the open coast owing to the steep, deep and in places rocky shoreface, the embayed nature of the beaches forming closed boundaries and swash-aligned beaches, and dominance of on-offshore transport. Long Reef is a major closed boundary with the fine (0.24 mm) whitish sand extending south of the Reef to Manly, while extending north to Palm Beach, it is coarser (0.32 mm) and iron-stained, indicating no mixing of the two. Figure 19.2 also illustrates the considerable longshore variation in both grain size and carbonate content, another indication of separate compartments and lack of transport and mixing. There is evidence the SSB's are being surficially reworked with sand being moved northwards under the prevailing southerly waves. Volumes are expected to be small and none of this sand can reach the coast. The SSB's are however a potential source of sand for beach nourishment (ACEOM 2010) and aggregate (Metromix 1993).

The Sydney coast is presently exposed to the most severe storms on the southeast coast (Fig. 17.2; Glatz et al. 2017) which result in major beach erosion and offshore sand transport, from which the beaches slowly recover. This has been exacerbated at Snapperman, Palm Beach, Bilgola, The Basin, Collaroy, Dee Why, South Curl Curl, Freshwater and Manly by the construction of houses and infrastructure in the beach hazard zone, leading to damage to and loss of property during severe storms, such as the June 2016 event (Harley et al. 2017; Mortlock et al. 2016). In addition to major beach oscillation, subtle ENSO-related changes in wave direction generate beach rotation (Short and Trembanis 2004; Harley et al. 2011), all of which will be impacted by predicted shifts in storm location and wave direction (Goodwin et al. 2016). Rising sea level and changing wave climate will increase the risk not just to the open coast beaches but also those in the outer sections of the bays which will experience increased wave height and storm surges. In addition, the far more extensive low-lying estuarine shores in the harbours, bays and lagoons (Narrabeen, Dee Why, Curl Curl, Manly, Pittwater), where many houses are already exposed to flooding, and the many reclaimed parts of Sydney Harbour and Port Botany, are going to be the most exposed to sea-level rise and increasing levels of storm surges and extreme water levels (Hanslow et al. 2018). They will become increasingly prone to inundation and in the more exposed locations to shoreline recession as flood tide deltas are reactivated.

Gordon (1989) reported that the first 'sea defences' in Sydney was a boulder seawall at Bondi built in 1909–1923. He recorded 22 Sydney beaches where there are some forms of protective works including 18 seawalls and revetments, dune management and minor nourishment had already taken place by 1989, with major dune management works and some additional seawalls and groyne built since. All this is clearly indicative of a coast already at risk and one that will become more vulnerable into the future.

In Broken Bay the Brisbane Water tidal channel and its shoreline will become increasingly dynamic, while the low-lying Woy Woy and the Brisbane Water shoreline will see sea-level and groundwater rising. In Pittwater, the flood tide delta will become deeper and continue to move southwards increasing shoreline instability on both sides of the bay. Likewise, in Sydney Harbour a deeper more active flood tide delta will bring higher waves and increased shoreline instability, and rising sea level and higher storm surges will raise the level of inundation. In Botany Bay the existing groynes and armouring around most of the bay shore is a testament to the existing threat posed by wave attacked and sand transport. All this will be exacerbated into the future.

Clearly one solution to Sydney's retreating beaches is beach nourishment using sand sourced from the massive SSB's (ACEOM 2010), sand that once resided on

Sydney's early to mid-Holocene beaches. ACEOM (2010) estimated that a 0.3 m rise in sea level would require 9 M m^3 of sand to maintain Sydney's beaches, nourished at a rate of 300 m^3 m^{-1}. In all the bays, existing reclaimed areas will need to be raised, while many low-lying areas previously above surge levels may also need to be raised, possibly using the same sand source.

19.5 PC:NSW02.04 The Illawarra Coast

19.5.1 Introduction

The Illawarra Coast extends for 158 km from Point Hacking south to Beecroft Head (Fig. 19.1a). The northern half is dominated by the Illawarra escarpment which forms the first 25 km and is composed of Narrabeen sandstone and claystone overlying the Illawarra coal measures, which are exposed in steep vertical sandstone cliffs up to 100 m high. To the south the escarpment slowly trends inland for 45 km extending 12 km inland in lee of Port Kembla. Permian basalt dominates the next 30 km of coast through Kiama down to Black Head. The head marks the northern boundary of the Shoalhaven Bight into which flows the Shoalhaven River and its WD delta and includes Seven Mile-Comerong Beach which extends from Gerroa for 19 km to Crookhaven Heads where the horizontal Nowra sandstone returns to the coast and continues to the large Beecroft Peninsula. Fifty metre high Beecroft Head forms the southern boundary of the bight and PC.

In between the escarpment and the coast is a widening undulating coastal plain upon which are located the small coastal coal mining towns of Stanwell Park, Coalcliff, Wombarra-Coledale-Scarborough-Clifton, Austinmer, Bulli and Thirroul which form the northern coastal suburbs of the larger Wollongong City (260,000) and are increasingly becoming satellites suburbs of Sydney. The city extends another 12 km south to Windang and includes the Port Kembla port and industrial area. South of Wollongong is the Shellharbour LGA with a rapidly growing population of 72,000 and then the Kiama LGA with a total population of 22,000, most spread along the 25 km of coast between Minnamurra and Gerroa. The southern Shoalhaven LGA (102,000) centred on the large town of Nowra (10,000) has smaller coastal communities at Shoalhaven Heads, Culburra and Currarong.

19.5.2 Beaches and Sand Transport

PC:NSW02.04 has an equal mix of rock and sand coast, with the 68 beaches occupying 49% of the shore. The beach sand ranges from fine to medium in size, with carbonate up to 60% in the north, decreasing to <10% in the south (Fig. 19.2), suggesting a range of sediment compartments. The coast faces east-southeast exposing many of the beaches to the dominant southerly swell. WD TBR dominates the

Table 19.15 PC:NSW02.04 the Illawarra beach type and states

BS	BS	No.	%	Length (km)	%	Mean (km)	σ (km)
3	RBB	8	11.8	15.2	19.6	1.9	2
4	TBR	28	41.2	52.5	67.7	1.9	2.6
5	LTT	12	17.6	5.9	7.6	0.5	0.4
6	R	20	29.4	3.9	5.0	0.2	0.2
		68	100	77.5	100	1.1	–

beaches by length (68%), followed by RBB (20%) with the 20 small R beaches making up 5% and 12 LTT the remaining 8% (Table 19.15). The longer higher energy beaches average 2 km in length, while the usually more embayed R beaches average just 0.2 km. Seventeen kilometre long Seven Mile-Comerong Beach is the longest on the south coast and one of the few to have a more dissipative double-bar system, in part owing to its fine sand size. Wright (1970) investigated its sediment characteristics and concluded the river is supplying fluvial quartz sand at its mouth, where the sand is coarsest (0.3 mm) fining to the north (0.16 mm), suggesting northerly transport of the sand. Carbonate is as low as <5% increasing slightly offshore (Short 1984). Elsewhere the PC has highly variable sediment texture with size averaging 0.33 mm (σ = 0.1 mm) and ranging from fine to coarse and carbonate averaging 29% (σ = 16%) but ranging from 5 to 68% (Fig. 19.2), all indicative of local sources and limited longshore transport between the many closed and leaky TCs.

For the most part, the beaches tend to have closed boundaries, including major boundaries at Kiama and Black Head (Chapman et al. 1982), with little if any transport between the SCs. While Healy and Lee (1975) predicted substantial longshore transport in the Wollongong region, BMT WBM (2017) found that the Wollongong embayed beaches '… are assumed to experience longshore and cross shore sediment transport that is retained within the embayment', a view supported by Geary and Lord (1981). Likewise, along the Shellharbour coast, SMEC (2010) found the three headland-bound beaches (Warilla, Shellharbour North and South) are largely self-contained, with limited sand reserves retained within the individual compartments, with little if any transport between the beaches. Bryant (1984b) also found that Stanwell Park is closed, Bulli is leaky, Warilla is losing sand to the north (since closed) and East is closed. The most recent survey by Carvalho et al. (2017) concluded the Wollongong SCs are leaky and apparently sediment-deficient compartments composed of five sand deposits separated by headlands and the breakwaters of Red Point-Port Kembla.

19.5.3 Barriers

The PC has 30 barriers that occupy 70 km (44%) of the coast. Most are relatively narrow Holocene mainland beaches consisting of up to a few foredunes. The exception is the massive Shoalhaven River-Seven Mile beaches with a volume of

1127 M m³ (66,320 m^3 m^{-1}) which comprises 93% of the PCs barrier volume. The only other barriers of note are Perkins Beach (27 M m^3) and Warrain Beach (11 M m^3). These three barriers border the three largest estuaries in the PC, namely, Lake Illawarra, the Shoalhaven River and Wollumboola Lake-Cabbage Tree Swamp, each acting as major sediment sinks on an otherwise steep rocky coast. The only dune transgression occurs at Marley and north Garie and along Perkins Beach where in the north it extends up to 1 km inland. Today the barriers are largely vegetated and stable with <1% presently unstable. In total, the barriers have a per metre volume of 17,114 m^3 m^{-1}, the second highest in the region (Table 19.4).

Hesp (1993) classified the barriers between Jibbon Beach (Hacking Point Fig. 19.15) and Kendalls Beach (Kiama) (SCs:NSW02.04.02-04) and found a wide range of barrier types that were related to the geological setting. Nine mainland beaches occur along the northern cliffed section and around headlands; 18 receded barriers are located along the coast between Stanwell Park and Kiama; 4 stationary barriers occur in small deep embayments; and 10 episodic transgressive dune barri-

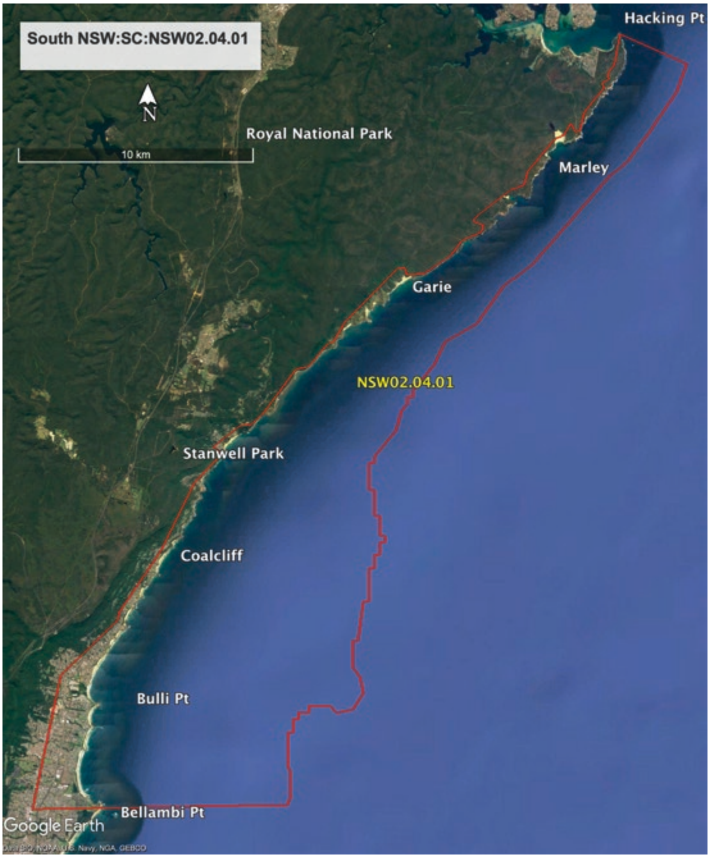

Fig. 19.15 SC:NSW02.04.01 occupied the steep northern Illawarra Coast. (Source: Google Earth)

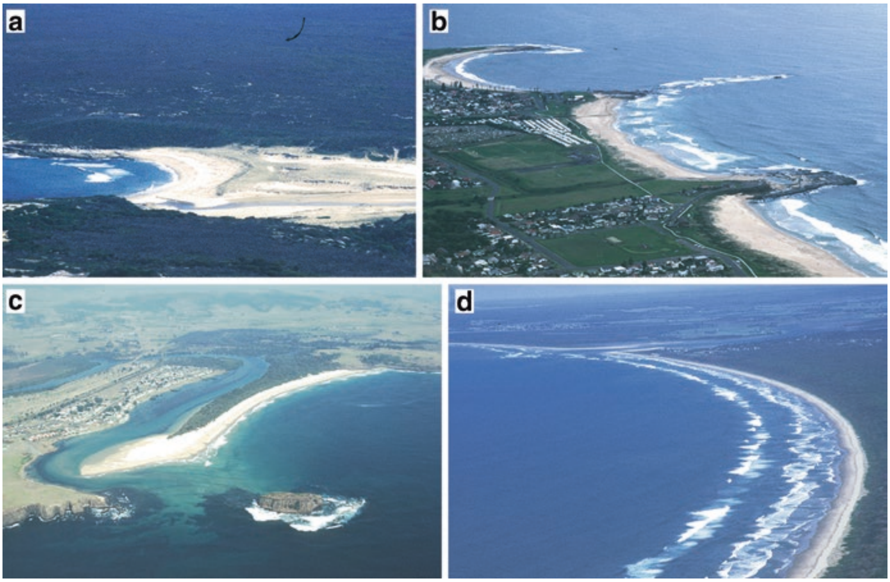

Fig. 19.16 (**a**) Marley Beach and dunes (NSW 341); (**b**) the embayed Sandon Point, Bulli and Woonona beaches (NSW 365-367); (**c**) the Minnamurra River mouth and barrier (NSW 389); and (**d**) the exposed double-barred Seven Mile Beach (NSW 400). (Photos: AD Short)

ers are located at the northern ends of exposed beaches where they face more to the south, while the sole prograded barriers lie in the moderately protected Minnamurra embayment (Fig. 19.16c) where the barrier faces east-northeast. Hesp reported that the barriers were initiated as sea level reached its present level ~7 ka. The largest barrier is associated with the clifftop dunes located between Marley (Fig. 19.16a) and Jibbon (2.25 M m^3). Pye and Bowman (1984) dated the dunes at between 9.8 and 5.4 ka, which is in agreement with the Kurnell dunes. Hesp (1993) concluded that these dates indicate that the dunes initially reached the clifftops between 11.4 and 10.6 ka when sea level was 15 m below present (Sloss et al. 2007).

Switzer and Burston (2010) examined a number of boulder deposits along the coast between Wollongong and Jervis Bay and found that large sandstone boulders have been deposited up to 30 m above sea level. They concluded they were deposited either by major storms or tsunami, though Courtney et al. (2012) doubt the latter.

The PC contains five SCs which are discussed below.

19.5.4 SC: NSW02.04.01 Hacking Point-Bellambi Point

SC: NSW02.04.01 commences at Hacking Point and trends southwest for 48 km to the prominent Bellambi Point (Fig. 19.15). The northern half down to Stanwell Park is a steep rocky southeast-facing coast with vertical sandstone-claystone cliffs and rock platforms, with 11 small beaches occupying just 3.2 km (14%) of the coast. This steep section is also paralled by a large SSB down to Garie Beach (Fig. 19.9). South from Stanwell Park, the Illawarra escarpment slowly trends inland, and the coastal gradient decreases allowing a series of generally small (<1 km) embayed beaches to form (Fig. 19.16b), with 18 beaches occupying 10 km (50%) of the predominately steep rocky coast. At Stanwell Park Bryant (1984b) measured beach changes between 1895 and 1980 and concluded the compartment was self-contained with no leakages.

Jones et al. (1979) investigated the barrier at Sandon Point Beach (NSW 365; Fig. 19.16b) and found that sea level reached its present level between 7.5 and 6.5 ka. At this time a large barrier was deposited between Thirroul and Bulli containing a backbarrier depression with muddy sediments. This is now capped by transgressive cobbles and sand deposited as shoreline receded over the earlier deposits.

19.5.5 SC: NSW02.04.02 Bellambi Point-Red Point

SC:NSW02.04.02 continues south of the low Bellambi Point for 18 km to the prominent Red Point (Fig. 19.17a). It consists essentially of two open east-facing embayments separated in the centre by Flagstaff Point and Wollongong Harbour. The northern embayment contains roughly 5 km of near continuous beach-barrier (Corrimal-Towradgi-Fairy Meadow-North Wollongong) and then the small Wollongong Harbour, while the southern embayment contains the 4 km long Wollongong City-Coniston beach and then the breakwaters and training walls of Port Kembla Harbour, which have replaced the once sandy shore with rocks and harbour walls, together with the more sheltered beaches in lee of Red Point. The longer exposed beaches are all TBR to RBB, while the sheltered are LTT to R. The four barriers in this SC occupy 12 km (66%) of the shore and have a volume of 15.3 M m^3 (1300 m^3 m^{-1}).

According to Hesp (1993) all the beaches are receding. The longer beaches are backed by low regressive barriers that have been heavily modified by residential, industrial and recreational development. The northern ends of the more exposed Corrimal and Towradgi beaches are both backed by small, now modified, transgressive dune fields, including dune overpassing at Corrimal-Bellambi Point. There are also clifftop dunes on Red Point which were dated by Bryant et al. (1988) at between 200 and 400 ka and those at Fishermans Point at 240 ka, indicating they were all deposited during earlier highstands of sea level. As noted above both Geary and Lord (1981) and BMT WBM (2017) concluded this section of coast/SC is closed, though Carvalho et al. (2017) suggested the five TCs in either side of Red Point are rock-bound but leaky, with a major boundary at Red Point and the Port Kembla breakwaters.

Linklater et al. (2018) use this SC to illustrate the NSW SeaBed mapping program. Their results show that the seabed is dominated by elevated rock platform

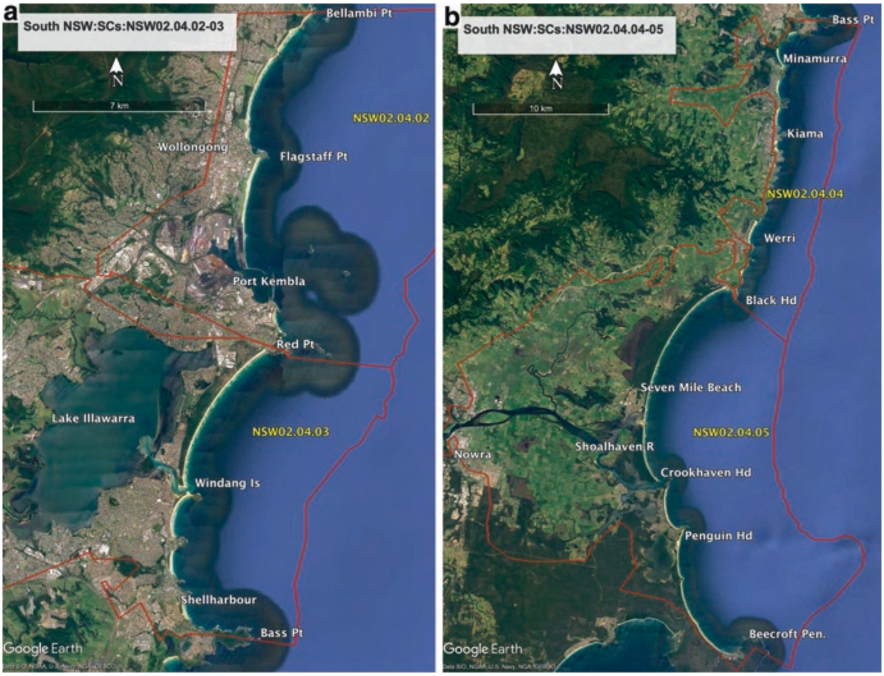

Fig. 19.17 (**a**) SC:NSW02.02.02-03 the Wollongong coast; and (**b**) SC:NSW02.02.04-05 centered on the Shoalhaven delta. (Source: Google Earth)

features (50%), with coarse sand the most dominant substrate class forming plains with gravel occupying lows in the plain. Inshore sediments are beach sand (Fig. 19.18). The results indicate the very limited sand sources located on the compartments seafloor.

19.5.6 SC: NSW02.04.03 Red Point-Bass Head

SC:NSW02.04.03 occupies the Lake Illawarra embayment and extends for 18 km between Red Point and the protruding basaltic Bass Point (Fig. 19.17a). It contains the 36 km^2 Lake Illawarra and its 7.6 km long Perkins-Windang beach barrier, south of which is a series of smaller embayed beaches (Warilla, north and south Shellharbour) including a few pocket beaches on Bass Point. The longer beaches are all TBR-RBB, while the sheltered are all R and composed of coarse material derived from the headland and carbonate detritus, with carbonate ranging from 20 to 60%. The southern Shellharbour Beach was cut by two training walls in 2017–2018, including a 500 m long curving attached breakwater, built to connect the new Waterfront Shell Cove small boat harbour and marina development to the sea

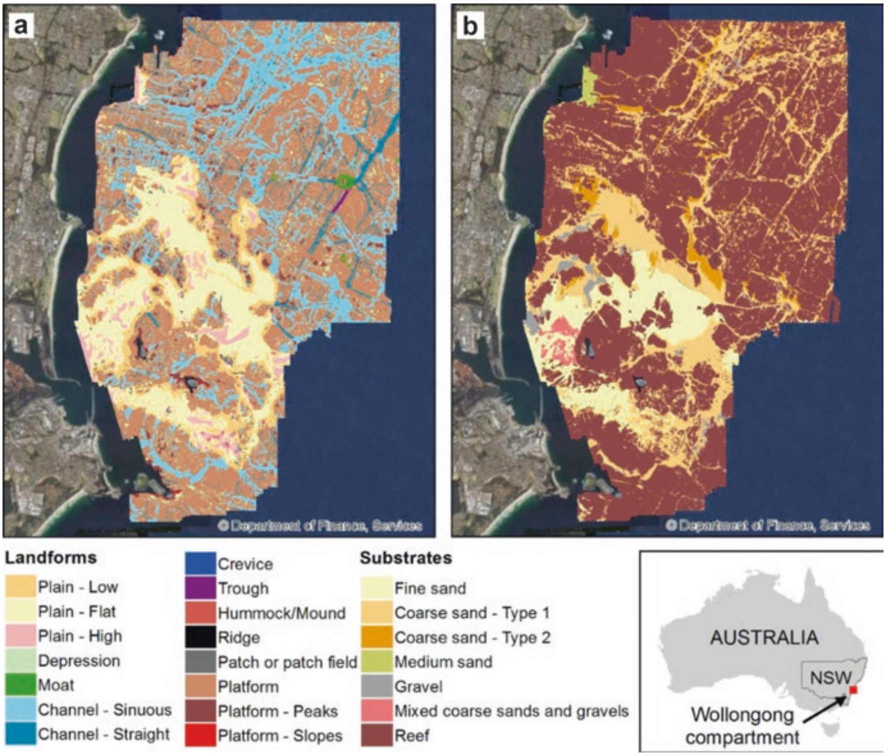

Fig. 19.18 Seabed classification of the Wollongong coast (NSW) showing (**a**) landform classification and (**b**) substrate classification (from Linklater et al. 2018, reprinted with permission). Note the extensive low rocky platforms dissected by numerous joint-aligned channels, with sand occupying depressions and drowned valleys

(Britton 2013; Britton et al. 2017). While there appears to be little if any longshore transport in this SC, the walls will realign the beach (Miller and Nielsen 1995) and impact its morphodynamics with rips running out along the walls during period of high waves. Their full impact remains to be seen.

Sedimentation in Lake Illawarra, a barrier estuary, was initially investigated by Roy (1984b) and later by Sloss et al. (2005) who reconstructed the evolution of the lake. They found it has a basal marine transgressive unit deposited between 8 and 7.5 ka, with more open marine conditions prevailing until ~5 ka, when the barrier became emergent and the lake became a low energy lagoonal environment. A slight fall in sea level between 3.2 and 2.5 ka further restricted circulation, while five bay head deltas prograded into the lake. Since then the deltas have continued to rapidly prograde and the lagoon basin infill, accompanied by an increase in sedimentation from <1 mm year^{-1} during the Holocene to between 2.6 and 7 mm year^{-1}, following European settlement and land clearing over the past 200 years (Sloss et al. 2004). In 2006–2007 the inlet was trained to maintain a permanent entrance which has stopped the transport of Warilla Beach sand into the entrance while increasing the tidal prism, which has led to an expansion of the flood tide delta and increase in tide range and salinisation within the lake (Nielsen and Gordon 2017).

Kumbier et al. (2018) modelled the impact of spring tide, storm surge, river flooding and sea-level rise in Lake Illawarra and the Shoalhaven estuary. They found in Lake Illawarra 5.1 km^2 would be inundated under present conditions, rising to 8.1 km^2 with a 0.4 m sea-level rise and 12.1 km^2 with a 0.9 m rise. In the Shoalhaven with its extensive low-level flood plain and backswamps, the respective areas are 75 km^2, 91 km^2 and 104 km^2. They concluded that infilled mature estuaries like the Shoalhaven will be far more vulnerable to saltwater intrusion and inundation once a tripping elevation is reached, while the immature estuaries like Lake Illawarra will be less vulnerable to inundation but vulnerable to substantial changes in estuary hydrodynamics.

SMEC (2010) found no evidence of transport between the embayed beaches between Bass Point and Warilla, while there is possible transport around the central Red Point. In the northern embayment, they suggest that sand may be bypassing the smaller headlands and reefs and reaching Bellambi Point. They also found that ~5 M m^3 of sand had been extracted from the Perkins-Windang dunes and tens of thousands from the once larger Corrimal-Towradgi-Fairy Meadow dunes. The northern compartment (NSW02.04.02) has a barrier volume of 15.3 M m^3 (1300 m^3 m^{-1}), while the southern (NSW02.04.03) has a volume of 35.5 M m^3 (2430 m^3 m^{-1}), both relatively low volumes, as is typical of much of this PC.

19.5.7 SC:NSW02.04.04 Bass Head-Black Point

SC:NSW02.04.04 is a 34 km long basaltic section of the coast, associated with the Permian Gerringong Volcanics, which trends south from Bass Point to Black Head (Fig. 19.17b). It contains 13 small embayed beaches which occupy 9.6 m (28%) of the coast, the remainder moderately steep, 20–60 m high basalt cliffs and rock platforms as well as a few small boulder beaches. The headlands afford moderate protection with most of the beaches being LTT and R, with only the exposed south-facing Killalea, Minnamurra (Fig. 19.16c), Bombo and Werri being TBR-RBB. The four longer beaches have the only barriers, with Killalea backed by stable transgressive dunes; Minnamurra and Werri being the only prograded barriers in the SC; and Bombo receding (Hesp 1993). These barriers have a total volume of just 3.8 M m^3 (570 m^3 m^{-1}) the smallest in the PC. It is unlikely there is any transport between the embayed beaches, with the southern Black Head and its offshore reefs and northern Bass Point apparently forming closed boundaries to the SC (Chapman et al. 1982).

The Minnamurra estuary is fed by a small inlet located at the southern end of the Minnamurra barrier (Fig. 19.16c). The estuary is interesting in that two extensive late Holocene sand sheets have been deposited up to 2 km into the estuary and overlie the flood tide delta and mud basin deposits. Switzer et al. (2005) conclude they have to be either the result of a very high magnitude storm or a tsunami, though Courtney et al. (2012) doubt the latter.

19.5.8 SC:NSW02.04.05 Black Point-Beecroft Head

SC:NSW02.04.05 contains the 25 km wide Shoalhaven Bight bordered by Black and Beecroft heads (Fig. 19.17b). Between the heads are three curving embayments (Seven Mile, Culburra and Warrain) containing seven beaches which occupy 31 km (78%) of the shore, including the 17 km long Seven Mile-Comerong Beach (Fig. 19.16d) that forms the eastern boundary of the Shoalhaven River and delta. The bight with its river and delta is a major sediment sink for both fluvial and marine sediments. Wright (1970) found the sand size decreased from 0.35 mm at the Shoalhaven River mouth to 0.21 mm in the north and concluded this implies a fluvial supply and northward transport. The beaches are all reasonably exposed with the fine quartz-rich (~95%) sand of Seven Mile maintaining a double-bar system and TBR dominating the other beaches, except the sheltered Abrahams Bosom in lee of Beecroft Head, whose overwash deposits were investigated by Switzer and Jones (2008).

The Shoalhaven River has a permanent trained entrance at Crookhaven Head and a periodically closed entrance at Shoalhaven Heads and is one of the few NSW rivers to have filled its estuary and deliver fluvial bedload to the coast. The WD delta consists of the long Seven Mile-Comerong Beach, both regressive barriers capped by foredune ridges and the backing rich deltaic plain. Roy (1984b, 1992) dated the evolution of the delta and recorded the estuarine mud basin infilling from 20 m depth from at least 8 ka, reaching the surface by 3 ka, at which time it was overlain by the flood tide delta and subsequently by floodplain deposits. The southern regressive Comerong Island regressed seawards from 6 ka to the present. On the northern side of the river mouth, Thom et al. (1981) dated the 1.5 km wide Seven Mile barrier. It was initiated following the sea-level stillstand (~6.5 ka) and regressed 1.5 km seawards, stabilising about 2 ka. The SC has a total barrier volume of 1140 M m^3 (38,630 m^3 m^{-1}), 98% contained in the larger Seven Mile system, and by far the largest in the PC.

While Seven Mile beach may be undergoing ongoing progradation, the river mouth causes major changes in the adjacent shoreline behaviour. When the Sholhaven Heads river entrance is opened by severe flooding, an extensive ebb delta forms off the mouth and generates delta margin erosion to its sides, leading to beach erosion and undermining of the Shoalhaven Heads surf club. When the mouth closes, the delta sand returns to shore prograding and protecting this section. There was an investigation into the feasibility of training the Shoalhaven entrance in the 1970s (Brown et al. 1977); however, this is very unlikely to happen.

While this is a more sediment-rich SC, there does not appear to be any linkage to the adjoining SCs, with the large steep Beecroft Peninsula separating it from Jervis Bay to the south and Black Head and its reefs and rocky shore to the north, containing sediment to within the bight. Short (1984) found the fine Seven Mile Beach sand extend to 18 m depth, beyond which is coarse transgressive sands suggesting the finer beach-river sand is contained within the nearshore.

19.5.9 PC Overview

The Illawarra Coast (PC:NSW02.04) is a reasonably exposed, south-trending shore dominated by its geology. It is bordered in the north by the steep 100–200 m high Illawarra escarpment which forms the first 25 km of coast and in the south by the steep Beecroft Head and larger Beecroft Peninsula. In between is the widening Wollongong coastal zone in the north paralleled by a SSB to Garie beach, then a series of small embayed beaches down to Port Kembla, followed by the Lake Illawarra embayment with its modified inlet and long barrier, then the basaltic coast and small embayed beaches between Windang Island and Black Head and finally the larger Shoalhaven Bight, river and delta (Figs. 19.15 and 19.17). Each of the five SCs appears to be closed with little or no leakage of sediment northwards. Sediment transport has been predominately onshore depositing transgressive units in the larger Lake Illawarra and Shoalhaven estuaries during the sea-level transgression, followed by regressive barrier deposits. The barriers are small in number and size, with only the Perkins-Windang and in particular the Seven Mile-Comerong system accumulating larger volumes of sand, some of the latter probably sourced from the Shoalhaven River, one of the few fluvial sources on the NSW coast. There appears to be some northerly transport and headland bypassing along parts of the Wollongong coast where headlands are subdued, though unlikely at the rates proposed by Healy and Lee (1975, Table 19.7). This sand is feeding (the now modified) transgressive dunes at the northern end of Corrimal, Towradgi, Perkins and Warilla beaches. In the past it transported Warilla sand into Lake Illawarra and moved along Seven Mile Beach where the sand fines to the north (Wright 1970). The remaining generally small embayed beaches appear to be closed TCs with no connection to adjoining TCs or SCs, together with major closed boundaries at Beecroft Peninsula, Black Head and Bass Point.

This PC is exposed to major storm events and severe beach erosion, with the beaches slowly recovering post-storm. However, as Hesp (1993) indicates, a number of beaches are already receding with possibly only Seven Mile prograding. All the beaches will be susceptible to sea level-induced recession, while changing wave climate may induce intra-embayment rotation and shoreline realignment. Sea-level rise will however have its greatest impact around the low-lying shores of Lake Illawarra and the extensive wetlands and flood plain of the Shoalhaven delta, which will experience rising water tables, increased salinisation and higher flood levels as predicted by Kumbier et al. (2018).

19.6 PC:NSW02.05 Jervis Bay-Wasp Head

19.6.1 Introduction

This PC occupies the southern part of the Sydney Basin, with a coast dominated by the horizontally-bedded Shoalhaven Group sandstone, which at its southern boundary abruptly abuts the steeply dipping Ordovician metasedimentary rock of the

Lachlan Fold Belt. The PC extends for 180 km and contains 106 beaches which occupy 83 km (46%) of the otherwise cliffed rocky coast. It commences at the 40 m high Beecroft Head and includes the cliffed Beecroft Peninsula, the moderately sheltered circular Jervis Bay, and then a south-southwest trending 100 km section down to Wasp Head (Fig. 19.1b) that is characterised by near continuous embayed beaches and headlands. Much of this coast is contained in the Jervis Bay, Booderee, Conjola, Meroo and Murramarang national parks, while Jervis Bay Marine Park occupies the entire bay and surrounding headlands extending from Warrain Beach to Sussex Inlet. Several generally small coastal towns and communities are restricted to the inner Jervis Bay area (Callala (3800), Huskisson (3500), Vincentia (6000), Jervis Bay (400)) and the coastal Sussex Inlet-Berrara (4500), Manyana region (2500), the regional centre of Ulladulla (7000) and Bawley Point-Kioloa-Durras (2000).

The coastal geology plays a major role in this PC controlling the coastal orientation and forming the numerous headlands and in places rock reefs and small islands. The generally horizontally bedded sandstone and shales are eroded to form steep cliffs usually with rock platforms at their base. There is an outcrop of the resilient essexite at Bawley Point, but otherwise the sedimentary rocks dominate the coast.

The coast is exposed to the same coastal processes as its neighbours with a prevailing moderate southerly swell, occasional high waves from the east through south and micro-tides. The prevailing winds are the south through east in summer and westerlies in winter, with the dominant westerlies blowing offshore (Fig. 18.21). Tides are micro with a spring range of 1.3 m and maximum range of 2 m (Fig. 17.3).

19.6.2 Sand, Beaches and Barriers

Sediments along this PC range from fine to medium sand (mean = 0.3 mm, σ = 0.15 mm), with some areas of coarse sand, and contain between 0 and 93% carbonate, with carbonate low in Jervis Bay (0–5%) and generally increasing, though highly variable, south of the bay (mean = 19%, σ = 23%) (Fig. 19.2). This mix is a product of the nature of the predominately embayed, geologically-controlled coast, with considerable compartmentalisation of the sediment and little exchange between compartments owing to the deep embayments, prominent headlands and deep nearshore. In addition, the rocky nature of much of the seabed favours the production of encrusting organisms which supply carbonate detritus to local beaches. Two sand provinces are apparent in this PC in Fig. 19.2. In Jervis Bay (1100–1150 km), the sand is fine (white) and very low in carbonate sand, while the adjacent open rock-dominated coast to the south (1150–1265 km) is carbonate-enriched with coarse sand in places. The prominence of carbonate continues south to Broulee Island (1320 km), south of which fine to medium, quartz-rich, low carbonate sand dominates to the Victorian border and beyond.

The nature of the 106 beaches reflects the combination of a dominating rocky shore exposed to moderate to occasionally high waves, with fine to medium sand

Table 19.16 PC:NSW02.05 beach types and states

BS	BS	No.	%	Length (km)	%	Mean (km)	σ (km)
3	RBB	12	11.3	18.9	22.7	1.6	1.2
4	TBR	27	25.5	28	33.7	1.0	1.4
5	LTT	22	20.8	14.8	17.8	0.7	1.1
6	R	45	42.4	21.4	25.8	0.5	0.8
		106	100	83.1	100	0.8	–

(Fig. 19.2). There are a substantial number of shorter (0.5–0.7 km) lower energy R (45) and LTT (22) which also occupy 44% of the beaches by length. This is a result of the many sheltered embayed beaches particularly in the Jervis Bay where all 40 beaches are either R or LTT, with the remainder located in sheltered embayments spread along the PC, with mean embayment ratio of 0.65 (Table 19.5). On the more exposed sections, there are 27 TBR and 12 RBB, which tend to be longer (1–1.6 km) and occupy the remaining 56% (Table 19.16). Bherwerre Beach (NSW 449) is the longest (7 km) and most exposed in the PC with one of the few double-bar system on the south coast.

There are 46 barriers along this PC which occupy 91 km (50%) of the shore. The barriers have a total volume of 405 M m^3 (5437 m^3 m^{-1}); however much of this has been deposited as transgressive dunes in the south-facing Wreck Bay area, which has acted as a major sand trap for both Holocene and Pleistocene sediment. Its barriers include the Steamers clifftop dunes (~10 M m^3; 16,700 m^3 m^{-1}), the Caves-Bherwerre transgressive dunes (~300 M m^3; 42,900 m^3 m^{-1}) and the Cudmirrah transgressive dunes (~37 M m^3; 9500 m^3 m^{-1}), in total 347 M m^3 or 86% of the PCs barriers. These barriers face south-southeast enabling them to face into the strong southwest winds, with the dunes aligned to 215°. The remaining 43 barriers have a total of ~60 M m^3 and a unit volume of just 750 m^3 m^{-1}, while the entire PC has a per metre volume of 5437 m^3 m^{-1} (Table 19.4). These figures highlight the role of the embayed south-facing Wreck Bay in acting as a major south coast sediment sink.

19.6.3 Sediment Transport

There is very limited longshore transport along this PC. This is a result of the embayed nature of the coast generating considerable wave refraction and the formation of swash-aligned beaches, which provide little potential for longshore transport. In addition, the headlands and bays act as sediment traps, particularly the large protruding headlands including the Beecroft Peninsula, St Georges Head, Warden Head and Burrewarra Point. The limited transport is in part reflected in the highly variable sediment texture illustrated in Fig. 19.2. There is however some intra-compartment transport as will be discussed in the following six SCs.

19.6.4 SC:NSW02.05.01 Beecroft Head-Point Perpendicular

SC:NSW02.05.01 is a steep rocky coast extending along the exposed eastern side of the Beecroft Peninsula from Beecroft Head to the 100 m high Point Perpendicular (Fig. 19.19). The 9 km of cliffed coast is devoid of beaches, and the nearshore drops steeply to a depth of 100 m just 3 km from shore. However, the presence of clifftop dunes on the southeastern side of the peninsula, on top of 100 m high cliffs, indicates that sand was supplied by sand ramps to the cliffs probably during the PMT, as along parts of the Central, Sydney and Illawarra coasts. Thom et al. (1986)

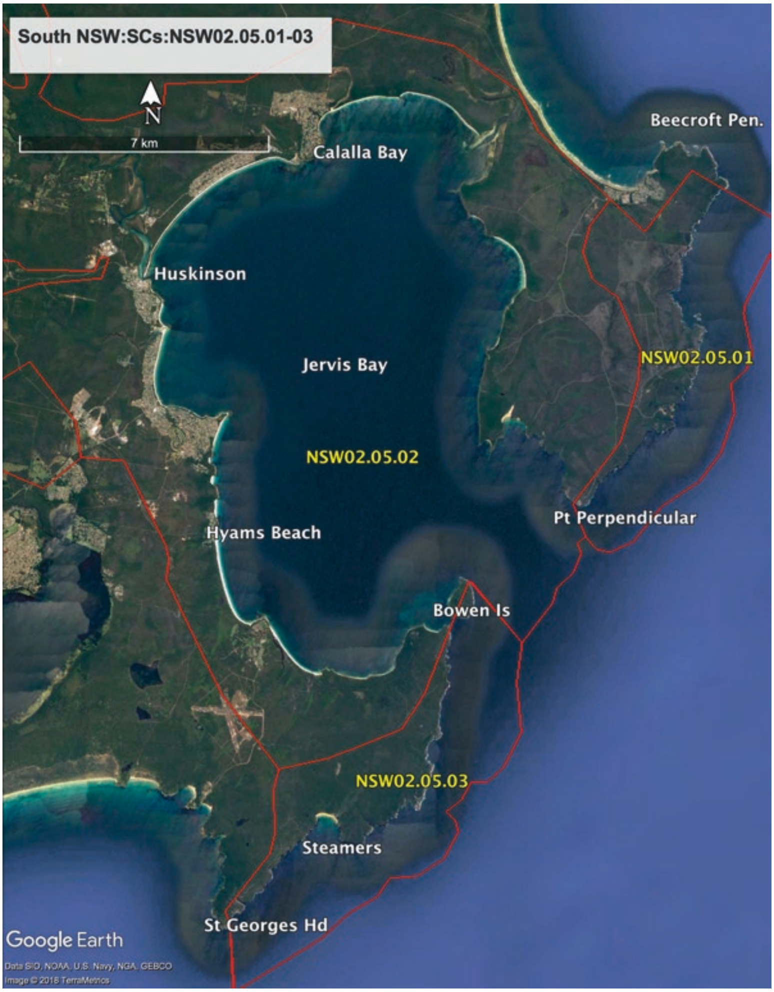

Fig. 19.19 SCs NSW02.05.01-03 includes Jervis Bay and its prominent rocky boundaries. (Source: Google Earth)

identify a deep fissure called the Devils Inlet as the probable route for this ramp, the fissure still blanketed in vegetated sand on its western face. Taylor et al. (1995) found that while the sand was predominately quartz with low carbonate, it has been cemented to form dune calcarenite. Roy (1998) mapped a large SSB off the peninsula (Fig. 17.4), probably both source of the ramp, and then sink for eroded sand.

19.6.5 SC:NSW02.05.02 Point Perpendicular–Bowen Island

SC:NSW02.05.02 contains the entire 53 km long shoreline of the curving Jervis Bay (Fig. 19.19). The bay occupies a broad synclinal structure in Permian sandstone, with the bay floor containing two episodes of late Cainozoic sediments, together with two Pleistocene drainage systems linked to a 60 m deep narrow sediment-filled canyon at the entrance (Albani et al. 1973). The roughly circular bay has a 3.6 km wide southeast-facing entrance between Point Perpendicular and Bowen Island that permits south through east swell to enter the bay and refract and diffract around the entire shore, delivering waves usually <0.5 m to the beaches, which are all either R or LTT, with only the most exposed Nelson Beach (NSW 428) shifting to TBR during period of high swell. During the 1974 storm event, the neighbouring Collingwood Beach was eroded back 40 m (Davies and Kesby 1987) indicating that larger waves can enter the bay during storm conditions. The 30 bay beaches occupy 28 km (53%) of the shore, the remainder horizontally bedded Nowra sandstone. The beaches are all swash-aligned with the sediment transported through the entrance and from the bay floor to build the beaches and barriers. The bay sand is pure white which Taylor et al. (1995) suggested is derived from stream deposits on the bay floor at low sea level, which have been leached white and then reworked onshore during and subsequent to the PMT. The fine white sands could also inlcuded leached Pleistocene dune sand that overpassed the southern slopes from Wreck Bay and Steamers Beach. In contrast the ocean beaches are of marine origin and richer in carbonate (40–50%). There are 12 barrier systems in the bay all either stable or regressive barriers that occupy 22 km of the shore and total 17.7 M m^3 in volume. The largest are the Hare Bay-Callala Bay (5.7 M m^3; 1583 m^3 m^{-1}) and the Callala (7.5 M m^3; 1485 m^3 m^{-1}), the latter consisting of a series of 5–7 m high foredunes that have prograded 0.5 km into the bay, with the beach now appearing to be stable. Oliver and Woodroffe (2016) dated the barrier and found it was initiated 7.5 ka and has been prograding bayward at a steady rate of ~0.1 m year^{-1} until near the present shoreline, receiving sediment at a rate of ~1600 m^3 year^{-1}, which equates to ~12 M m^3, comparable to the estimated 7.5 M ^{3} for the subaerial portion of the barrier. Thom et al. (1986) also reported remnants of an inner Pleistocene barrier at Callala and other evidence of Pleistocene deposits at Currambene Creek and Murrays Beach at the southern entrance to the bay.

The 1 km long spit at the southern end of the Callala Beach deflects the mouth of Currambene Creek (Fig. 19.20a) and together with the deflection of the Callala Bay creek 1 km to the south suggests there may be some limited southwesterly sand

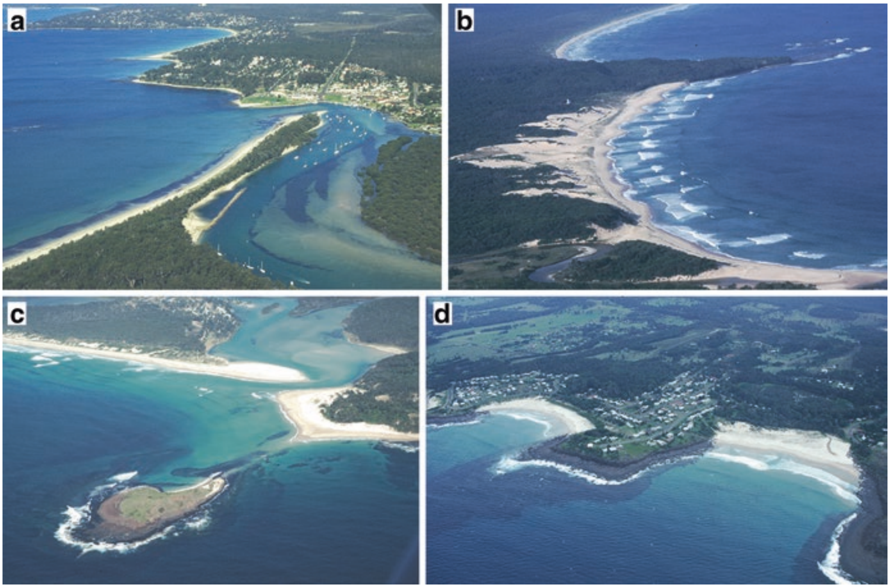

Fig. 19.20 (**a**) The deflected mouth of Currambene Creek at Huskisson (NSW 422); (**b**) the rip-dominated Cudmirrah Beach (NSW 451) and its transgressive dunes; (**c**) Green Island and Lake Conjola inlet (NSW465); and (**d**) the embayed Cormorant and Gannet beaches (NSW 487 and 488). (Photos: AD Short)

transport along these beaches. The entire bay is however a sediment trap, which has received sand from the bay floor through its entrance and from dune overpassing from Bherwerre and Steamers beaches. It does not, however, export any sand to the adjoining SCs.

The southern Hyams Beach (Fig. 19.19) is composed of pure white quartz sand and claims to be the whitest beach in NSW and one of the whitest in Australia. Two other beaches make the same claim which is clarified in Sect. 34.7 and Table. 34.5.

19.6.6 SC:NSW02.05.03 Bowen Island-St Georges Head

SC:NSW02.05.03 extends south from the cliffed southern entrance to the bay and consists of 13 km of cliffed, rocky coast between Bowen Island and St Georges Head, with the only beach the south-facing Steamers, with the small Rocky Creek delivering terrigenous material to its sheltered deeply embayed mouth. The 0.7 km long Steamers is bordered by prominent headlands reaching 130–140 m and backed by slopes rising steeply to 140 m. Large volumes of sand were delivered to this exposed beach during and following the PMT. The sand climbed the backing slopes and migrated 6 km to Murrays Beach where it overpassed into the bay entrance. This is one of the largest clifftop dune systems in NSW, with a volume on the order of 10 M m^3 of sand, with a per metre volume of 14,300 m^3 m^{-1}. The dunes contain up to 12% carbonate material which has resulted in their partial lithification into dune calcarenite, one of the few locations on the NSW coast which this occurs. The beach is now stable to recessional and the dunes densely vegetated, with the calcarenite exposed in patches.

19.6.7 SC:NSW02.05.04 St Georges Head-Red Head

SC:NSW02.05.04 contains south- to southeast-facing Wreck Bay, with its 15 km wide entrance and 27 km of shore made up of 21 beaches which occupy 16 km (60%) of the shore, including the 7 km long south-facing Bherwerre and 3 km long Cudmirrah (Fig. 19.21). The beaches range from small deeply embayed and sheltered R between St Georges Head and Summercloud Bay to the longer very exposed double-barred Bherwerre and Cudmirrah (RBB) (Fig. 19.20b) to the embayed and increasingly sheltered beaches (TBR-LTT-R) down to Red Point. The bay contains eight barrier systems including the large Cave-Bherwerre and Cudmirrah, which in total contain 340 M m^3 of sand with a per metre volume of 22,500 m^3 m^{-1}. This relatively high volume is due to the two larger barriers, with the other six smaller barriers facing east and containing stable foredune/s and total just 2.5 M m^3 and 3125 m^3 m^{-1}. Thom et al. (1986) dated the Bherwerre barrier and found that its climbing north-trending longwalled parabolic dunes overly older Pleistocene dunes, and were active at least 8.6 ka and continued to supply sand until as recently as 3 ka, before they stabilised. The dunes were however active in the 1970s when national parks decided to stabilise them.

In addition to the barriers and their climbing dunes, there has been considerable sand transport into St Georges Basin, which backs Bherwerre Beach, and into the Sussex Inlet tidal delta. Sloss et al. (2005, 2006a) proposed that the basin would have had a similar evolution to Lake Illawarra and Burrill Lake, with substantial marine transgression into the bays during the PMT, followed by the formation of the large barrier. Thom et al. (1986) also report on a Pleistocene clifftop dune at Macleans Point on the northern shore of St Georges Basin, indicating prior Pleistocene sedimentation.

Wreck Bay is the largest sediment sink on the NSW coast south of Sydney owing to its orientation into the prevailing southerly winds and waves and closed eastern boundary (St Georges Head). The waves have supplied the sand, and the wind has transported it up to several kilometres inland and to elevations of over 100 m, with some reaching Jervis Bay. In addition to the quartz-rich shelf sand delivered during and following the sea-level transgression, the beaches are rich in carbonate (10–48%) indicating that there has also been considerable local biogenetic input.

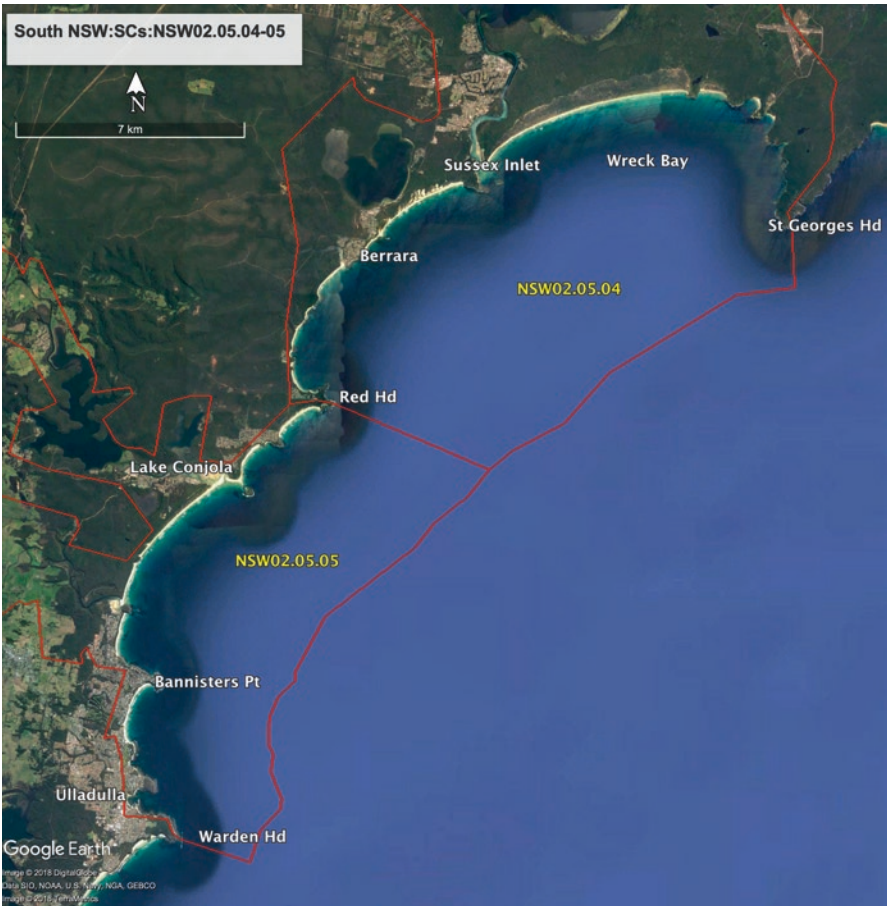

Fig. 19.21 SC:NSW05.04-05 includes the exposed Wreck Bay. (Source: Google Earth)

19.6.8 SC:NSW02.05.05 Red Head-Warden Head

SC:NSW02.05.05 continues south of Red Point as a series of embayed beaches to Warden Head, 17 km to the south (Fig. 19.21). This is a rock-dominated coast containing a series of 11 embayed beaches ranging in length from 0.1 to 1.5 km and occupying 12 km (71%) of the compartment. The small sheltered beaches are R, while the longer more exposed beaches are TBR to RBB. Ulladulla Harbour is located deep inside a 0.5 km wide bedrock bay, with additional protection provided by two attached breakwaters, and contains a very sheltered R beach.

Five of the beaches are backed by barriers with a total length of 12.6 km. They have a total volume of 14.5 M m^3 and unit volume of just 1160 m^3 m^{-1}, indicative of the limited sediment supply in this SC. Much of this sand is located in the larger Conjola-Buckleys barrier which has stabilised transgressive dunes rising to 20 m along the Conjola barrier and to 15 m along the northern Inyadda barrier. The Conjola barrier encloses the Lake Conjola barrier estuary with its inlet located at the northern end of the beach in lee of Green Island (Fig. 19.20c). The lake occupies a narrow 6 km long drowned valley, with the flood tide delta extending 3 km into the lake. Sloss et al. (2010) investigated the evolution of the estuary and found it contained a buried Pleistocene barrier, overlain by a transgressive marine sand sheet deposited between 7.5 and 5.5 ka, which was subsequently buried by flood tide delta sand from 5 ka. More marine open water conditions prevailed until 3 ka following which a slight fall in sea level led to a restriction in tidal flow and more brackish conditions.

It appears that all the beaches and barrier developed during and immediately following the PMT are presently stable to possibly receding. There is potential for northward transport along Narrawallee-Buckleys-Conjola beaches to the flood ride delta and also in lee of Green Island to Manyana. Like its northern neighbour, the beaches are rich in carbonate (10–25%) indicating a combination of sources from shelf quartz sand together with local biogenetic input.

19.6.9 SC:NSW02.05.06 Warden Head-Wasp Head

SC:NSW02.05.06 is another rock-dominated SC that extends for 61 km to the south-southwest to Wasp Head, the southern boundary of the Sydney Basin, and also the southern PC boundary (Fig. 19.22). The compartment contains 43 generally small embayed beaches (mean = 0.6 km) (Fig. 19.20d), with just one long beach (Wairo = 4.7 km). South of Pretty Beach, the mountains reach the coast with steep slopes rising from the shore to a height of 285 m at Durras Mountain. This section contains eight very small, deeply embayed pocket beaches composed of sand and/or locally derived gravel. Owing to the degree of embaymentisation and sheltering from the waves, 20 of the beaches particularly south of Pretty Beach are short (0.3 km) and R-LTT. The 33 more exposed beaches tend to be longer (0.9 km) and range from TBR to RBB, with only Wairo having a double-bar system.

There are 20 barriers in the SC with an average length of 2 km and occupying 40.5 km (66%) of the coast. There are more exposed barriers at Burrill, Wairo, Tabourie, Racecourse, Kioloa and Durras, whose northern more south-facing ends have experienced minor dune transgression extending up to 0.4 km inland and to heights of 25 m. The longer Wairo Beach is noted for its >20 m high aggraded foredune. The larger barriers contain much of the 24 M m^3 of sand in this SC; however, they have a per metre volume of just 600 m^3 m^{-1}, attesting to the overall low volumes transported into this SC.

The SC has three barrier estuaries at Burrill Lake, Lake Tabourie and Durras Lake and the usually blocked Willinga Lake. Burrill Lake is typical of the WD estuaries along the southern NSW coast with a narrow inlet leading to a 2 km long flood tide delta and then the estuarine mud basin. Sloss et al. (2006b) examined the evolution of the estuary and found the narrow incised 40 m deep river valley contained basal

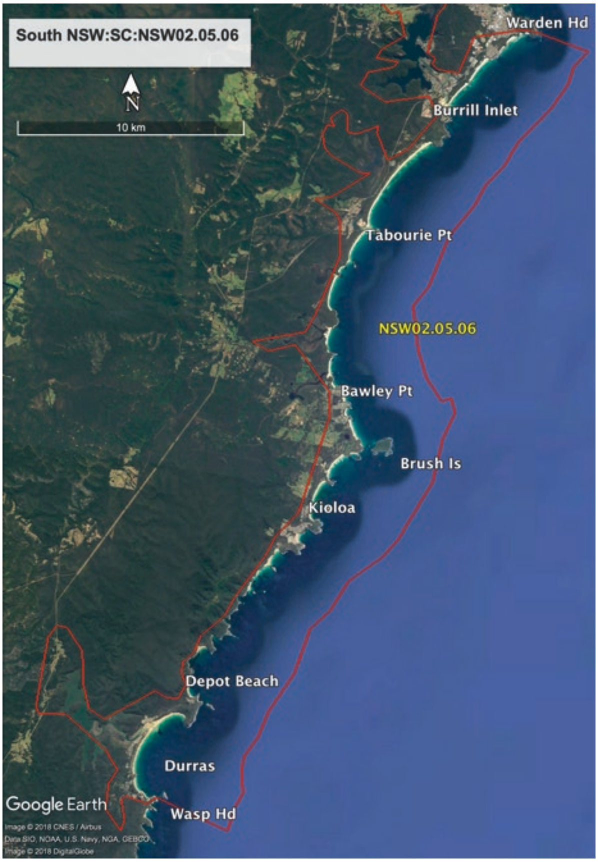

Fig. 19.22 SC:NSW02.05.06. (Source: Google Earth)

Pleistocene fill overlain by Holocene marine sediments deposited during the sea-level transgression ~7.8 ka, with more open marine conditions prevailing until about 4.5 ka when the barrier restricted tidal flows. This was followed by a late Holocene fall in sea level (1–2 m) about 3 ka which further restricted circulation. The fluvial bayhead delta is slowly prograding into the lagoon, and the central mud basins continue to infill. It is likely the other estuaries followed the same evolutionary path.

This is the most sediment-deficient of the SCs in this PC. While there is the likelihood of local sand transport along some of the longer beaches and into the four estuaries and their small northern transgressive dunes, there is little likelihood of transport around the many headlands, with most beaches appearing to behave as separated closed TCs. This is further confirmed by the highly variable carbonate content (0–75%, mean = 25%, σ = 28%), in places between adjoining beaches. The substantial carbonate contribution also points to locals as well as shelf sources of sediment, the local carbonate derived from the algae-encrusted rocky seafloor and marine epifauna.

19.6.10 PC Overview

This PC is a predominately rocky coast containing a series of generally small embayed beaches ranging from sheltered to exposed. However, it also contains two major but contrasting sediment sinks – the sheltered Jervis Bay with a relatively small (17.7 M m^3) but trapped volume of sand and the exposed Wreck Bay with a massive 340 M m^3 of sand, much of which has been deposited in extensive transgressive dunes including clifftop dunes. It is likely that most of this sand accompanied the PMT with generally stable to receding conditions today. The substantial contribution of carbonate sand to the open coast beaches and barriers requires further investigation as it may signify a continuing local source of carbonate sand. There appears to be no exchange of sand between the SCs and little transport within the SCs, apart from along some of the longer beaches.

This is a relatively low-risk section of coast with no property presently at risk. Rising sea level and changes in wave climate will however impact the shore leading to beach recession and possible realignment, together with greater and more frequent inundation of the estuaries and wetlands, and low-lying coastal development as at the Sussex Inlet canal estate.

19.7 PC:NSW02.06 Wasp Head to Cape Howe

19.7.1 Introduction

This is the longest PC in the southern NSW region. The 328 km of coast encompasses the entire NSW portion of the Lachlan Fold Belt (Fig. 19.1b), which begins abruptly at Wasp Head and continues down to Cape Howe, the PC and regional boundary, then through Victoria and eastern Tasmania. The NSW region is typified by the heavily folded metasedimentary rocks of the fold belt, together with occasional outcrops of intrusive and extrusive igneous rocks, and in the Merimbula area the only Tertiary deposits on the NSW coast consisting of clays and sand. The geology exerts considerable control in this PC, controlling the almost due north-south orientation and generally narrow steep shelf, a product of the Tasman Sea rifting, while along the coast the often steep hinterland and rocky shore from headlands and reefs leading to numerous generally small embayed beaches with a mean length of just 0.7 km, together with a few small rivers (Clyde, Moruya, Tuross, Bega, Towamba; Table 17.3) and over 50 creeks draining to small barrier estuaries and coastal lagoons.

Coastal processes remain dominated by moderate southerly swell originating from the midlatitude cyclones, together with occasional higher more easterly swell and storm waves generated by east coast cyclones (Fig. 17.2; Table 18.13; Shand et al. 2010). Tides remain micro with a mean spring range of 1.3 m and maximum range of 2.0 m. The dominant winds tend more southwest blowing offshore, with only the summer northeast sea breeze providing onshore winds (Fig. 18.21).

This PC has always been distant from Sydney with the main commercial transport by sea until the 1950s. Unlike the NSW north coast, the south coast is growing but growing slowly, it is too far to attract weekend trippers (expect from Canberra) and it lies to the cooler south rather than the favoured warmer north from Sydney. It does however attract retired Melbournites to the far south coast. As a consequence, the population remains relatively low, and much of the coast is occupied by national parks (Murramarang, Eurobodalla, Mimosa Rocks, Bournda, Ben Boyd) and Nadgee Nature Reserve. All the coast towns and communities are located on estuaries or where suitable ports could be established in the nineteenth century as at Nelligen, Moruya, Narooma, Bermagui, Tathra, Merimbula and Eden. The largest town is the northern Batemans Bay (13,200). Running down the coast from there are the towns/districts of Malua Bay (2500), Broulee (3200), Moruya (6300), Tuross Head (2300), Dalmeny (2100), Narooma (3500), Bermagui (2500), Tathra (3500), Tura (3800), the inland town of Bega (5300), Merimbula (5000), Pambula (3000), Eden (3800) and Wonboyn (300), with a total regional population of about 67,000 spread along the 330 km of coast. The only erosion hotspots are Sunshine and Caseys beaches in Batemans Bay, while the Batemans Bay CBD, Corrigans Beach and the Narooma flats are prone to marine inundation.

19.7.2 Sediment, Beaches and Barriers

The beach sand along this PC is predominately fine to medium quartz sand (mean = 0.28 mm, $\sigma = 0.1$ mm), which are initially rich in carbonate between Wasp Head and Broulee Island (40–85%) (1264–1320 km; Fig. 19.2) and then are low in carbonate (mean = 4%, $\sigma = 2\%$) all the way down to Cape Howe and beyond. Overall carbonate averages 19% ($\sigma = 28\%$). The sand combined with a breaker wave climate that ranges from fully exposed ($H_b = 1.5$ m, T = 10 s) to very sheltered produces 207 beaches ranging from R to RBB (Table 19.17), with just 12 double-barred beaches. The beaches total 149 km in length occupying 45% of the coast, with an average length of just 0.72 km ($\sigma = 1.1$ km). The remainder of the coast is generally irregular, cliffed and rocky, with jagged rock platforms, a result of the vertically dipping strata, together with reefs in many locations.

There are 69 relatively small barriers along this PC, which occupy 133 km (41%) of the coast. They have a mean length of 1.9 km ($\sigma = 1.8$ km) and total volume of

Table 19.17 PC:NSW02.06 beach types and states

BS	BS	No.	%	Length (km)	%	Mean (km)	σ (km)
3	RBB	13	6.3	29	19.4	2.2	1.2
4	TBR	80	38.6	81	54.3	1	1.4
5	LTT	50	24.2	24.8	16.6	0.5	0.6
6	R	64	30.9	14.4	9.7	0.2	0.3
		207	100	149.2	100	0.7	–

184 M m^3 (1380 m^3 m^{-1}) the lowest PC volume in the southern NSW region and representing just 3% of the region's total barrier volume (Table 19.6). They range from prograding to stationary to receding, with no transgressive dunes (Fig. 17.4). The smaller volumes are due to a combination of factors including the relatively steep inner shelf which prevents some sand from reaching the coast; the easterly orientation of the coast with the dominate southwest winds blowing offshore which almost totally precludes the development of transgressive dunes; and the high degree of embaymentisation leading to lower energy embayed beaches. There are however two SSB's located off Narooma-Montague Island and off Green Cape (Fig. 17.4, Roy 1998). The larger barriers are all regressive foredune ridge plains and are discussed in the following 11 SCs.

19.7.3 SC:NSW02.06.01 Wasp Head-Three Islet Point

SC:NSW02.06.01 is a rugged section of coast trending south-southwest for 12 km between Wasp Head and Three Islet Point, the northern entrance to Batemans Bay (Fig. 19.23). The coast is dominated by narrow southeast-tending valleys and headland and reefs, with forested slopes rising to 50 m within a kilometre of the shore. The entire SC is located in Murramarang National Park and is uninhabited. There is however an access track from Durras South to North Head.

The coast contains eight small pocket beaches which total just 1.8 km (mean = 0.2 km) each located at the base of one of the valleys. Their sediment is a mix of coarser lithic material and one (Richmond) rich in carbonate (64%). Each is a separate TC with no connection to the adjoining beaches. As they face southeast, some are reasonably exposed with a boundary controlled rip-dominated surf zone, while those sheltered by reefs are R to LTT. They all consist of a single foredune cut by the valley creek usually at the northern end. The only small barriers are in the Richmond, Oaky and North Head embayments each with a volume of about 75,000 m^3.

19.7.4 SC:NSW02.06.02 Three Islet Point-Mosquito Bay Point

SC:NSW02.06.02 contains Batemans Bay a funnel-shaped, southeast-orientated drowned valley, with a 6.4 km wide entrance between the PC boundaries at Three Islet Point and Mosquito Bay Point (Fig. 19.23). The bay narrows to 250 m at the bridge located 9 km into the bay. While it faces into the prevailing southerly waves, the presence of the Tollgate Islands and Black Rock reef in the entrance substantially lowers waves coming into the bay. In addition, a large shallow flood tide delta fills the inner bay causing wave breaking and further reducing breaker wave height within the bay, which averages 0.5–1 m in the outer northern bay reducing to <0.5 m along the inner and southern bay shore (Coghlan et al. 2017). However, the bay is

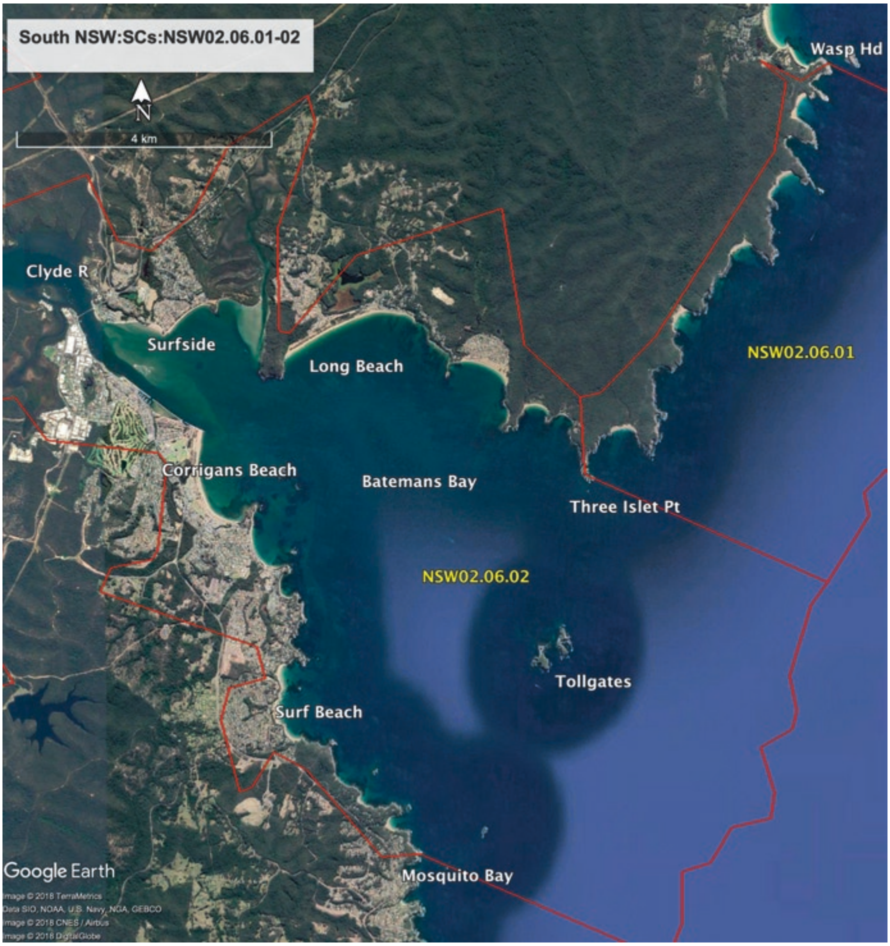

Fig. 19.23 SCs NSW02.06.01-02 includes the funnel-shaped Batemans Bay. (Source: Google Earth)

exposed to storm surges which occasionally inundate the low-lying bay shore, with Treloar et al. (1989) predicting surges up to 2.5–3.5 m with an RI of 20 years.

There are 18 beaches spread around the bay shore totalling 11.3 km in length and occupying 43% of the shore, the remainder being rocky headlands, reefs and the 3 km of armouring along the southern Batemans Bay CBD shore including the southern training wall. The beaches are all either R or LTT, with rips only occurring on the more exposed Long Beach during periods of higher waves and against some boundary headlands.

There are eight low regressive barriers (Chain Bay, Maloneys, Long, Cullendulla, Surfside, Corrigans, Caseys, Sunshine) located in the larger embayments with a total volume of 6 M m^3 (680 m^3 m^{-1}). Each is a separate TC with no linkages, other than between east and west Surfside where there is bypassing around the small rocky point-reef that separates the two, possibly on the order of 100 m^3 $year^{-1}$ (Coghlan et al. 2017). The bay barriers are to varying degrees linked to the flood tide delta, and its morphodynamics undoubtedly plays a role in breaker wave height and direction and sediment budgets. At present most of the beaches are stable, apart from Cullendulla Creek and Surfside, which are both receding most likely due to change in the tidal delta morphology. The northern Cullendulla Creek contains the only cheniers in NSW, which were initially dated by Lewis (1976) as reported in Thom et al. (1981) and later by Donner and Jungner (1981). The dates indicate the deep embayment had to infill with tidal deposits before the first chenier was deposited ~2.5 ka, typical of chenier and beach ridge environments (see, e.g. Short et al. 1989). As the bay continued to infill, beach ridges were deposited towards the slightly more exposed outer bay between about 2 and 1 ka. The outer bay regressive barriers (North Beach-Long Beach) are however likely to have formed during and following the sea-level stillstand and rapidly infilled their relatively small accommodation space. On the southern side, construction of the training wall in 1905 and its extension in 1991 trapped approximately 0.65 M m^3 of sand leading to the progradation of Corrigans Beach by up to 0.7 km in lee of the wall, to a now stable position.

The shape and orientation of Batemans Bay make it an ideal sink for sand delivered by the predominately southerly swell. This sand has however largely accumulated in the ~15 km^2 flood tide delta. Assuming the delta averages 10 m in thickness, this would represent 150 M m^3 of sand, two orders of magnitude greater than the small bay barriers. The reason for the sand residing in the delta rather than the barriers is the low wave energy within the bay, leading to the formation of small regressive barriers, including cheniers and beach ridges, and no transgressive dunes, with most sand left to reside in the tidal delta.

Coghlan et al. (2017) examined shoreline stability around the bay using 70 years of photogrammetry. They found that the northern Maloneys Beach is stable, Long Beach is accreting between 0.05 and 0.2 m $year^{-1}$, Surfside has retreated and presently rotates as sand waves move through the beach and the southern Sunshine Bay is accreting at 0.05 m $year^{-1}$. These results indicate that there could be ongoing supply to the beaches from the flood tide delta and possibly nearshore.

19.7.5 SC:NSW02.06.03 Mosquito Bay point-Bingie Bingie Point

SC:NSW02.06.03 is a 44 km long compartment extending from the northern Mosquito Bay point to the protruding Bingie Bingie Point (Fig. 19.24). It consists of two parts: a northern rock-dominated heavily indented section down to the prominent Burrewarra Point and a more open embayed section down to Bingie Bingie containing some major barrier deposits and the Moruya River mouth. The

Fig. 19.24 SC:NSW02.06.03 is centred on the Moruya River with regressive barriers to either side. (Source: Google Earth)

headlands from Mosquito Bay south to Moruya Heads are composed of steeply dipping metasedimentary shales and sandstones, with well-developed but jagged supratidal rock platforms cut in the vertically dipping strata. The southern headlands are either basalt (Broulee Island, Pedro Point, Black Head) with wide flat intertidal platforms or impervious dolerite (Murrumburrah Point-Bingie Bingie Point) with no platforms.

The compartment has 37 beaches totalling 24 km (55%), with the indented northern section's 15 beaches totalling only 2.4 km, while the longer beaches to the south averaging 1 km including the 6 km long Bengello. The more sheltered northern beaches tend to be R, apart from the exposed Malua Bay and Rosedale (TBR), while the southern beaches include the double-barred Bengello which are TBR-RBB. The other distinctive feature of this SC is the sediment texture, with the northern beaches averaging 58% carbonate and the southern just 3.2% (boundary at 1320 km Fig. 19.2). This dramatic change is attributed in part to the Moruya River acting as a low sea-level source for quartz-rich sand in the south, the closed TC boundary at Melville Point-Burrewarra Point, and the rocky seabed along the northern section that hosts the carbonate detritus. The quartz-rich low carbonate province extends all the way to the border at Cape Howe and well into Gippsland (Fig. 20.2), implying this is the northern boundary of a larger sediment province.

Bengello Beach (NSW 562) is the site of one of the world's longest beach survey records which include the impact of the major 1974 erosion event (McLean and Thom 1975; Thom and Hall 1991; McLean et al. 2010, 2018). They found the beach not only fully recovered from the storm but prograded beyond the initial 1972 shoreline position, possibly suggesting ongoing river- and/or shelf-supplied progradation. Bengello was also the site of some of the first beach and rip experiments in Australia (Wright et al. 1979).

Short et al. (2014) found that the adjacent Moruya-Pedro beaches (NSW566–7) undergo substantial oscillation and rotation in response to changes in wave height and wave direction, respectively. Also, between 2007 and 2017, the mean shoreline position of both beaches while very dynamic, both oscillating and rotating, shows a very slight positive trends over 10 years (Vos et al. 2018), again hinting at the possibility of ongoing shelf supply.

The SC contains seven barriers, three of which are small stable foredunes, while four are large regressive foredune ridge plains. The Broulee-Bengello barrier is the largest with a volume of 61 M m^3 (6710 m^3 m^{-1}). It was initiated at the sea-level stillstand ~6.5 ka and underwent rapid progradation until about 3 ka (Thom et al. 1978; 1981). More recent dating by Oliver et al. (2015) indicates it started prograding ~7.2 ka with uniform progradation at a rate of ~0.27 m $year^{-1}$ until about 400 years ago. Tamura et al. (2018) used the recent foredune progradation to develop a two-dimensional chronological model to improve the age estimates of the Bengello ridges. Following this, Tamura et al. (2019) examined the outer ridges in detail and found evidence of a severe erosion events around 1650–1700AD, followed by beach recovery, and comparable to the 1970's severe erosion, which was estimated a 1:100–1:200 year event by Burston (2006).

South of the Moruya River is the 1.5 km wide adjoining Moruya and Pedro regressive barrier systems capped by 5–6 m high foredune ridges with a subaerial volume of 15 M m^3 (2830 m^3 m^{-1}). Oliver et al. (2018) dated the Pedro barrier and found it commenced ~6 ka followed by rapid progradation to 4 ka by which time it has filled the embayment and sand began leaking northwards around Pedro Point to the Moruya barrier. Since then a large apparently stable 12 m high foredune has developed behind the northern Pedro beach. They found the subaerial and subaqueous barrier has accumulated 7200 m^3 m^{-1}, comparable to the above figure for the subaerial portion. They also found that during the initial phase of barrier evolution, the Congo inlet flood tide delta, located at the southern end of the system, accumulated ~2 M m^3 of sand, indicating the importance of flood tide deltas as major sediment sinks.

The northern embayed beaches were examined by Coghlan et al. (2017) who found that Malua Beach was stable, Guerilla Bay was accreting 0.15 m year^{-1}, Barlings Beach rotated but was stable and only Tomakin is slightly erosional at 0.07 m year^{-1}. These results indicate the beaches are at least stable and may be slightly accretional, suggesting an offshore source for the embayed beaches including biogenetic material and possible longshore source for Broulee. They also examined sediment transport along this section and found the northern bays were closed TCs with on-offshore transport related to storm-driven megarips and beach recovery. They also found there was probably sediment exchange in the Barlings Beach-Tomakin embayment (Fig. 19.25a), with the three beaches deliv-

Fig. 19.25 (**a**) Barlings and the Tomakin beaches (NSW557-559) and the Tomaga River mouth; (**b**) Tuross Lake entrance following a major flood events that has breached the barrier; (**c**) the trained Bermagui River mouth and Horseshoe Bay (NSW 624-625); (**d**) the Merimbula inlet and flood tide delta (NSW 671); (**e**) the dynamic Towamba River mouth and its unstable barrier (NSW 695); and (**f**) transgressive dunes overpassing Cape Howe and the southernmost beach in NSW (NSW721). (Photos: AD Short)

ering sand to a common nearshore via megarips but contained between Barlings Island and Mossy Point.

The southern section between Borulee Island and Bingie Bingie Point contains longer beaches and more subdued headlands with sand possibly bypassing Mullimburra Point, while sand appears to be moving along the northern Meringo-Congo beaches bypassing the subdued Black Point and around Congo Point to Pedro Beach. As noted above the Pedro barrier filled its accommodation space by 4 ka and is connected via the sand-fronted Pedro Point to Moruya Beach which has also filled its embayment and in turn may be bypassing sand northwards around Moruya Head and the Moruya River tidal delta to Bengello Beach. Bengello Beach may still be prograding (McLean et al. 2018) and at its northern end is episodically connected via breaches in the Broulee Island spit to Broulee Beach delivering quartz-rich sand (5% carbonate) to the carbonate-rich (60%) beach (Coghlan et al. 2018), with Broulee Beach accreting over the past 70 years between 0.55 and 0.7 m year^{-1}. However, the still considerably difference in carbonate content between Broulee and Bengello indicates Broulee Island and tombolo are a major, but leaky, obstacle to longshore transport. There therefore appears to be limited intra-SC longshore transport possibly from as far south as Bingie Bingie north to Broulee, which is supported by Chapman et al. (1982).

19.7.6 SC:NSW02.06.04 Bingie Bingie Point-Mystery Bay

SC:NSW02.06.04 trends essentially due south from Bingie Bingie Point to Cape Dromedary at Mystery Bay (Fig. 19.26a) a distance of 37 km and contains 34 beaches averaging 0.75 km in length (σ = 1.25 km) and occupying 25.7 km (69%) of the coast. The easterly orientation, lack of prominent headlands and predominately sandy shore have resulted in just three R beaches, one LTT with the remainder either TBR or TBR-RBB, indicating an exposed rip-dominated coast, with 85 beach rips spaced 200–300 m usually operating. Barriers occupy 24% of the coast; however they have a total and per metre volumes of just 20 M m^3 and 830 m^3 m^{-1}. These low values are a result of the total lack of regressive barriers owing to lack of suitable accommodation space and the lack of transgressive dunes owing to the strong winter southwesterlies blowing offshore (Fig. 18.21). The SC therefore lacks the orientation, space and onshore wind energy to build significant barrier systems. The largest three barriers are each part of barrier estuaries, namely, Bingie (Coila Lake), South Tuross (Tuross Lake; Fig. 19.25b) and Brou (Tarougra and Brou lakes), each of which has extensive flood tide deltas. Roy and Peat (1976) examined the sedimentation in the adjoining Coila and Tuross lakes. They found that the small Coila Creek (23 km^2) is not supplying sand to the lake which has an estuarine sediment facies, while the larger Tuross River (1700 km^2) carries a high sediment load and has built a floodplain and fluvial delta infilling much of the lake. At Narooma the Wagonga Inlet was trained in 1977 (Philip 1978) to improved navigation; however the entrance bar remains very dangerous. The new entrance also increased

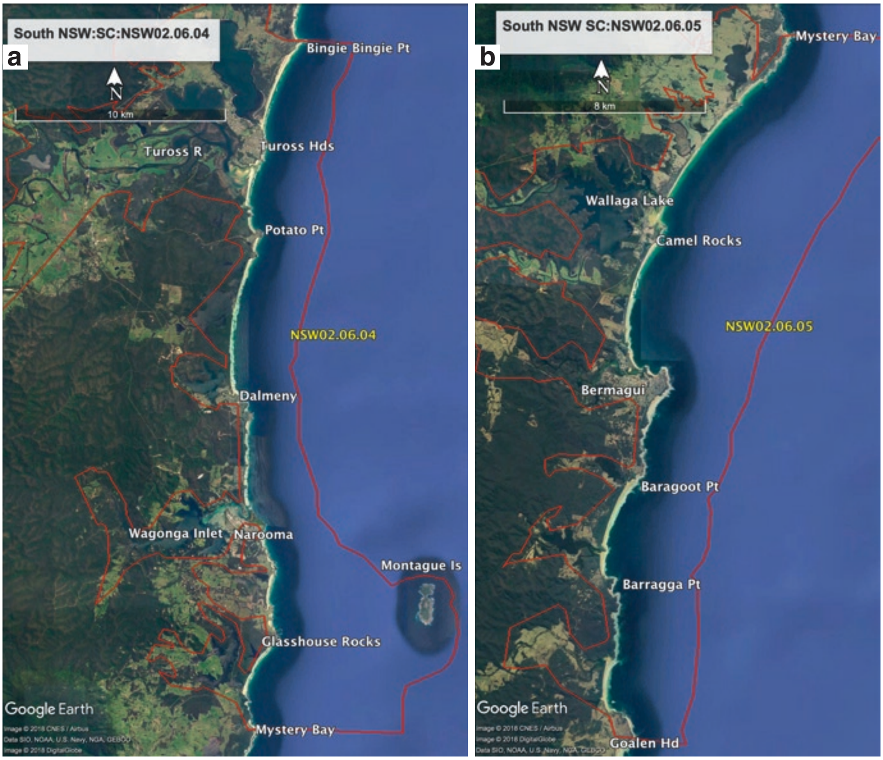

Fig. 19.26 (**a**) SC:NSW02.06.04 and (**b**) SC:NSW02.06.05. (Source: Google Earth)

transport of marine sand into the estuary and allowed the development of a new beach (Bar Beach NSW 597) on the northern side of the training wall.

There may be limited longshore transport in this SC owing to the generally small headlands and no major obstacles until Mystery Bay. Chapman et al. (1982) proposed there may be transport between Dromedary (Narooma) and Burrewarra Point, which would require sand to bypass Bingie Bingie Point, but Cape Dromedary itself is a major obstacle. This is supported in part by the coarsening in sand south of the cape (1380 km Fig. 19.2).

19.7.7 SC:NSW02.06.05 Mystery Bay-Goalen Head

SC:NSW02.06.05 continues south for another 35 km to Goalen Head and consists of a series of curving slightly embayed beaches and barriers separated by rocky sections (Fig. 19.26b). The only development on the coast is the small town of Bermagui and its trained inlet (Fig. 19.25c). The southern end of Eurobodalla National Park extends 3 km south of the SC boundary at Mystery Bay, with the remaining coast freehold and mainly used for grazing cattle. The SCs 26 beaches occupy 22 km (63%), with an average length of 0.84 km ($\sigma = 1$ km), the remainder rocky headland composed of steeply dipping metasedimentary rocks down to Barragga Point, with Goalen Head composed of Devonian volcanics. Half the beaches are located amongst the rocky sections and headlands and are short (mean length = 0.38 km) sheltered and maintain R to LTT states, while the other half are longer (1.2 km) and more exposed with predominately rip-dominated TBR and four RBB. There are eight barriers all located in lee of the longer more exposed beaches with an average length of 2.5 km and total length of 20 km (57%). They have a total volume of just 8.1 M m^3 (405 m^3 m^{-1}). Their small size is again due to the lack of accommodation space for regressive barriers combined with the predominately offshore winds precluding dune transgression. Sand has however been lost into a number of small barrier estuaries and lagoons including Tilba Tilba, Wallaga, Bermagui (Fig. 19.25c) and Murrah, which all have extensive flood tide deltas.

Some sand may be moving northwards along the longer beaches and possibly bypassing the smaller headlands between Barragga and Bermagui and around Camel Rock, but is not expected to bypass Cape Dromedary in the north.

19.7.8 SC:NSW02.06.06 Goalen Head-Tathra Head

SC:NSW02.06.06 is a relatively straight 35 km long section of rock-controlled coast that trends south-southwest to Tathra Head and includes four estuaries including the mouth of the Bega River (Fig. 19.27a). Most of the coast is located in Mimosa Rocks National Park and densely vegetated, with open grazing land backing the remainder, and the small Tathra township the only development with the old jetty and a beachfront surf club and caravan park the only waterfront development. The 22 beaches total 12.6 km in length (48%) and average just 0.6 km ($\sigma = 0.7$ km). Despite the prevalence of rocky shore and several headlands, the straightness of the coast exposes most of the beaches to the prevailing southerly waves, with most either TBR or TBR-RBB and just four R-LTT. The beaches are backed by five barriers that extend for 12 km (46%) and have a volume of just 4.7 M m^3 (400 m^3 m^{-1}). At Middle Lagoon and Gillards beaches, Young et al. (1993) found Pleistocene deposits at an elevation of 4.8 m which dated 126 and 124 ka. Thom et al. (1986) dated the barrier chronology of the southernmost Tathra barrier (1 M^3) located at the mouth of the Bega River which is supplying fluvial sand to the embayment (PWD 1980). They found the regressive 200 m wide barrier was initiated ~7.4 ka, with the mid-barrier dating 4.2 ka and the outer foredune at 2.6 ka and the modern beach at 1.4 ka, the latter no doubt containing older reworked shell material. The barrier appears to be presently stable, with a steep nearshore composed of beach material that widens from <1 km in the south to 2 km at the northern headlands, suggesting megarips and river flooding may be depositing the material further seawards with some probably lost from the compartment. Geary and Lord (1981) found the

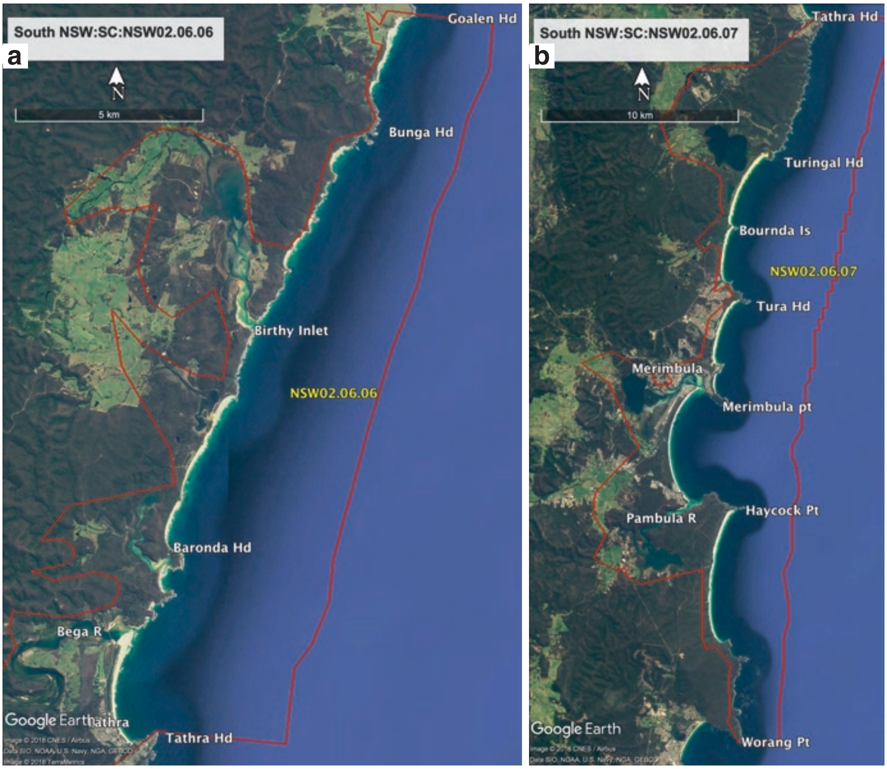

Fig. 19.27 (**a**) SC:NSW02.06.06 and (**b**) SC:NSW02.06.07

compartment was closed with only episodic supply from the Bega River. Roy and Stephens (1980) estimated the 1971 flood deposited 1.5 M m^3 of sand offshore, with the sand transported northwards from the mouth. However, Thom et al. (1986) reported no evidence of headland bypassing to the northern Nelson Bay and Cowdroys beaches, which together with the coarser shelly inner shelf sand and seabed reefs to the north and south of the embayment suggest this is a closed TC. Roy and Stephens (1980) proposed the barrier was initially supplied with shelf sand and regressed, followed by a stable to receding shore as sand was lost offshore, and now with fluvial sand reaching the coast during flood the shoreline regression has been renewed.

Like the adjoining SCs, the low barrier volume is a product of the lack of accommodation space and predominately offshore winds. The four estuaries (Wapengo-Bithry, Middle, Nelson and Bega) each however have flood tide deltas which have acted as sinks for onshore transport; in the case of Bithry, the delta extends 3 km into the narrow drowned Wapengo valley. The Bega River has fluvial sand deposits extending to the mouth and is delivering fluvial sand to the coast during major flood events. There may be limited longshore sand transport along this SC owing to the straightness of the coast and lack of prominent headlands; however, there are extensive rocky sections and inshore reefs which may counter the transport, as is the case at Baronda Head and Tathra.

19.7.9 SC:NSW02.06.07 Tathra Head-Worang Point

SC:NSW02.06.07 trends due south from Tathra Head for 53 km with metasedimentary rocky shore dominating either end and six curving embayed beaches sections in between, together with the mouths of the Merimbula and Pambula rivers (Fig. 19.27b). The 19 beaches average 1.4 km in length ($\sigma = 1.8$ km) and total 26.2 km (49%) of the coast, the remainder containing rock platforms backed by cliffs and generally steeply rising vegetated slopes. Most of the coast between Tathra and Tura Head is contained in Bournda National Park, while the coast between Tura and Pambula is moderately developed with the coastal communities of Tura, Merimbula (Fig. 19.25d) and Pambula Beach, each generally set well back from the beaches, with only the Pambula caravan park at possible risk. Ben Boyd National Park commences on the southern side of the Pambula River extending south to Worang Point and Twofold Bay. The geology is a mixture of Devonian volcanics (Tathra to Wallagoot) and then a series of prominent headlands (Tura, Merimbula, Haycock, Worang) composed of the Ben Boyd formation (massive mudstones and red sandstones), with Tertiary clays and sands in the intervening embayments (Tura, Merimbula and Haycock-Pinnacles). The beaches are a mix of generally short (0.24 km), deeply embayed R, including boulder beaches, and longer (2.6 km) more exposed TBR-RBB, tending to LTT-R at their southern ends.

The only reasonable accommodation space is located across the mouths of Wallagoot Lake and Merimbula River, both barrier estuaries, and the drowned Pambula River mouth which has a narrow 5 km long flood tide delta. The regressive Bournda and Merimbula barriers have volumes of 3.7 and 6.7 M m^3, respectively, out of an SC total of 12.1 M m^3. Tura, Short Point and 7 km long Long Beach make up the remaining barriers, which combined have a relatively low per metre volume of 576 $m^3\ m^{-1}$. This low volume can be in part attributed to the lack of accommodation space, with Long Beach essentially a mainland beach hard up against unconsolidated Tertiary sediments. However, both Wallagoot and particularly Merimbula-Pambula embayments have considerable additional accommodation space. This implies that the shelf sands have been exhausted and that the barriers are either stable or receding. In addition, none of the rivers are delivering sand, and the boundary rocky coast and internal headlands prevent longshore transport, leaving each of the barriers to act as a closed TCs.

19.7.10 SC:NSW02.06.08 Worang Point-Red Rock

SC:NSW02.06.08 encompasses all of Twofold Bay (Fig. 19.28a). The bay is 5 km wide at its open entrance and 7 km long, with a moderately sheltered 24 km long shoreline containing 25 beaches which occupy 9.3 km (39%) of the bay shore. In addition, there are six barriers and three small rivers, Palestine (28 km^2), Nullica (53 km^2) and Towamba (1026 km^2), the latter actively supplying coarse lithic-rich sand to the bay during flood events (Hudson 1991). The bay shore has a mix of development ranging from the town of Eden to smaller settlements, and tourist facilities spread around parts of the bay including the Navy wharf at East Boyd Bay and the woodchip facility and jetty at Jews Head. The Boydtown caravan park and hotel are most at risk owing to the low-lying nature of the low barrier. The beaches have an average length of 0.4 km (σ = 0.6 km). Only the outer Aslings Beach has rips (TBR), with the more sheltered inner bays beaches being either R or LTT, in part depending on grain size.

The bay has four main barriers: the stationary Aslings, regressive Boydtown, dynamic Whale Beach (Fig. 19.25e) and the very sheltered regressive Fisheries. Hudson (1991) also found that while the Aslings barrier is relatively narrow (~100 m), 7 m high and stable, it is fronted by a substantial convex shoreface wedge of fine to medium quartz sand with ~5% carbonate.

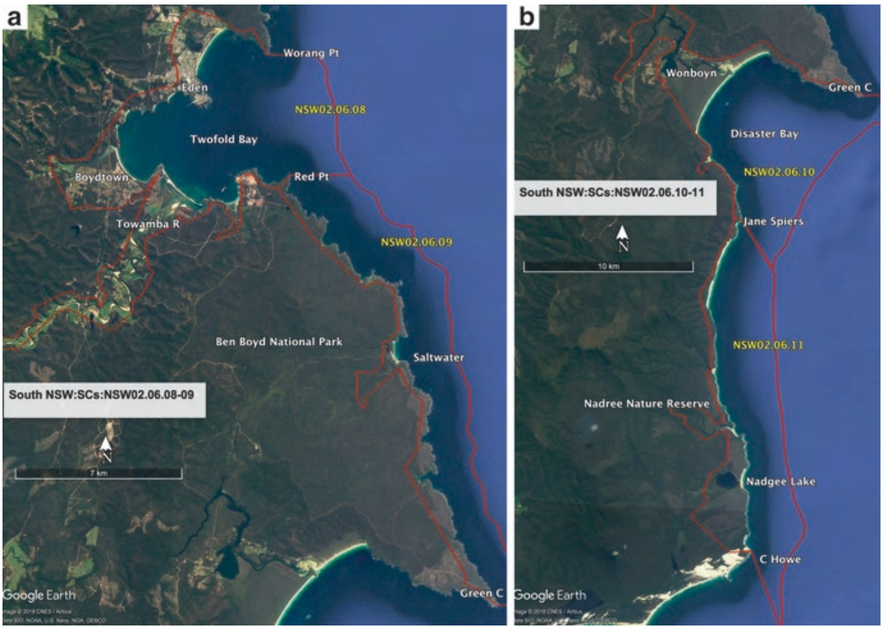

Fig. 19.28 (**a**) SCs NSW02.06.08 and 02.06.09 and (**b**) SCs NSW02.06.10 and NSW02.06.11. (Source: Google Earth)

Oliver et al. (2017) investigated the low (2–4 m high) 2 km wide Boydtown barrier, which is capped by 50 beach-foredune ridges. They found it initially prograded slowly (0.16 m $year^{-1}$) between 7.5 and 1.5 ka and then more rapidly since 1.5 ka (0.65 m $year^{-1}$) which they attribute to the input of Towamba fluvial sediments (Fig. 19.25e). Hudson found the Towamba, which drains Devonian granites, had filled its valley with sand by 4.7 ka, following which it began to supply sand to its Whale Beach barrier. The barrier consists of a single vegetated 50 m wide foredune (Fig. 19.25e) which is destroyed during major flood events with the sand deposited in the bay. This sand forms a coarse lobe of fluvial sediment grading to fine fluvial sand in the inner bay, while the outer bay sediments appear to be shelf in origin. Hudson proposed that the fine sand has been supplied to the Boydtown barrier since ~4 ka, which Oliver et al. found is continuing to prograde. The small sheltered Fisheries barrier is a low 300 m wide regressive beach ridge plain, which is composed of >70% carbonate material in marked contrast to the other quartz-rich barriers (Thom et al. 1986). The barriers have a total volume of 12 M m^3 (83% contained the Boydtown barrier) with a per metre volume of 1820 m^3 m^{-1}. This larger unit volume is as result of the combined shelf and fluvial sediment supply coupled with the abundant accommodation space offered within the bay resulting in the development of the extensive Boydtown barrier.

Hudson (1991) also investigates the nearshore sediments between Twofold Bay and Green Cape and found the bay has acted as a sink for both marine and fluvial sediments, with the marine supply now ceased but with ongoing supply from the Towamba during major flood events. There is no evidence for longshore sand transport within or outside the bay, with substantial boundary headlands (Worang and Red Point) and rocks reefs.

Thom et al. (1986) summarised the Holocene evolution of the bay. They found that between 6.5 and 3 ka, excess nearshore sand was transported into the bay initiating progradation of the Boydtown barrier and formation of the Aslings and Whale Beach barriers. After 3 ka the nearshore supply to the northern bay decreased or ceased leading to erosion of the Aslings barrier, while in the south the Towamba estuary infilled and began supplying coarse fluvial sand to the southern bay, with the finer component transported into the bay to supply the Boydtown barrier, while Fisheries barrier received no fluvial sediment. The Towamba fluvial sediment is expected to continue to supply the southern bay allowing ongoing barrier progradation.

19.7.11 SC:NSW02.06.09 Red Rock-Green Cape

SC:NSW02.06.09 is a 27 km long section of rocky shore located between Red Point and the protruding and prominent Green Cape (Fig. 19.28a), the rocks composed of massive mudrock and coarse sandstone, and all contained within Ben Boyd National Park, and located either end of the park's 'light to light' walking track. There are six small deeply embayed pocket beaches totalling just 1.4 km in length (5%) including some boulder beaches, the remainder sloping and cliffed rocky shore with rock platforms, and all backed by dense vegetation. The only development is camping areas at Saltwater Creek and Bittangabee Bay and the Green Cape Lighthouse. The only barrier is located at 0.5 km long Saltwater Creek with accommodation space provided by the junction of two small creek mouths; it has a volume 0.25 M m^3. While this SC is lacking in onshore sand deposits, Hudson (1991) mapped a 15 km long SSB located in 40–80 m depth and extending from Mowarry Point south to Green Cape. It has a surface area of ~40 km^2, which depending on its thickness represents a few hundred M m^3, one of the largest deposits on the south coast and exceeded only by the Sydney SSB's and its neighbouring SSB on the southern side of Disaster Bay (Roy 1998). The lack of onshore sediments can be attributed to the steep inshore gradient which prevented onshore transport.

19.7.12 SC:NSW02.06.10 Green Cape-Jane Spiers

SC:NSW02.06.10 is occupied by the exposed southeast-facing Disaster Bay (Fig. 19.28b), the name a warning for ships mistakenly entering the bay. The bay is located entirely within Ben Boyd National Park north of Wonboyn Lake and Nadgee Nature Reserve south of the lake. There is no development on the beach and barrier. The bay has a 10 km wide mouth between Green Cape and Jane Spiers and was originally 10 km long but has since been partly infilled with a 2 km wide regressive barrier capped by 40 6–7 m high foredune ridges. The bay has acted as a major sediment sink for marine sands (99% quartz) with a barrier volume of 33 M m^3 (5140 m^3 m^{-1}), though still relatively small compared to the adjoining massive SSB's. The small Wonboyn River (352 km^2) flows into the lake but is not delivering sand to the coast. The 7 km long beach is a higher energy TBR-RBB with up to 25 beach rips along the shore. A flood tide delta extends 4 km into the lake forming the northern boundary of the barrier. The barrier was initially radiocarbon dated by Thom et al. (1981) and then by Oliver et al. (2017) using OSL. Thom recorded a regressive phase beginning ~6.5 ka and continuing to the present, while Oliver found it was initiated ~7.5 ka and then prograded slowly at 0.08 m $year^{-1}$ until 4.5 ka and then at 0.32 m $year^{-1}$ until present and now appears to be slowing or stopped as suggested by the 8 m high frontal dune.

The bay has acted as major Holocene sediment sink for marine sands leading to the formation of the barrier and flood tide delta. It now appears the shelf sediment source has slowed or ceased. While sand has moved into the bay, there is no export of sand from the bay with the headlands and deep water extending up to 6 km seawards, making it a closed SC and TC.

19.7.13 SC:NSW02.06.11 Jane Spiers-Cape Howe

SC:NSW02.06.11 is the southernmost SC in the region and continues due south for 22 km to Cape Howe (Fig. 19.28b), the cape named by Cook in 1770, and the Victorian, PC and regional border. The entire SC is located within Nadgee Nature Reserve with the only public access to the coast at Wonboyn beach. The coast consists of steeply sloping vegetated terrain which provides very limited accommodation space apart from the mouth of the small Little Creek, Nadgee River and Nadgee Lake (a barrier lagoon). Three unstable barriers occupy the mouth of these streams each prone to erosion by stream flooding and waves. Most of the coast is rocky (15 km, 68%) apart from eight embayed beaches which total 7.1 km in length and average 0.8 km. Most are higher energy TBR-RBB, together with a couple of more sheltered R-LTT. There are six small mainland beach barriers totalling 1.6 M m^3, with a per metre volume of just 230 m^3 m^{-1}, attesting to the very limited accommodation space and onshore transport. The southernmost beach (NSW 721) is located on the northern side of the low rocky Cape Howe and is receiving sand overpassing the cape and the border, at unknown rates, from the extensive transgressive dunes to the south (Fig. 19.25f).

Hudson found the coast is paralleled by a large SSB located at depths between 40 and 90 m that extends south from off Disaster Bay for at least 15 km and probably all the way to Cape Howe and beyond towards Gabo Island. This SSB has probably been supplied with sand from the adjacent Gippsland region, with the sand both bypassing and overpassing Cape Howe (Fig. 19.25f) and is deposition in the SSB owing to the abrupt change in coastal orientation coupled with the deep inshore waters.

19.7.14 PC Overview

PC NSW02.06 at 328 km is the longest in the southern NSW region and contains the greatest number of beaches (207). However, together with its northern neighbour (PC02.05), it has the lowest per metre volume of barrier deposits in the region (Table 19.6). This can be attributed to a number of factors. The first is the generally straight easterly orientation which is devoid of major sediment sinks, with all the PCs major sinks occurring in south- to southeast-facing embayments; second is the rugged, rocky and steep nature of parts of the coast and nearshore which limit accommodation space and preclude onshore and longshore transport and have led to the development of at least two SSB's; and third is the prevailing offshore southwesterlies which hinder to formation of extensive transgressive dunes.

Forty-five percent (149 km) of the PC is sandy beaches which are a mix of generally shorter (<0.5 km), sheltered R-LLT and exposed, generally longer (1–2 km) TBR-RBB. The barriers tend to be small mainland beaches, with the only substantial barriers all regressive beach to foredune ridge plains, including the only cheniers in NSW at Batemans Bay. Most of the beaches and barriers appear to be stable. The only ‘hotspots’ along this PC are located in the low-lying inner sections of Batemans Bay (Surfside, Batemans Bay CBD) and Corrigans Beach, together with Caseys Beach and the Narooma flats, the latter a low-lying but developed estuarine sand spit. All of these hotspots will become increasingly vulnerable to inundation with rising sea level and higher storm surges. The beaches are expected to begin receding with rising sea level as any potential shelf supply becomes more distant. There are more than 60 generally small lakes and estuaries along this coast, all of which will be heavily impacted by rising sea level, which will increase the tidal prism and salinization, reactivate flood tide deltas and raise flood and inundation levels. However, much of this PC is also located in national parks and nature reserves, and apart from the present and future ‘hotspots’, much will be left to fend for itself.

19.8 Regional Overview

The southern NSW region contains some of the most and least developed coastline in the State. The central NSW region between Port Stephens and Sydney and Nowra is the most populated and highly developed in Australia with a population ~ 5 M, while south from Nowra much of the coast is located in national parks and reserves, with the generally small towns and communities normally located around estuaries. In terms of the future, the coast can be divided into three parts:

- The rocky coast which occupied 580 (56%) of the coast and which will be left to fend for itself as sea level slowly rises.
- The 551 open coast sandy beaches which occupy 448 km (43%). Most of these are either stable to receding, with very few showing signs of progradation, while Gordon (1988) found that there was an average shoreline recession of 0.23 m year^{-1} based on 32 sites along NSW coast between Fingal and Tathra. However, 259 beaches (47%) are located in the 33 national parks, nature reserves and state conservation areas, which also cover 463 km (45%) of the coast. It is expected these, with little or no property or infrastructure at risk, will be left to themselves.
- This leaves the other 292 beaches, of which only 9 are presently coastal hotspots, with 5 or more properties at risk (Jimmys, Entrance North, Noraville, Norah Head, Wamberal, Bilgola, The Basin (Mona Vale), Collaroy and Surfside (Batemans Bay)). Rising sea level, changing wave climate and extreme water levels will however expand this list into the future.

As discussed in Chap. 18, Kinsela et al. (2017) modelled the impact of rising sea level on NSW beaches and found that by 2100 the southern NSW beaches will be eroded on average between 100 and 150 m. As a result the number of at-risk properties that have been mapped in existing LGA coastal management plans will increase from the present ~750 to 2100, while at 1% exceedance, they increase from ~1600 to ~4200, together with roads and infrastructure. As Kinsela et al. (2016b) state 'The maps are intended to guide strategic decision making at the regional level and to provide risk information to enable prioritisation of more detailed risk assessment'. There are five possible responses to the present and impending threats to property and infrastructure, namely: do nothing, retreat, adapt, nourish or defend. These threats are present in every NSW coastal LGA, and their coastal zone management plans both identify the hazards and risk and propose solutions. While some of these responses have been implemented to varying degrees, many plans are still trying to determine the most effective and acceptable actions. Ongoing call for nourishment of Sydney's threatened beaches (Gordon 2009; ACEOM 2010) has so far achieved no result. What responses can or will be implemented remain to be seen.

The NSW SeaBed mapping program commenced in 2017 with the aim of mapping NSW secondary sediment compartments (e.g. Fig. 19.18) with multibeam and marine Lidar to (1) determine the distribution and variability in nearshore sediment types and better understand alongshore-across-shore sediment transport; and (2) further develop a state-wide coastal digital elevation model (Linklater et al. 2018, 2019). This program will provide information required to accurately map the nature of the seabed and in particular sediment location, type, volume and transport pathways, all essential to the understanding of each compartment's sediment and shoreline dynamics (https://www.environment.nsw.gov.au/research-and-publications/our-science-and-research/our-research/water/offshore-mapping).

The third area is the 137 estuaries (drowned river valleys, barrier estuaries and coastal lagoons/ICOL's) which extend the full length of this region. These have extensive low-lying shorelines which will be impacted by rising sea level and marine and fluvial inundation, higher salinities and associated ecological impacts including the 'squeezing' of inter- and supratidal ecosystems. The more open estuaries including the four main bays (Broken, Sydney, Botany and Hacking) will also become deeper leading to less wave attenuation and allowing higher energy waves within the systems which will exacerbate many already unstable and dynamic estuarine beaches and spits, such as Jimmys Beach, Snapperman Beach and Surfside. All estuarine flood tide deltas will also be reinvigorated leading to increased loss of sand to the estuaries from adjoining beaches. The greatest threat to the NSW coast therefore lies in the sheltered but low-lying estuarine environments which will bear the brunt of rising sea level and changing estuarine dynamics and chemistry.

Hanslow et al. (2016, 2018) mapped potential inundation of land and properties in 184 NSW estuaries with current, 0.5 m, 1 m and 1.5 m sea-level rises, using the methodology developed by Morris et al. (2013). They found with a 1.5 m rise the area inundated increased from 413 to 2315 km^2 and properties from 600 to 43,300. These results highlight the greater impact of sea-level rise in estuaries compared to the open coast. They also found the majority of these properties are located in northern NSW (NSW01.01-03), the Hunter region (NSW02.01), Central Coast (NSW 02.02) and Sydney region (NSW02.03), with least impact in the Illawarra (NSW02.04–05) and South Coast (NSW02.06). However, in terms of individual estuaries, the most vulnerable are, in order, Lake Macquarie, Georges River, Brisbane River, Tuggerah Lake, Richmond River, Hunter River, Tweed River, Clarence River, Parramatta River and Port Stephens, with six of these located in the southern NSW region. These results indicate that along the NSW coast by 2100, there will be ~4000 properties on the open coast at risk to beach erosion, while in the estuaries there will be ~40,000 properties at risk to inundation, an order of magnitude more properties.

In addition to sea-level rise-induced erosion and inundation, Mortlock and Goodwin (2015) predict an increase in the modal wave energy for the central NSW shelf for each 1° southerly shift in the STR during winter and a reduction of similar magnitude during summer. In both seasons there is an anticlockwise rotation of wave power towards the east and southeast at the expense of southerly waves. The reduced obliquity of constructive wave power would promote a general disruption to northward alongshore sediment transport, with the cross-shore component becoming increasingly prevalent. This would have ramifications for the entire coast impacting longshore transport, headland bypassing and beach rotation.

References[1]

ACEOM (2010) Beach sand nourishment scoping study. Report prepared for Sydney Coastal Councils Group Inc., Sydney, 116 p plus appendices

Albani A, Johnson BD (1974) The bedrock topography and origin of Broken Bay. NSW J Geol Soc Aust 21:209–214

Albani AD, Carter AN, Johnson DB (1973) The bedrock topography of Jervis Bay, new South wales. Fraser R (ed) Oceanography of the South Pacific, New Zealand National Comm. UNESCO, Wellington, pp 179–184

Andrew EC (1912) Shoreline studies at Botany Bay. Proc Roy Soc NSW 46:165–179

Austin TP, Short AD, Hughes MG, Ranasinghe R, Vila-Concejo A (2009) Tidal hydrodynamics of a micro-tidal, wave-dominated flood-tide delta: Port Stephens, Australia. J Coastal Res SI 56:693–697

Austin TA, Vila-Concejo A, Short AD, Ranasinghe R (2018) A conceptual model of flood-tide delta morphodynamics in micro-tidal estuaries. Geosciences 8:324. https://doi.org/10.3390/geosciences8090324

Bird ECF (1967) Depositional features in estuaries and lagoons of the south coast of New South Wales. Aust Geogr Stud 2:113–124

Bishop P, Hughes M (1989) Imbricate and fitted fabrics in coastal boulder deposits on the Australian east coast. Geology 17:544–547

Blumberg G, Bortfeld D, Jayewardene I, Kelleher N, Medi P, Watson P (2009) Jimmys beach sand renourishment scheme. Coasts and Ports 2009, Wellington, NZ, pp 435–441

[1] *Note*: The NSW open coast is divided into 23 coastal LGAs that are required to develop coastal zone management plans. To this end they also undertake coastal hazard and process studies, which from 2018 are required to use a sediment compartment approach, examining whole SCs and their sediment sources, transport and sinks, rather than individual beaches or parts of the coast. All past reports are usually available online from the council websites and provide a detail assessment of each LGA coastline and in many cases individual beaches. They provide a wealth of information on the NSW coast, its geology, geomorphology, processes, hazards and management and are updated on a recurring basis, with future reports adopting the compartment approach. Some of the existing reports are referenced in this and the following chapter.

BMT WBM (2012) Jimmys Beach sand nourishment assessment. Final report prepared for Great Lakes Council by BMT WBM, Broadwater, 87 p plus appendices

BMT WBM (2014) Newcastle coastal zone hazard study. Final Report, prepared for Newcastle City Council, Newcastle, 157 p plus appendices

BMT WBM (2017) Wollongong Coastal Zone Management Plan. Prepared for Wollongong City Council by BMT WBM, Newcastle, 68 p

Boleyn DA, Campbell BL (1968) Littoral drift in the vicinity of Newcastle Harbour entrance. Public Works Department, Sydney, 47 p

Britton G (2013) Shell Cove Boat Harbour development, NSW. In: 14th Australasian Port Harbour Conference, Sydney, pp 133–138

Britton G, Goldie P, Morgan B, Lam D (2017) Breakwater design, contracting strategy, and construction – Shell Cove Boat Harbour. Australasian Coasts & Ports 2017:172–178

Brown CT, Le Plastier BJ, Heathcote KA (1977) The entrances of the Shoalhaven River. In: 3rd Australian conference on coastal and ocean engineering, Institution of Engineers Australia, pp 143–149

Bryant E (1984a) Sediment characteristics of some eastern Australian foreshores. Aust Geographer 16:5–15

Bryant E (1984b) Stanwell Park beach changes 1895–1980: description, causes and representativeness. In: Proceedings of the 18th Austlaian Institute of Engineering. Illawarra Group.

Bryant E, Nanson G, Young A, Young R (1988) Illawarra landscapes. In: 26th Intl Geog. Congr, Short excursion L3, Department of Geograpghy, University of Wollongong

Burston J (2006) Coastal inundation hazard along the New South Wales coast. Ph.D. thesis, School Geoscience, University of Sydney, Sydney

Carvalho R, Kinsela M, Hanslow D, Hamylton S, Linklater M, Ingleton T, Morris B, Allen K, Woodroffe CD (2017) Identifying sediment compartment dynamics on the Illawarrea Coast. NSW coastal conference, Port Stephens

Chapman DM, Geary M, Roy PS, Thom BG (1982) Coastal evolution and coastal erosion in New South Wales. Coastal Council New South Wales, Sydney, 341 p

Coghlan IR, Carley JT, Harrison AJ, Howe D, Short AD, Ruprecht JE, Flocard F, Rahman P (2017) Eurobodalla coastal hazard assessment. WRL technical report 2017/09, Water Research Laboratory, UNSW, Sydney, 180 p plus appendices

Coghlan IR, Short AD, Carley J, Harrison A, Vos K, Lenehan N, Wiecek D (2018) Broulee: an island no more? 27th NSW coastal conference, Merimbula, 17 p

Coltheart L (1997) Between Wind and Water: a history of the ports and coastal waterways of New South Wales. Hale Iremonger, Sydney, 208 p

Coull M, Willoughby M (2003) Beach restoration in Botany Bay – satisfying community and approving authority expectations. Coast and Ports Australasian Conference, Auckland, 8 p

Courtney C, Dominey-Howes D, Goff J, Chagué-Goff C, Switzer AD, McFadgen B (2012) A synthesis and review of geological evidence of palaeotsunamis along the coast of southeast Australia: the evidence, issues and potential way forward. Quaternary Sci Rev 54:99–125

Coutts-Smith AJ (2004) Significance of mega-rips along an embayed coast. PhD School Geoscience. University of Sydney, Sydney, 221 p

Cowell PJ (1986) Wave induced sand mobility and deposition on the south Sydney inner-continental shelf. In Frankel E, Keene JB, Waltho AE (eds) (1986) Recent sediments in eastern Australia: marine through terrestrial. Publication: Geological Society of Australia, NSW Division. No. 2:1–27

Cowell PJ, Nielsen H (1991) Management of beach erosion due to low swell, inlet and greenhouse effects: case study with computer modelling. In: 10th Australasian conference on coastal and ocean engineering, Auckland, pp 329–334

Davies PT, Kesby NA (1987) Coastal protection 'had' or 'soft'. In: 8th Australasian conference on coastal and ocean engineering, Sydney, Institution of Engineers Australia, pp 98–102

DHI (2006) Stockton Bight coastal processes study. Newcastle city Council, DHI, Newcastle, 189 p

Donner J, Jungner H (1981) Radiocarbon dating of marine shells from southeastern Australia as a means of dating relative sea level changes. Ann Acad Sci Fennicae Series A III 131:5–44

Druery BM, Geary MG (1985) The measurement of sediment transport in NSW estuaries. Aust Conf Coastal Ocean Engr Christchurch 2:151–160

Field ME, Roy PS (1984) Offshore transport and sand-body formation: evidence from a steep, high-energy shoreface, southeastern Australia. J Sediment Petrol 54:1292–1302

Foster DN, Gordon AD (1978) Beach protection, Cronulla. In: 4th Australian conference on coastal and ocean engineering, Adelaide, Institution of Engineers Australia, pp 8–12

Frost G (2011) Review of coastal processes and evaluation of the impact of the constructed groynes along Lady Robinsons Beach, Botany Bay, New South Wales, Australia. B. Env. Honors thesis, Faculty of Science, University of Wollongong, Wollongong, 99 p

Gale SJ, de Rochefort CA, Moore SR, Timms AJC (2018) The origin and stratigraphic significance of the Quaternary Waterloo Rock of the Botany Basin of south-east Australia. Aust Geographer 49:291–316

Gallop SL, Harley MD, Brander RW, Simmons JA, Splinter KD, Turner IL (2017) Assessing cross-shore and alongshore variation in beach morphology due to wave climate: storms to decades. Oceanography 30:120–125. https://doi.org/10.5670/oceanog.2017.304

Geary MG, Lord DB (1981) Development in the coastal hazard zone; a coastal engineering perspective. In: 5th Australian conference on coastal and ocean engineering, Perth, Institution of Engineers Australia, pp 183–187

Glatz M, Ftizhenry M, Kulmar M (2017) It's time for an update – extreme waves and directional distributions along the New South wales coastline. NSW Coastal Conf. Port Stephens, 22 p. http://www.coastalconference.com/papers.php

Goodwin I, Mortlock T, Browning S (2016) Tropical and extratropical-origin storm wave types and their influence on the East Australian longshore sand transport system under a changing climate. J Geophys Res Oceans. https://doi.org/10.1002/2016JC011769

Gordon AD (1982) An assessment of beach processes in the Hawks Nest region. Working paper. NSW Public Works Department, Coastal Engineering. Branch, Sydney

Gordon AD (1987) Beach fluctuations and shoreline change – NSW. In: 8th Australasian conference on coastal and ocean engineering, Launceston, Institution of Engineers Australia, pp 103–107

Gordon AD (1988) A tentative but tantalizing link between sea-level rise and coastal recession in New South Wales. In Pearman GI (ed) Greenhouse: planning for climate change, CSIRO, EJ Brill, Leiden, Australia, pp 121–134

Gordon AD (1989) Sydney's sea defences. In: 9th Australasian conference on coastal and ocean engineering, Adelaide, Institution of Engineers Australia, pp 149–154

Gordon A (2009) The potential for offshore sand sources to offset climate change impacts on Sydney's Beaches. Coasts and Ports 2009, Wellington, NZ, pp 12–132

Gordon AD, Hoffman JG (1986) Sediment features and processes of the Sydney continental shelf. In Frankel E, Keene JB, Waltho AE (eds) (1986) Recent sediments in eastern Australia: marine through terrestrial. Publ. Geol. Soc. Australia, NSW Division No 2, pp 29–51

Gordon AD, Lord DB (1980) An approach to understanding coastal processes. In: Proceedings of the 17th international conference on Coastal Engineering, Sydney, pp 1235–1254

Gordon AD, Roy PS (1977) Sand movement in Newcastle Bight. In: 3rd Australian conference on coastal and ocean engineering, Melbourne, Institution of Engineers Australia, pp 64–69

Griffin JD, Hemer MA, Jones BG (2008) Mobility of sediment grain size distributions on a wave dominated continental shelf, southeastern Australia. Mar Geol 252(1–2):13–23

Hails JR (1969) Then origin and development of the Umina-Woy Woy beach ridge system, Broken bay, NSW. Aust Geogr 11:1032

Hann JM (1986) Late Quaternary depositional evolution of Botany Bay. In Frankel E, Keene JB, Waltho AE (eds) (1986) Recent sediments in eastern Australia: marine through terrestrial. Publ. Geol. Soc. Australia, NSW Division No 2, pp 101–116

Hanslow DJ, Dela Cruz J, Morris BD, Kinsela MA, Foulsham E, Linklater M, Pritchard TR (2016) Regional scale coastal mapping to underpin strategic land use planning in south east Australia. J Coast Res 75:987–991

Hanslow DJ, Morris BD, Foulsham E, Kinsela MA (2018) A regional scale approach to assessing current and potential future exposure to tidal inundation in different types of estuaries. Scientific Reports, published online. 8:7065. https://doi.org/10.1038/s41598-018-25410-y

Harley MD, Turner IL, Short AD, Ranasinghe R (2011) A re-evaluation of coastal embayment rotation in SE Australia: the dominance of cross-shore versus alongshore sediment transport processes. J Geophys Res 116:F04033. https://doi.org/10.1029/2011JF001989

Harley MD, Turner IL, Short AD (2014) Hydrodynamic and morphodynamic controls of embayed beach rotation. J Geophys Res. https://doi.org/10.1029/2004JC002791

Harley MD, Turner IL, Short AD, Bracs MA, Phillips MS, Simmons JA, Splinter K (2015) Four decades of coastal monitoring Narrabeen-Collaroy Beach: the past, present and future of this unique dataset. Australasian Coast Ports Conference, Auckland, 6 p

Harley MD, Turner IL, Splinter KD, Phillips MS, Simmons JA (2016) Beach response to Australian East Coast Lows: a comparison between the 2007 and 2015 events, Narrabeen-Collaroy Beach. J Coastal Res SI 75:388–392

Harley MD, Turner IL, Kinsela MA, Middleton JH, Mumford PJ, Splinter KD, Phillips MS, Simmons JA, Hanslow DJ, Short AD (2017) Extreme coastal erosion enhanced by anomalous extratropical storm wave direction. Scientific Reports, nature.com

Healy TR, Lee F (1975) Flourescent tracing experiment and littoral drift estimations, Port Kembla NSW. In: 2nd Australian conference on coastal and ocean engineering, Gold Coast, Institution of Engineers Australia, pp 38–45

Hesp PA (1993) Late Quaternary coastal geomorphology of the South Sydney-Illawarra coast. In Thoms MC (ed) Catchments and Coasts in Eastern Australia, Deparment of Geography, University of Sydney, Sydney, Research Monograph 5:72–87

Hudson JP (1991) Late Quaternary evolution of Twofold Bay, southern New South Wales. MSc thesis, Department of Geography, University of Sydney, Sydney, 210 pp

Jones BG, Young RW, Eliot IG (1979) Stratigraphy and chronology of receding barrier-beach deposits on the northern Illawarra coast on New South Wales. J Geol Soc Am 26:255–264

Kinsela MA, Daley MJA, Cowell PJ (2016a) Origins of Holocene coastal strandplains in Southeast Australia: Shoreface sand supply driven by disequilibrium morphology. Mar Geol 374:14–30. https://doi.org/10.1016/j.margeo.2016.01.010

Kinsela MA, Morris BD, Daley MJA, Hanslow DJ (2016b) A flexible approach to forecasting coastline change on wave-dominated beaches. J Coastal Res SI 75:952–956

Kinsela MA, Morris BAS, Linklater M, Hanslow DJ (2017) Second-pass assessment of potential exposure to shoreline change in New South Wales, Australia, using a sediment compartments framework. J Mar Sci Engr 5:61. https://doi.org/10.3390/jmse5040061

Kulmar MA, Gordon GA (1987) Coastal processes of the Pittwater northwestern foreshores. In: 8th Australasian conference on coastal and ocean engineering, Sydney, Institution of Engineers Australia, pp 108–112

Kumbier K, Carvalho RC, Woodroffe CD (2018) Modelling hydrodynamic impacts of sea-level rise on wave-dominated Australia estuaries with differing geomorphology. J Mar Sci Engr 6:66. https://doi.org/10.3390/jmse6020066

Lawson NV, Atkinson W (1978) Kyeemagh, Botany Bay – analysis of man induced beach alignment. In: Fourth Australian Conf Coastal Ocean Engr, Adelaide, Inst Engr Aust, vol 2

Lewis M (1976) Beach ridge development in Cullendulla Creek embayment, Batemans Bay, New South wales. BSc Hons thesis, Department of Geography, University of Sydney, Sydney

Linklater M, Ingleton T, Kinsela M, Morris B, Allen K, Sutherland M, Hanslow D (2018) Seabed classification approach for SeaBed NSW coastal seafloor mapping program. In: HYDRO18 Conf, Australian Hydrographic Society, Sydney, 14 p

Linklater M, Ingleton T, Kinsela M, Morris B, Allen K, Sutherland M, Hanslow D (2019) Seabed feature classification along a subtropical-temperate continental shelf. Geosciences 9:141. https://doi.org/10.3390/geosciences9030141

Lord D, Watson P, Avis P (1995) Offshore dredging for beach nourishment, Shoal Bay, NSW. In: 12th Australasian conference on coastal and ocean engineering, Melbourne, Institution of Engineers Australia, pp 439–444

Lucas AH, Anderson PG (1973) Newcastle Harbour entrance shoal wave model and Sand tracing. In: 1st Australasian conference on coastal engineering, Sydney, pp 89–97

Mariani A, Flocard F, Carley JT, Drummond C, Guerry N, Gordon AD, Cox RJ, Turner IL (2013) East Coast Study Project – National Geomorphic Framework for the Management and

Prediction of Coastal Erosion, Water Research Laboratory, WRL Research Report. School Civil Environmental Engineering, UNSW, Manly Vale
Masselink G (1999) Alongshore variation in beach cusp morphology in a coastal embayment. Earth Surface Processes Landforms 24(4):335–347. https://doi.org/10.1002/(SICI)1096-9837(199904)24:4:335::AID-ESP968>3.0.CO;2-H
McKenzie P (1958) Rip-current systems. J Geol 66:103–113
McLean RF, Thom BG (1975) Beach changes at Moruya, 1972–1974. In: 2nd Australian conference on coastal and ocean engineering, Gold Coast, Institution of Engineers Australia, pp 12–17
McLean R, Shen J, Thom BG (2010) Beach Change at Bengello Beach, Eurobodalla Shire, New South Wales: 1972–2010. NSW Coastal Conference, Batemans Bay http://www.coastalconference.com/papers.php
McLean R, Shen J, Thom BG (2018) Big bite, little bite: fast recovery, slow recovery': storm impacts at Bengello Beach, Moruya, 1998 to 2018. 27th NSW Coastal Conference, Merimbula, 73 (abstract)
Metromix (1993) Sydney marine aggregate proposal: environmental impact assessment. Prepared by RW Corkery & Co Pty Ltd, Sydney, 416 p
Miller BM, Nielsen AF (1995) Physical modelling study of Shell Cove boat harbour. In: 12th Australasian conference on coastal and ocean engineering, Melbourne, Institution of Engineers Australia
Moratti M (1997) Stockton Beach Erosion, Monitoring & Management. In: 13th Australasian conference on coastal and ocean engineering, Christchurch, pp 465–470
Morim J, Cartwright N, Etemad-Shahidi A, Strauss D, Hemer M (2016) Wave energy resources along the Southeast coast of Australia on the basis of a 31-year hindcast. Appl Energy 184:276–297
Morris BD, Foulsham E, Hanslow D (2013) An improved methodology for regional assessment of tidal inundation hazards in NSW estuaries. In: 23rd Australasian conference on coastal and ocean engineering, Sydney, Institution of Engineers Australia
Mortlock TR, Goodwin ID (2015) Directional wave climate and power variability along the Southeast Australian shelf. Cont Shelf Res 98:36–53. https://doi.org/10.1016/j.csr.2015.02.007
Mortlock TR, Goodwin ID, McAneney JK, Roche K (2016) The June 2016 Australian east coast low: importance of wave direction for coastal erosion assessment. Water, 9, 121. https://doi.org/10.3390/w9020121
NCC (2016) Coastal management plan. Newcastle City Council, Newcastle, 109 p
Nielsen AF, Gordon AD (2017) Breakwaters and training walls: the good, the bad and the ugly. NSW Coastal Conf., Port Stephens 8 p
Nielsen AF, Lord DB, Treloar PD (1992) Sand transport on the inner continental shelf, Sydney, Australia. 4th Australasian Ports Harbour Conference, Sydney, pp 267–273
Oak HL (1984) The boulder beach: a fundamentally distinct sedimentary assemblage. Annals Assoc Amer Geogr 74:71–82
Oliver TSN, Woodroffe CD (2016) Chronology, morphology and GPR-imaged internal structure of the Callala Beach prograded barrier in southeastern Australia. J Coast Res SI 75:318–322
Oliver TSN, Dougherty AJ, Gliganic LA, Woodroffe CD (2015) Towards more robust chronologies of coastal progradation: optically stimulated luminescence ages for the coastal plain at Moruya, south-eastern Australia. The Holocene 25:536–546
Oliver TSN, Thom BG, Woodroffe CD (2017) Formation of beach-ridge plains: an appreciation of the contribution by Jack L. Davies. Geograph Res 55:305–320
Oliver T, Tamura T, Short AD, Woodroffe CD (2018) Rapid shoreline progradation followed by vertical foredune building at Pedro Beach, southeastern Australia. Earth Surf Process Landf. https://doi.org/10.1002/esp.4510
Patterson Britton (1993) Collaroy/Narrabeen beach nourishment investigations. Report prepared for Warringah Council. Patterson Britton and Partners, Sydney
Philip NA (1978) Coastal processes and the Wagonga Inlet breakwater. In: 4th Australasian conference on coastal and ocean engineering, Adelaide, pp 201–206

PWD (1980) Tathra erosion study. Coastal Engr. Branch report no. PWD 79015, Public Works Department, Sydney
Pye K, Bowman GM (1984) The Holocene marine transgression as a forcing function in episodic dune activity in eastern Australia. In: Thom BG (ed) Coastal Geomorphology in Australia. Academic, Sydney, pp 179–196
RH DHV (2014) Draft coastal zone management plan for Collaroy-Narrabeen beach and Fishermans beach. Report prepared for Warringah Copncil by Royal Haskoning DHV, Sydney, 78 p plus appendices
Roy PS (1984a) The geology and marine sediments on the south Sydney inner shelf, S.E. Australia, New South Wales. NSW Geological Survey Report GS 1984/1158 (Parts I and II)
Roy PS (1984b) Holocene sedimentation histories of estuaries in southeastern Australia. In Hodgkin EP (ed) Estuarine Development of Southern Hemisphere, Dept Cons Env Perth Bull 161:23–59
Roy PS (1985) Marine sand bodies on the south Sydney shelf, S.E. Australia. Coastal Studies Unit technical report 85/1, Coastal Studies Unit, University of Sydney, Sydney, 35 p plus appendices
Roy PS (1992) Holocene estuary evolution – stratigraphic studies from southeastern Australia. SERPM Spec Publ 51:241–263
Roy PS (1994) Holocene estuary evolution – stratigraphic studies from southeastern Australia. In Dalrymple RW, Boyd R, Zaitlin BA (eds), Incised-valley systems: origin and sedimentary sequences. Spec Publ Soc Sed Pet 51:241–264
Roy PS (1998) Cainozoic geology of the coast and shelf. In: Scheibner E (1998) Geology of New South Wales, synthesis, geological evolution v2. Mem Geol 13(2). Geol Survey NSW, Sydney, pp 361–385
Roy P (2001) Sand deposits of the NSW inner continental shelf. Geoscience Surveys, Sydney
Roy PS (2004) The geology and marine sediments on the south Sydney inner shelf, S.E. Australia. NSW Geol. Survey Report GS 1984/1158 (Parts I and II)
Roy PS, Boyd R (1996) Quaternary geology of the southeast Australia: a tectonically stable, wave-dominated, sediment deficient margin. IGCP project # 367, Field Guide to the central New South Wales coast, NSW Geol. Survey, Sydney, 174 pp
Roy PS, Crawford EA (1979a) Quaternary geology of the Newcastle Bight inner continental shelf, New South Wales. Records Geol Survey NSW, Sydney, 19, Part 2:145–188
Roy PS, Crawford EA (1979b) Holocene geological evolution of the southern Botany Bay-Kurnell region, central New South Wales. Rec Geol Survey NSW, Sydney, 20, Part2:159–250
Roy PS, Peat C (1976) Bathymetry and bottom sediments of Tuross estuary and Coila Lake: Records Geol Survey NSW. Sydney 18:103–134
Roy PS, Stephens AW (1980) Geological controls on process-response, S.E. Australia. 17th international coastal engineering conference, Sydney, pp 913–933
Roy PS, Zhuang W-Y, Birch GF, Cowell PJ, Congxian L (1997) Quaternary geology of the Foster-Tuncurry coast and shelf, southeast Australia. Geol Survey NSW Department of Mineral Resouces, Sydney, 405 p
Shand TD, Goodwin ID, Mole MA, Carley JT, Browning S, Coghlan IR, Harley MD, Pierson WL, Kulmar MA (2010) NSW coastal storms and extreme waves. 19th NSW Coastal conference Batemans Bay, 14 p. http://www.coastalconference.com/2010/papers2010/Tom%20Shand%20full%20paper.pdf
Short AD (1978) Characteristic beach morphodynamics on the southeast Australian coast. In: 4th Australian conference on coastal and ocean engineering, Adelaide, Institution of Engineers Australia, pp 148–152
Short AD (1979) Three-dimensional beach stage model. J Geol 87:553–571
Short AD (1984) Beach and nearshore facies, south east Australia. Mar Geol 60:261–282
Short AD (1985) Rip current type, spacing and persistence, Narrabeen beach, Australia. Mar Geol 65:47–71
Short AD (2007) Beaches of the New South Wales Coast, 2nd edn. Sydney University Press, Sydney, 398 p

Short AD, Hesp PA (1982) Wave, beach and dune interactions in south eastern Australia. Mar Geol 48:259–284
Short AD, Hogan CL (1989) Sydney's southern beaches – characteristics and hazards. In Fabbri P (ed) Recreational uses of coastal areas, Kluwer Academic Publisher, pp 199–209
Short AD, Hogan CL (1994) Rips and beach hazards, their impact on public safety and implications for coastal management. J Coastal Res SI 12:197–209
Short AD, Trembanis A (2004) Decadal scale patterns in beach oscillation and rotation Narrabeen Beach, Australia- time series, PCA and wavelet analysis. J Coastal Res 20:523–532
Short AD, Trenaman NL (1992) Wave climate of the Sydney region: an energetic and highly variable ocean wave regime. Aust J Mar Freshw Res 43:765–791
Short AD, Wright LD (1981) Beach systems of the Sydney Region. Aust Geographer 15:8–16
Short AD, Buckley RC, Fotheringham DG (1989) Preliminary investigation of beach ridge progradation on the Eyre Peninsula and Kangaroo Island. Trans Royal Soc South Aust 113:145–161
Short AD, Bracs MA, Turner IL (2014) Beach oscillation and rotation: local and regional response on three beaches in southeast Australia. J Coastal Res SI 70:712–717
Sloss CR, Murray-Wallace CV, Jones BG, Wallin T (2004) Aspartic acid racemisation dating of mid-Holocene to recent estuarine sedimentation in New South Wales, Australia: a pilot study. Mar Geol 212:45–59
Sloss CR, Jones BG, Murray-Wallace CV, McClennen CE (2005) Holocene sea level change and the evolution of a barrier estuary: a case study, Lake Illawarra, NSW, Australia. J Coastal Res 21:943–959
Sloss CR, Murray-Wallace CV, Jones BG (2006a) Aminostratigraphy of two Holocene wave-dominated barrier estuaries in southeastern Australia. J Coastal Res 22:113–136
Sloss CR, Jones BG, McClennen CE, de Carli J, Price DM (2006b) The geomorphological evolution of a wave-dominated barrier estuary: Burrill Lake, New South Wales, Australia. Sediment Geol 187:229–249
Sloss CR, Murray-Wallace CV, Jones BG (2007) Holocene sea-level change on the southeast coast of Australia: a review. The Holocene 17:999–1014
Sloss CR, Jones BJ, Switzer AD, Nichol S, Clement AJK, Nicholas AW (2010) The Holocene infill of Lake Conjola, a narrow incised valley system on the southeast coast of Australia. Quaternary Intl 221:23–35
SMEC (2010) Shellharbour Coastal Hazards Analysis. Final Report, prepared for Shellharbour City Council
SMEC (2014) Jimmys Beach coastal zone management plan. Report prepared form Great Lakes Council by SMEC, Brisbane, 49 p
Strachan W, Coltheart L, Lord D (1997) The Labour of Hercules – A History of Coastal Engineering in New South Wales. In: 13th Australasian conference on coastal and ocean engineering, Christchurch, pp 693–698
Switzer AD, Burston JM (2010) Competing mechanisms for boulder deposition on the southeast Australian coast. Geomorphology 114:42–54
Switzer AD, Jones BG (2008) Setup, deposition, and sedimentary characteristics of two storm overwash deposits, Abrahams Bosom beach, southeastern Australia. J Coastal Res 24:189–200
Switzer AD, Pucillo K, Haredy RA, Joines BG, Bryant EA (2005) Sea level, storm, or tsunami: enigmatic sand sheet deposits in a sheltered coastal embayment from southeastern New South Wales, Australia. J Coastal Res 21:655–663
Tamura T, Cunningham AC, Oliver TSN (2018) Two-dimensional chronostratigraphic modelling of OSL ages from recent beach-ridge deposits, SE Australia. Quaternary Geochronol. https://doi.org/10.1016/j.quageo.2018.03.003
Tamura T, Oliver TSN, Cunningham AC, Woodroffe CD (2019) Recurrence of extreme coastal erosion in SE Australia beyond historical timescales inferred from beach ridge morpho-stratigraphy. Geophys Res Letters 46:4705–4714. https://doi.org/10.1029/2019GL083061
Taylor G, Abell R, Paterson I (1995) Geology, geomorphology, soils and earth resources. In Cho G, Georges A, Stoutjesdijk E, Longmore R (eds) (1995) Jervis Bay: a place of cultural, scientific and educational value. Australian Nature Conservation Agency, Canberra, pp 41–52

Thom BG (1965) Late Quaternary coastal morphology of the Port Stephens-Myall lakes area, NSW. J Proc Royal Soc NSW 98:23–26

Thom BG (1974) Coastal erosion in eastern Australia. Search 5:198–209

Thom BG (1983) Transgressive and regressive stratigraphies of coastal sand barriers in southeast Australia. Mar Geol 56:137–158

Thom BG, Hall W (1991) Behaviour of beach profiles during accretion and erosion dominated periods. Earth Surf Process Landf 16:113–127

Thom BG, Oliver TSN (2018) Evidence for a change in wind regime during the Last Glacial Maximum from the Sydney region. Aust J Earth Sci. https://doi.org/10.1080/08120099.2019.1522668

Thom BG, Polach HA, Bowman GM (1978) Holocene age structure of coastal sand barriers in New South Wales, Australia. Royal Military College, Duntroon, 86 p

Thom BG, Bowman GM, Gillespie R, Temple R, Barbetti M (1981) Radiocarbon dating of Holocene beach-ridge sequences in south-east Australia. Department of Geography, UNSW monograph 11, Canberra, 36 p

Thom BG, Roy PS, Short A D, Hudson J, Davis RA Jr (1986) Modern coastal and estuarine environments of deposition in southeastern Australia. Guide Excur. 4A, 12th international Sed Congress, Canberra, 279 p

Thom BG, Shepherd M, Ly CK, Roy PS, Bowman GM, Hesp PA, (1992) Coastal geomorphology and Quaternary geology of the Port Stephens-Myall Lakes area. Department Biogeography Geomorphology, Monograph, 6, Australian National University, Canberra, 407 p

Thom BG, Hesp P, Bryant E (1994) Late glacial "coastal" dunes in Eastern Australia and implications for landscape stability during the Last Glacial Maximum. Palaeogeogr Palaeoclimatol Palaeoecol 111:229–248

Thom BG, Eliot I, Eliot M, Harvey N, Rissik C, Sharples C, Short AD, Woodroffe CD (2018) National sediment compartment framework for Australian coastal management. Ocean Coastal Mgt 154:103–120

Treloar PD, Collins PJ, Lawson NV (1981) Groyne field design – Silver beach – Kurnell, NSW, In: 5th Australian conference on coastal on ocean engineering, Perth, pp 72–73

Treloar PD, Gordon AS, Carr RS (1989) Batemans Bay ocean inundation study. In: 9th Australasian conference on coastal and ocean engineering, Adelaide, Institution of Engineers Australia, pp 268–274

Turner IL, Harley MD, Short AD, Simmons JA, Bracs MA, Philiips MS, Splinter KD (2016) A multi-decade dataset of monthly beach profile surveys and inshore wave forcing at Narrabeen, Australia. Scientific Data 3:160024. https://doi.org/10.1038/sdata.2016.24

Vila-Concejo A, Short AD, Hughes MG, Ranasinghe R (2007) Flood-tide delta morphodynamics and management implications, Port Stephens, Australia. J Coastal Res SI 50:705–709

Vila-Concejo A, Short AD, Hughes MG, Ranasinghe R (2009) Formation and evolution of a sand wave on an estuarine beach. J Coastal Res SI 56:153–157

Vila-Concejo A, Hughes MG, Short AD, Ranasinghe R (2010) Estuarine shoreline processes in a dynamic low-energy system. Ocean Dynam 60:285–298. https://doi.org/10.1007/s10236-010-0373-7

Vos K, Splinter K, Simmons J, Harley M, Turner IL (2018) Satellite remote sensing to extract long-term series of shoreline change. 27th NSW Coastal conference, Merimbula, 95 (abstract)

Wainwright DJ, Ranasinghe R, Callaghan DP, Woodroffe CD, Jongejan R, Dougherty AJ, Rogers K, Cowell PJ (2015) Moving from deterministic towards probabilistic coastal hazard and risk assessment: development of a modelling framework and application to Narrabeen Beach, New South Wales, Australia. Coastal Engr 95:92–99. https://doi.org/10.1016/j.coastaleng.2014.11.009

Wallis IG, Chidgey SS (1989) Coastal currents of New South wales. In: 9th Australasian conference on coastal and ocean engineering, Adelaide, Institution of Engineers Australia, pp 158–162

Watson PJ (1997) Port Stephens sand nourishment projects – evaluation, monitoring and sustainability. In: 13th Australasian Coastal Ocean Engineering Conference on Christchurch, New Zealand, Centre for Advanced Engineering 1:453–458

Watson P (2000) Jimmys Beach, Port Stephens, NSW: an expensive leaning experience in coastal management. Intl Conf Coastal Engr, Sydney 4:3566–3579
WBM (2000) Newcastle coastline hazard definition study, Final Report, prepared for Newcastle City Council
WC (2014) Draft coastal zone management plan for Collaroy-Narrabeen beach and Fishermans Beach. Warringah Council, Sydney, 78 p
Wenping JA, Craig A, Vila Concejo A, Cowell P, Ranasihnfe R (2009) Dominant hydrodynamic processes at Jimmy's beach, Pert Stephens, Australia: a numerical modelling study. Coast Ports 2009, Wellington NZ, pp 849–756
Williams T (1992) Mega-rips on the Sydney coastline – observational techniques and modelling. BSc (Hons) thesis, Department of Geography, University of Sydney
Willoughby MA, Trindage J, Foster DN (1995) The impact of major development on the coastal processes of Botany Bay. In: 11th Australasian conference on coastal and ocean engineering, Townsville, Institution of Engineers Australia, pp 37–46
Wright LD (1970) The influence of sediment availability on patterns of beach ridge development in the vicinity of the Shoalhaven River delta, NSW. Aust Geographer 11:336–348
Wright LD, Short AD (1984) Morphodynamic variability of surf zones and beaches: a synthesis. Mar Geol 56:93–118
Wright LD, Chappell J, Thom BG, Bradshaw MP, Cowell PJ (1979) Morphodynamics of reflective and dissipative beach and inshore systems, Southeastern Australia. Mar Geol 32:105–140
Wright LD, Coffey F, Cowell PJ (1980) Near-shore oceanography and morphodynamics of the Broken Bay-Palm Beach region, NSW, implications for dredging. Coastal Studies Unit Tech Rept 80/1. Coastal Studies Unit, University of Sydney, Sydney, 208 p
Wright LD, Short AD, Nielsen P (1982) Morphodynamics of high energy beaches and surf zones: a brief synthesis, Coastal Studies Unit Technical Report 82/5, Coastal Studies Unit, University of Sydney, Sydney 64 p
WSC (1978) Controls of coastal erosion. Warringah Shire Council, Sydney, 43 p
WSC (1985) Coastal management strategy. Report prepared for Warringah Shire Council by Public Works Department, Sydney, 111 p
You Z-J, Laine R, Hanslow DJ, Baldock T, Wiecek D (2014) Field measurements of beach-dune dynamic profiles to assess erosion hazard on the coast of NSW, Australia. Coastal Engr Proc:11 pp. https://doi.org/10.9753/icce.v34.management.23
Young RW, Bryant EA, Price DM (1993) Last interglacial sea levels on the south coast of New South wales. Aust Geogr 24:72–75
Young S, Lewis G, Couriel E, Hartley A, Clarke G (2017) NSW entrance bar management – bar crossing safety and bar to beach: linking dredging operations with coastal hazard mitigation and beach amenity improvements. NSW Coastal Conference, 13 p

Websites

Coastal imaging: http://ci.wrl.unsw.edu.au/current-projects/narrabeen-collaroy-beach/
Coastsnap: http://www.environment.nsw.gov.au/research-and-publications/your-research/citizen-science/digital-projects/coastsnap
MHL http://new.mhl.nsw.gov.au/data/realtime/wave/
NSW SeaBed mapping: https://www.environment.nsw.gov.au/research-and-publications/our-science-and-research/our-research/water/offshore-mapping

Chapter 20
Gippsland Region

Abstract The Gippsland region commences at Cape Howe, includes the long Ninety Mile Beach, and extends down to South Point on Wilsons Promontory, the southern tip of the continent. It faces the south through to the east into Bass Strait and has a humid temperate climate, with westerly winds delivering waves along this drift-aligned coast. Sediments are quartz-rich, with longshore transport to the north and east deposited in the Cape Howe dunes and a shelf sand body off the cape. Ninety Mile Beach has a long regressive barrier, which has minor dune transgression at its eastern end as it curves more into the westerly winds. Further east transgressive dunes become more common cumulating with the large dune field at Cape Howe which it overpasses into NSW. This chapter describes the coastal processes, beaches, barriers, sediment transport and sediment compartments along the Gippsland-eastern Wilsons Promontory coast.

Keywords Gippsland · Ninety Mile Beach · Wilsons Promontory · Bass Strait · Beaches · Barriers · Sediment transport · Sediment compartments

20.1 Introduction

The Gippsland region is located along the southeastern corner of the Australian continent and includes Ninety Mile Beach and Wilsons Promontory with its southern boundary the continent's southernmost point at South Point (39°S). The coast represents a transition in coastal orientation from the more east-facing NSW coast to the increasingly south-facing southern coast that in Gippsland faces southeast into Bass Strait. In addition, micro-tides that have prevailed along the entire NSW coast increase to meso by the southern part of this region. These changes begin abruptly at the regional and State boundary at Cape Howe, where the orientation changes from east to south (120° to 160°) and begins the 449 km long sweep of curving shore that trends west to Ninety Mile Beach and then increasingly south to Wilsons Promontory. The region is divided into three PCs: the more rugged eastern Croajingolong coast (PC:VIC01.01), the gently curving 222 km long Ninety Mile

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Beach (PC:VIC01.02), and the more indented and rugged Wilsons Promontory (PC:VIC01.03) (Fig. 20.1; Table 20.1). The three PCs contain a total of six SCs each of which is discussed below.

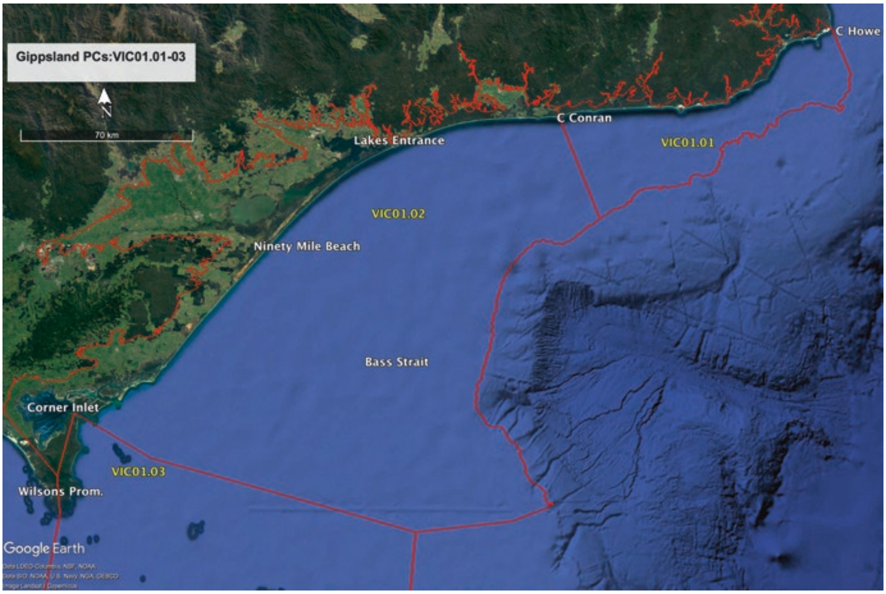

Fig. 20.1 The Gippsland region (VIC01) and its three PCs (VIC01.01-03) faces southeast into the shallow Bass Strait. (Source: Google Earth)

Table 20.1 Gippsland region PCs and SCs

PC No.[a]	Name	Boundaries	Beach ID[b]	No. beaches	km[c]	Total km
Gippsland						
VIC 01.01.01	Croajingolong	Cape Howe-Rame Hd	VIC 1-42	42	0–60	60
VIC 01.01.02	Croajingolong	Rame Hd-Cape Conran	VIC 43-71	29	60–133	73
PC:VIC01.01		*PC sub-total*		*71*		*133*
VIC 01.02.01		Cape Conran-Red Bluff	VIC 72-76	5	133–193	60
VIC 01.02.02	Ninety Mile	Red Bluff-Shoal Inlet	VIC 77-78	2	193–331	138
VIC 01.02.03	Corner Inlet	Shoal Inlet-Entrance Pt	VIC 79-87	9	331–381	50
PC:VIC01.02		*PC sub-total*		*16*		*248*
VIC01.03	E Wilson Prom.	Entrance Pt-South Pt	VIC 88-106	19	381–449	68
VIC01		*Regional total*	*VIC 1-106*	*106*	*0–449*	*449*

[a]NCCARF compartment number
[b]ABSAMP beach ID
[c]Distance from NSW/VIC border

20.2 Geology

The Gippsland geology is dominated by the Lachlan Fold Belt (Fig. 1.2) which occupies the Croajingolong coast and hinterland between Cape Howe and Cape Conran, together with the Wilson Promontory coast which consists predominately Devonian granites, with some Ordovician metasedimentary rocks in the east. In between is the Tertiary Gippsland Basin (Fig. 1.3) which extends up to 50 km inland and out across the continental shelf and is manifest at the coast by Ninety Mile Beach, which at 222 km is one of the three longest beach systems in Australia.

The rugged geology and sandy geomorphology have also influenced the lack of development along this coast and lead to the formation of three national parks and one coastal park. These are Croajingolong (50 km of coast), Cape Conran Coastal Park (20 km), The Lakes (79 km) and Wilsons Promontory (70 km) national parks, in all 49% of the coast, a produce of the rugged infertile terrain and central sandy coast, little of which was taken up for agricultural development remained crown land. In addition, there are marine parks at Cape Howe, Point Hicks, just south of Seaspray, Corner Inlet and the around the tip of Wilsons Promontory. The only coastal towns are at Mallacoota (1200), Marlo (350) and Lake Entrance (8100), with small communities spread along Ninety Mile Beach at Loch Sport (850), Golden-Paradise Beach (450) and Seaspray (350). Like the rest of the Victorian coast, a public foreshore reserve runs along most of the coast (96% of the Victorian coast) which has generally precluded foreshore development, except where leased (e.g. caravan park, sailing club, surf club) or licenced (e.g. tour operator). This means most of the coast strip, including all the Gippsland coast, is in public ownership with only approved lessees or licensees operating in the foreshore area and no private development.

20.3 Coastal Processes

The change in orientation of the coast at Cape Howe exposes the Gippsland coast to a changing set of marine processes emanating out of Bass Strait. Mean spring tide range which is 1.0 m at Gabo Island and most of the way down Ninety Mile Beach increasing to 2.4 m along the southern end of the beach and into Corner Inlet, dropping back to 2 m on Wilson Promontory. At the same time, wave height gradually decreases down the beach and into the inlet resulting in a switch from wave to more tide-modified coastal processes. Bass Strait's rather complex tides were modelled by Wijeratne et al. (2012) who found they are amplified by a combination of direct gravitational forcing and half-wavelength resonance of the M_2 tide.

The Gippsland wave climate is a product of Bass Strait and its coastal orientation and is controlled by four factors. First, is the dominant west to southwest regional wind regime that generates most of the waves which tend to arrive as sea, rather than swell, with fetch also decreasing to the west; second, is the south to southeast orientation of the coast increasingly exposing it to the south through westerly waves; third, is the increased sheltering to the west from southern ocean swell; and fourth, is the low-gradient continental shelf which widens to 180 km in the south attenuating the waves and reducing breaker wave height. At northern and eastern boundary at Gabo Island, waves arrive from the southwest through to the northeast, with dominant southerly waves arriving 30% of the time, while in western Bass Strait, they arrive almost exclusively from the southwest with a $H_s = 1.6$ m and $T = 8.5$ s (Wright et al. 1982). They found the waves exceed 1 m 40% of the time, 2 m 20% and 3 m 4%.

Wind roses for the coast also show the dominance of southwest winds at Wilsons Promontory's Tidal River, with westerly winds dominating at Sale, other southerly wind at Lakes Entrance and northeast winds at Gabo Island (Wright et al. 1982). Throughout, however, the southwest winds remain the dominant wind and dominant wave generator.

20.4 Beaches and Sediments

The Gippsland coast occupies a sedimentary basin with higher relief to either side. Along the rugged eastern Croajingolong coast, the hinterland is drained by a series of small rivers: the Genoa (1846 km^2), Benedore, Wingan (520 km^2), Mueller (573 km^2), Thurra, Cann, (1216 km^2) and the larger Snowy (15,096 km^2). In the central Gippsland lakes catchment are the Mitchell, Avon and La Trobe rivers (totalling 20,449 km^2) each of which has deposited deltas in the lakes, while in the south, only small streams drain into Corner Inlet and to the Wilsons Promontory coast. All the rivers flow to estuaries or lagoons with only the Snowy presently supplying sand to the coast.

The Gippsland beach and surf zone sand range from fine to medium sand (mean = 0.41 mm), with local occurrences of coarse sand, particularly along parts of Ninety Mile Beach and in the southern Wilsons Promontory (PC:VIC01.03). All are quartz-rich with carbonate averaging 5.6% (σ = 4%) (Table 20.2; Fig. 20.2). Beaman (2005) reported that quartz sand extends out across the flat Gippsland-Bass Strait shelf to 110 m depth and around granite highs, with wave ripples extending to 65 m depth. Ferland and Roy (1997) found the quartz relatively mature, sub-rounded and with high iron-staining suggesting reworking during successive sea-level fluctuations. The sand is delivered to the shelf during low sea level by the numerous rivers and streams and reworked onshore across the shallow shelf during and following the PMT and then reworked longshore.

The Gippsland coast is predominately sandy with the 106 beaches occupying 324 km (72%) of the shore. The persistent moderate to occasionally high westerly waves and fine to medium sand maintain a predominately rip-dominated single to

Table 20.2 PC:VIC01 sand size and % carbonate

n	153
Size (mm)	0.41
σ (mm)	0.24
Sorting	0.53
% carbonate	5.6
σ (%)	4.0
% range	0–21

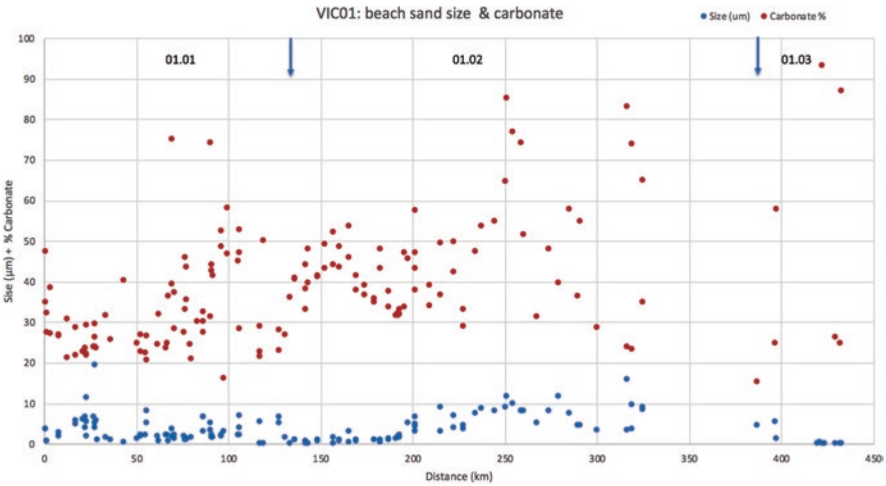

Fig. 20.2 Gippsland region (PC:VIC01) beach sand size and carbonate. Arrows indicated SC boundaries. Distance in km from NSW/VIC border at Cape Howe

Table 20.3 Gippsland region (VIC01) beach types and states

BS	BS	No.	%	Total km	% (km)	mean (km)	σ (km)
3	RBB	26	24.3	174.5	49.5	6.5	18
4	TBR	38.0	35.5	92.1	26.1	2.4	3.5
5	LTT	22.0	20.6	61.1	17.3	2.8	6
6	R	21	19.6	24.7	7.0	1.2	3
		107	100	352.4	100	3.3	–

double bar system. WD TBR and RBB occupy 327 km (73% of the beach length), with R and LTT the remaining 120 km (27%) (Table 20.3). Ninety Mile Beach has a double bar TBR-RBB along most of its northern and central section, dropping to a single bar LTT along the more sheltered southern 40 km, south from Seaspray. Likewise, all of the 21 eastern Wilsons Promontory beaches (PC:VIC01.03) are sheltered, a number with coarse sand derived from the local granite, and all are R to LTT. Short (1996) provides a description of each of the 107 beaches in this region.

20.5 Sand Transport

The Gippsland region sits across a major sedimentary basin and owing to its wave climate and orientation has a major longshore transport system. Ninety Mile Beach and parts of the eastern Croajingolong coast (PC:VIC01.01-02) have predominately drift-aligned beaches, with wind and waves arriving at an angle from the southwest. This combined with the energetic in places double-bar surf zone provides an ideal system for northeast to east longshore sand transport towards Cape Howe. Transport rates are expected to be negligible along the rocky and embayed Wilsons Promontory coast, with tidal currents more than waves dominating transport through the Corner Inlet inlets and extensive tidal deltas. On Ninety Mile Beach, transport is predominately wave driven with low rates in the low energy south gradually increasing up the beach as wave height increases and orientation swings more to the east. It would be expected to increase from the order of 10,000 s in the south to perhaps 100,000 m^3 $year^{-1}$ in the east, though it also becomes increasingly interrupted by headlands. However, the presence of the large transgressive Mallacoota-Cape Howe dunes systems and the large SSB's off Gabo Island (Ferland and Roy 1997) and Cape Howe-Disaster Bay (Hudson 1991) attests to the northern regional boundary being a major sediment sink for this transport system.

The trend in sand texture (Fig. 20.2) also supports a northeast to east transport with overall downdrift fining. Along Ninety Mile Beach, the sand is generally medium, the coarser outliners due to reworked inlet material (Thom et al. 1986). The sand fines northwards and becomes more uniform fine to medium east from Point Hicks (80 km), all with low carbonate, a trend which continues into NSW (Fig. 19.2).

20.6 Barriers

The Gippsland coast is a sedimentary basin, with a wide shallow shelf, an abundance of sand and a predominately sandy shore. However, while there are barriers of the length of the coast, they do not reflect the volumes of sand available on the shelf nor that which has passed through the system. This is owing to a number of factors. Much of the Gippsland Lakes accommodation space has been occupied by at least two inner Pleistocene barriers; there is likewise little accommodation space along the rocky sections of coast with only small inlets and usually closed barrier lagoons; the dominant wind blows longshore with little opportunity to develop large transgressive dunes until the end of the system at Mallacoota-Cape Howe; and the now dammed Snowy River is delivering a diminished supply of sand to the coast. This coast is where the sediment is in transit rather than being accommodated.

There are however 44 barrier systems along the coast with a total volume of 4436 M m^3 (129,320 m^3 m^{-1}) (Table 20.4). They are dominated by two large systems, the terminal Mallacoota-Cape Howe transgressive dunes (2000 M m^3, 105,263 m^3 m^{-1}) and the long Ninety Mile Beach (660 M m^3, 5569 m^3 m^{-1}), which combined contain 60% of the barrier volume. The beaches and barriers are discussed in more detail in the flowing sections on the Gippsland PCs and SCs.

20.7 PC:VIC01 Cape Howe to Cape Conran

The eastern Gippsland PC:VIC01 commences at the State border at Cape Howe and trends roughly southwest for 60 km to Rame Head and then 73 km west to Cape Conran. It incorporates a rugged section of coast where the sloping predominately

Table 20.4 Gippsland region PC:VIC01.01-01.03 and regional barrier dimensions

VIC01-03	VIC01.01	VIC01.02	VIC01.03	VIC01
No.	25	9	6	44
Total length (km)	100.5	208.5	34	343
Mean min width	60	120	120	–
Mean max width	640	760	1400	–
Mean height (m)	4	12	5	–
Area (ha)	24,852	8070	5420	38,342
Unstable (ha)	15,227	130	270	15,630
Total volume (M m^3)	2766	1070	600	4436
Unit volume (m^3 m^{-1})	27,657	45,131	2735	12,932

granite and some metasedimentary rock reach the coast forming numerous usually small headland and rocky sections, which are drained by several small rivers and streams which flow into the 17 barrier estuaries and lagoons along the shore, most of which are intermittently open and closed (McSweeney et al. 2017) . The PC contains two SCs.

20.7.1 SC:VIC01.01.01 Cape Howe-Rame Head

SC:VIC01.01.01 is located at the end of the Gippsland sand transport system. It commences at Cape Howe where the coast turns and trends southwest for 60 km to the prominent Rame Head (Fig. 20.3). In between are 42 beaches composed of fine to medium quartz-rich sand, which occupy 40 km (68%) of the shore, with an average length of 0.95 km. The SC can be divided into two sections, the eastern Mallacoota-Cape Howe barrier system containing 25 km of near continuous sandy beaches occupying 90% of the shore down to Seacave Beach (VIC 12) all contained in four curving sandy embayments. To the west of Seacave is a rock-dominated section down to Cape Conran with 30 shorter beaches (mean = 0.4 km) occupying 37% of the shore with rocks forming the remainder. All the beaches are well exposed and most are TBR-RBB, together with numerous topographic rips flowing out against the rocks and headlands.

The Mallacoota-Cape Howe barrier extends across the drowned Genoa River valley forming the Mallacoota barrier estuary, while to the east, it has also dammed the freshwater Lake Barracoota. The continuous strip of sand is divided into four curving beaches by three cuspate forelands formed in lee of Tullaberga and Gabo Islands and Iron Prince Rocks near Cape Howe. The western side of the Gabo Island foreland faces south allowing the southwest wind to develop massive transgressive transverse dunes up to 60 km high that extend up and over the Devonian granite for 8 km to Cape Howe (Fig. 20.4a), which they overpass and deliver sand into NSW. At present, approximately half the dunes are bare of sand and active, with Rosengren (1978) finding they were migrating eastward at up to 13 m year^{-1}.

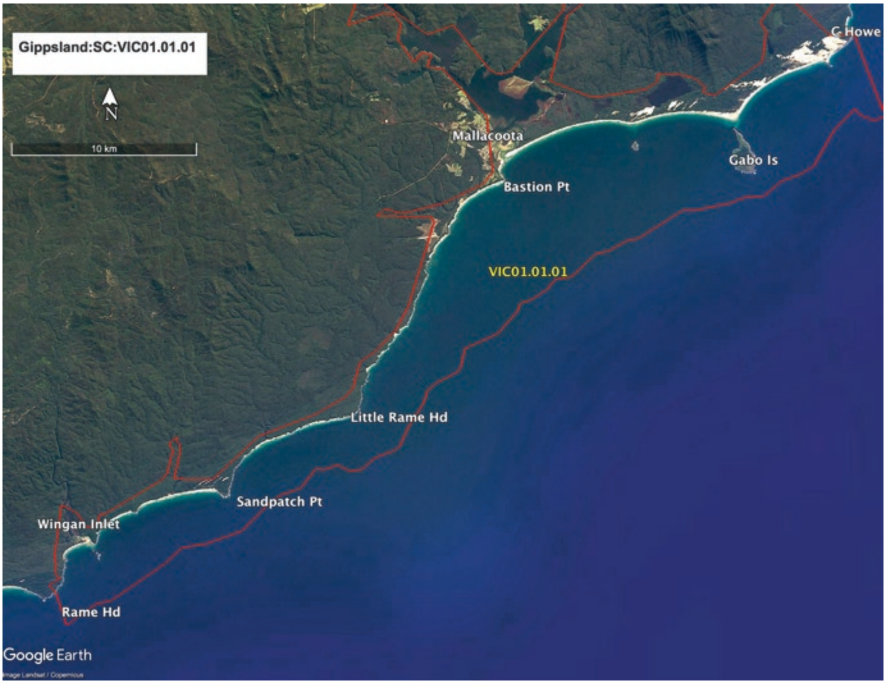

Fig. 20.3 SC:VIC01.01.01 Cape Howe to Rame Head. (Source: Google Earth)

Mallacoota Inlet is the largest estuary in the PC and has a very dynamic inlet which is usually open to the sea and a 3 km^2 flood tide delta and ~40 km^2 lake feed by the Genoa and Wallagaraugh rivers. The estuaries hydrology and sediments were investigated by Reinson (1977) who also found remains of an inner Pleistocene barrier.

Bastion Point marks the beginning of the rock-dominated section of the SC and also the location of the only structure on the coast, a rather contentious groyne and breakwater. From here, the coast trends southwest for 6 km as a series of eight near continuous beaches to Seacave beach (Fig. 20.4b) and the beginning of Croajingolong National Park and a 10 km long predominately rocky shore down to Little Rame Head. The next 20 km of coast trends to the west-southwest and contains three rock-controlled embayments each containing a series of small beaches separated by rocky shore, together with a small barrier lagoons/estuaries fed by the small Benedore, Red and Wingan (Fig. 20.4c) rivers, respectively. The beaches to the east of the Benedore and Red rivers have in the past supplied sand to shore oblique transgressive dunes that have trended west and overpassed Sandpatch Point and Little Rame Head. The Rame Head dunes are now well vegetated and stable, while the Sandpatch dunes, as the name implies, contain four active longwalled parabolics (Fig. 20.4d).

Fig. 20.4 PC:VIC01.01 coast (**a**) Iron Prince Rock and the Cape Howe transgressive dunes (VIC 1-3); (**b**) the bedrock controlled Seacave-Quarry beaches (VIC 10-12); (**c**) Wingan Inlet (VIC 42) with scarped dunes that have overpassed Rame Head to left; (**d**) parabolic dunes just west of Point Hicks (VIC 61) and (**e**) the blocked mouth of Bemm River Inlet (VIC 66-67). (Photos: AD Short)

20.7.2 SC:VIC01.01.02 Rame Head-Cape Conran

SC:VIC10.10.02 commences at Rame Head and trends essentially due west (268°) to Cape Conran (Fig. 20.5), a distance of 73 km, with the coast divided into a series of long generally sandy embayments by Petrel Point, Point Hicks, Pearl Point and Cape Conran. The 29 beaches occupy 59.5 km (81.5%) of the shore, the remained a mix of jagged steeply dipping Ordovician mudstone and rounded Devonian granite.

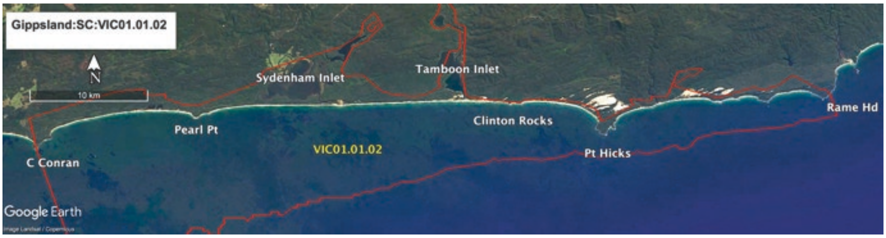

Fig. 20.5 SC:VIC01.01.02 Rame Head to Cape Conran. (Source: Google Earth)

The beaches are generally well exposed to the southwest waves and are predominately TBR-RBB, with the longer more exposed beaches having a RBB-LBT outer bar. They are composed of quartz-rich sand that is fine in the east coarsening in places to the west (Fig. 20.2).

The SCs relatively straight WD beaches have blocked four small river mouths – the Mueller, Thurra, Cann and Bemm (Fig. 20.4e) – which have formed the Mueller, Thurra, Tamboon and Sydenham estuarine lagoons, respectively, all ICOL's with usually blocked mouths. Each of the inlets is deflected to the east by the southwesterly waves, which are expected to be driving easterly longshore transport on the order of 100,000 $m^3\ m^{-1}$, and which is also expected to bypass the smaller headlands and rocky sections and possibly, with the assistance of megarips, the larger Cape Conran, Point Hicks and Rame Head. In addition to the longshore transport, there are transgressive dunes (all longwalled parabolics) in lee of the eastern most southwest-facing sections of the longer beaches. These dunes have overpassed Rame Head (now stable) to supply Wigan beach; they are active in lee of Petrel Point and are actively overpassing Point Hick to supply sand to the sand-choked Thurra River which delivers it straight back to the coast.

20.7.3 PC Overview

This is an exposed, dynamic moderate to high energy PC which is experiencing longshore sand transport, headland overpassing, both stable and active, and undoubtedly considerable headland bypassing of the many small and possibly some of the larger headlands, at least as far as Little Rame Head. At this point, the coast trends to the northeast sheltering the next rocky section from the full force of the waves and probably interrupting the sand transport, which would resume again along the western Mallacoota beaches. Sand has been lost into the several small tidal inlets and the larger transgressive dunes and possibly offshore during storm events. However, considerable sand has been transported to and beyond Cape Howe supplying the large Mallacoota-Cape Howe barrier (2000 M m^3) and large SBB's located off Gabo Island and extending north from Cape Howe, the final high stand sink for the Gippsland sand transport system. The onshore barrier deposits total

2766 M m^3, which represents 27,657 m^3 m^{-1}. The presence of Pleistocene barrier deposits including cemented humate soils (coffee rock) at Clinton Rocks, Tamboon Inlet, Dock Creek and Cape Conran and Pleistocene dune calcarenite on Point Hicks (Bird 1993) indicates that sand has been moving along this coast at past sea level-high stands. The Pleistocene deposits run continuously between Rame Head and Ewings Marsh and lie behind Point Hicks and Cape Conran where they extend up to 3 km inland. It is likely longshore transport was more active during and soon after the PMT and has slowed since, as indicated by the many small receded beaches and well-vegetated headland (overpass) dunes.

20.8 PC:VIC01.02 Ninety Mile Beach: Cape Conran to Corner Inlet

This PC spans the Gippsland Basin coast and, apart from the grantic boulders at Point Ricardo and Tertiary marine sediments at Red Bluff, is an entirely sedimentary shoreline with the 16 generally long beaches, occupying 232 km (94%) of the shore, including a continuous 125 km long section of Ninety Mile Beach between Lakes Entrance and Shoal Inlet. It includes the Gippsland Lakes and its associated estuarine systems, one of the largest in Australia with an area of 350 km^2. The lakes consist of three large interconnected lakes (Wellington, Victoria and King), together with a coastal lagoon (Lake Reeve) and several inner Pleistocene barrier remnants (including Banksia Peninsula, Raymond Island, Sperm Whale Head) and the outer Ninety Mile Beach Holocene barrier. The lakes were a barrier lagoon until a permanent opening to the sea was constructed at Lakes Entrance in 1889 which increased the tidal prism, tide range and salinity within the lakes. The lakes have been described by several authors with Bird (1993) providing a general overview.

Oliver et al. (2018) found that the inner barrier (Sperm Whale Head) was deposited ~125–108 ka when sea level was within −2 to +3 m of present sea level. It was reworked by westerly glacial winds between 23 and 18 ka, during a period of enhanced regional aridity. The winds generated more than 30 east-trending parabolic dunes disturbing the linear foredune ridges, with an estimated 160 M m^3 of sand eroded from the ridges and redistributed as transgressive dunes. These dunes were misinterpreted by Bryant and Price (1997) who suggested they were wave-deposited barriers formed when sea level was substantially lower, invoking tectonic uplift or a massive tsunami to explain their presence.

Thom (1984) and Thom et al. (1986) provide a depositional sequence for the Holocene outer barrier commencing ~7 ka when the transgressive barrier reached close to its present position as a series of inlet-separated barrier islands. Thom (1984) found a paleo-inlet existed in the vicinity of Ocean Grange to ~4 ka, the inlet marked by the presence of an abandoned flood tide delta and coarse (tidal) sediments on the beach, which are indicated by the coarsening on Fig. 20.2 around 250–260 km (Paradise-Golden Beach), with another possible inlet around 320 km (Reeves Beach). This was followed by barrier aggradation and closure of most of the inlets, together with some local seaward progradation including 0.5 km barrier regression between Paradise Beach and Stockyard Hill. The 1 km wide Boole Poole Peninsula to the north of the former inlet is part of a regressive Holocene barrier, separated from the present beach by the former inlet called Bunga Arm which was linked to a major tidal inlet at Ocean Grange until at least 2 ka. When the inlet closed it resulted in a decrease in salinity and a change from salt to freshwater ecology in the lakes. Following the closure, a barrier spit extended east to Eastern Beach enclosing Bunga and Cunningham arms. Thom et al. concluded the Gippsland barriers are composed of sand reworked from inner shelf sand bodies; that sand is being transported to the northeast to the long-term sink at Cape Howe; and that a transport imbalance could be the cause of persistent shoreline recession south of Honeysuckle with general shoreline stability elsewhere.

The entire Ninety Mile Beach is exposed to the prevailing westerly winds and waves, with wave energy increasing eastwards along the beach as fetch increases. Tides average 1 m along most of the beach, increasing in Corner Inlet to 2.4 m. The PC is divided into three SCs, the eastern extending to Red Bluff, then the long Ninety Mile Beach and finally the barrier islands and inlets of Corner Inlet.

20.8.1 SC:VIC01.02.01 Cape Conran-Red Bluff

SC:VIC01.02.01 trends essentially due west from Cape Conran for 60 km to Red Bluff, and except for the cape, a few rocks at Point Ricardo and the small 20 m high Red Bluff, it is a continuous sandy shore with the five long beaches occupying 59 km (88.5%) of the shore (Fig. 20.6). The only drainage to the coast is the Snowy River and the usually blocked Lake Tyres and small Lake Bunga. The Snowy delivers fluvial sand to the coast during floods as confirmed by McLennan (1976). However, since the 1960s, its headwaters have been managed, and its water diverted and presumably sand supply has decreased. The Snowy River mouth (Fig. 20.7a) can be deflected up to 6 km to the east by the prevailing southwest waves. It breakouts to the west during major floods, leaving an elongated lagoon in lee of the unstable barrier. The western Lake Tyres and Lake Bunga are coastal lagoons (ICOL) and usually closed.

Fig. 20.6 SC:VIC01.02.01 Cape Conran to Red Bluff. (Source: Google Earth)

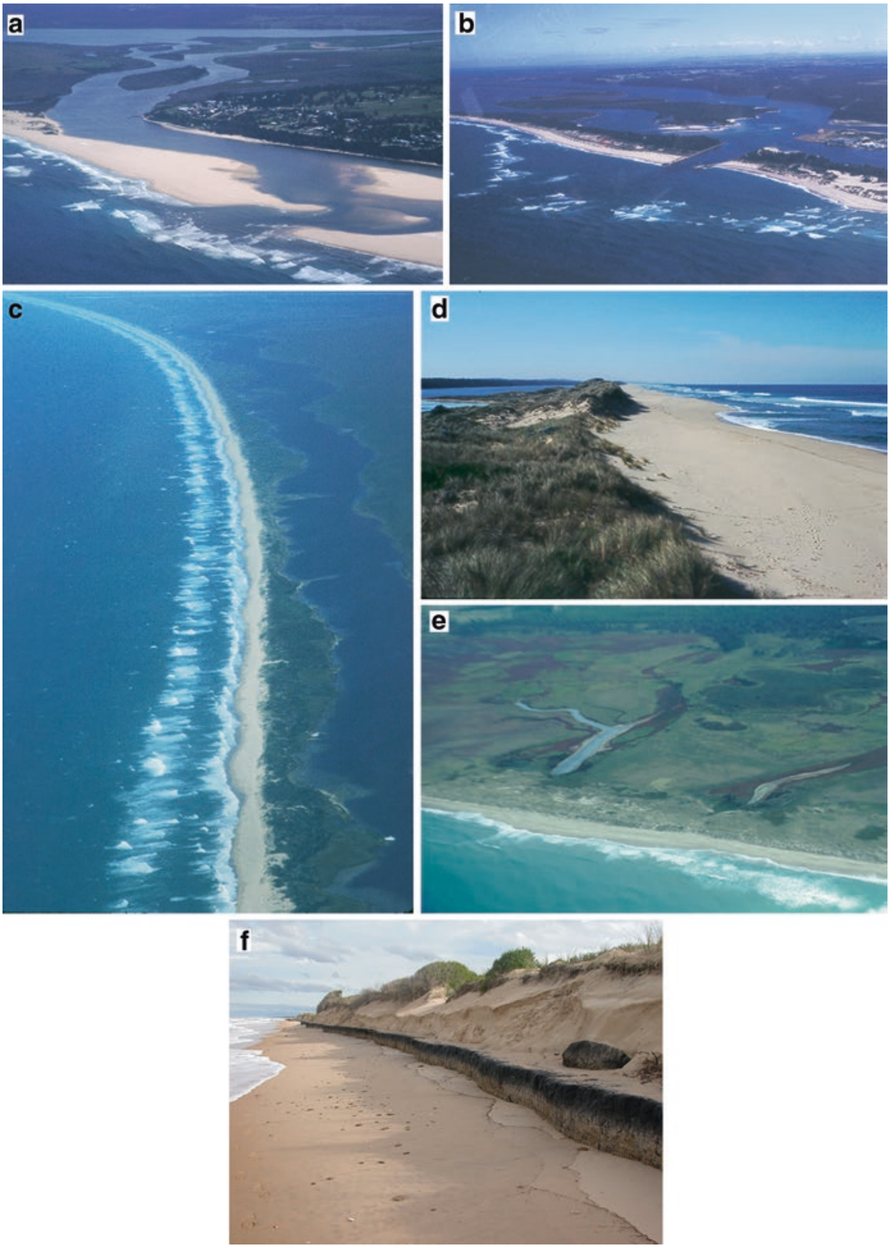

Fig. 20.7 (**a**) the deflected mouth of the Snowy River and the small town of Marlo (VIC 74-75a); (**b**) Lake Entrance training walls and ebb tide delta (VIC 77-78a); (**c**) the Bunga Arm section of the long Ninety Mile Beach and barrier (VIC 78d); (**d**) the narrow receding foredune at Bunga Arm (VIC 78d); (**e**) truncated Denison Creek just south of Seaspray (VIC 78q) and (**f**) exposed lagoonal peats at McGauran Beach (VIC 78r). (Photos: AD Short)

All the beaches are all well exposed and maintain rip-dominated TBR-RBB inner bar and outer LBT. As the prevailing southwest waves arrive at an acute angle to the south-facing shore, they generate longshore transport expected to be on the order of 100,000 m^3 $year^{-1}$ or more. The sand readily bypasses the sandy Point Ricardo, a cuspate foreland, while a megarip forms against Cape Conran which may assist bypassing of the cape. In the past dunes have overpassed the cape, but these are now stable and well vegetated. The beaches are backed by continuous relatively narrow (100–200 m), 20–30 m high aggraded barrier, which increases in width (>1 km) in lee of the headlands which the dunes overpass. The high foredune becomes increasingly unstable towards the eastern end of the beaches as they align more towards the westerly wind, with numerous small blowouts forming, particularly along the narrow Ewings March barrier, where some are migrating over the backing marsh deposits. The barriers have a total volume of 250 M m^3, which represents a per metre volume of 4460 m^3 m^{-1}.

20.8.2 SC:VIC01.02.02 Ninety Mile Beach: Red Bluff-Shoal Inlet

SC:VIC01.02.02 contains Ninety Mile Beach, one of Australia's three longest beaches. It extends continuously for 145 km from the small protruding Red Bluff to Shoal Inlet (Fig. 20.8) and in doing so curves to the west-southwest then southwest to Bunga Arm then due southwest for 100 km to Shoal Inlet. The beach is exposed to persistent moderate southwest to southerly waves that increase in height to the east as fetch increases. Along the more exposed section north from Seaspray, the waves maintain a double-bar system dominated by TBR-RBB, while south from Seaspray as waves decrease a single-bar LTT extends to Shoal Inlet. The entire beach is backed by a stable to receding foredune with no dune transgression owing to the obliquity of the prevailing wind that blow along, rather than onshore.

Wright et al. (1982) investigated the morphodynamics of Ninety Mile Beach at Eastern Beach where a double bar system with a 3 m deep trough separates the dynamic inner and outer bars. They found that fine to medium nearshore sand extended out to 15 m depth at which point there was a marked break in slope from ~3° to <1° and a change to coarse (0.6–0.8 mm) outer nearshore sand which included cobbles and whole shells. In the surf zone, they recorded average easterly longshore currents at 0.5 m s^{-1}, and during their 2-week field experiment, the bar and rip systems migrated 150 m to the east, indicative of the strong easterly currents. They also found that easterly tidal currents dominated and made a substantial secondary contribution to longshore sediment transport. These finding not only verify the strong wave-driven easterly sand transport and but also the fact the transport is assisted by the tidal currents.

Sand transport is continuous the length of the beach, with the only interruption at Lake Entrance (Fig. 20.7b) where sand moves in through the entrance to the flood tide delta (FTD) as well as bypassing the training walls. The entrance was opened

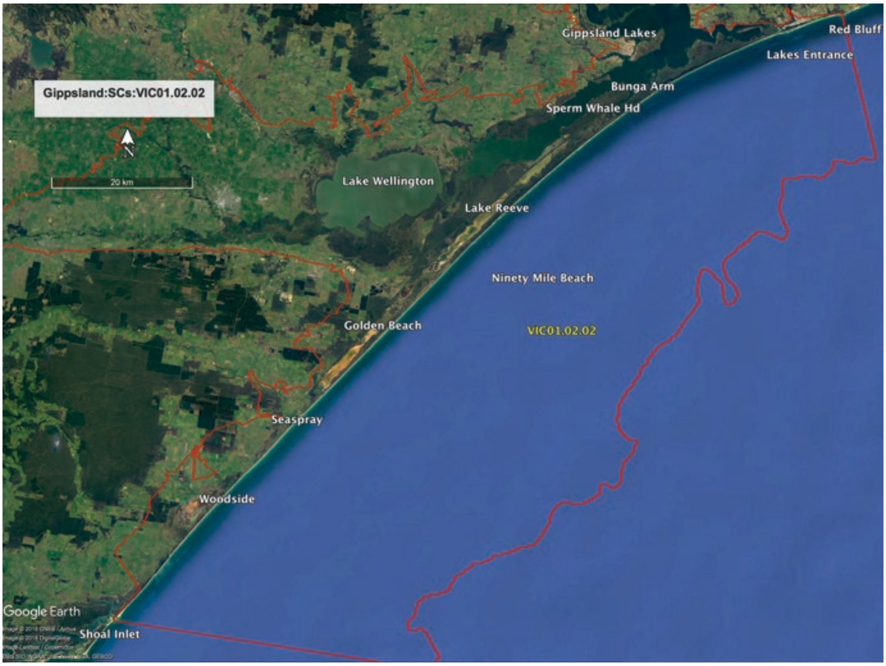

Fig. 20.8 SC:VIC01.02.02 Ninety Mile Beach between Red Bluff and Shoal Inlet. (Source: Google Earth)

and trained in 1889 following which a FTD developed which hindered navigation. Wheeler et al. (2010) examined the evolution of the FTD between 1889 and 2009 and found that it grew as runoff into the lakes decreased due to damming resulting in a shoaler entrance and need for maintenance dredging (Jefferey et al. 2009). Wheeler et al. found that with rainfall predicted to decrease and longshore transport to increase more sand will accumulate on the FTD. At present, the entrance requires continuous dredging to maintain a navigable entrance, with on the order of 200,000–300,000 m^3 year^{-1} relocated annually. A sand slurry bypass system has been trialled pumping about 100,000 m^3 year^{-1} but has not as yet been installed permanently. These figures suggest the longshore transport rate may be of the same order of magnitudes, i.e. >100,000 m^3 year^{-1}, with reported estimates of net easterly longshore transport rates at Lake Entrance ranging from zero to 500,000 m^3 year^{-1} (Wheeler et al. 2010).

The beach is backed by a continuous narrow barrier that is only breached by the Lakes Entrance inlet and training walls. It ranges however from a 500 m wide regressive barrier around Golden Beach to a narrow 10–20 m high stable foredune along most of the northern-central section to a very narrow (<50 m) wide scarped receding foredune (Fig. 20.7c, d) in the south. In some places, it is eroding into lagoonal peats (e.g. McGauran beach; Fig. 20.7f) and truncating streams (e.g. south Seaspray; Fig. 20.7e). The long barrier has a relatively small volume of 660 M m^3 (5570 m^3 m^{-1}).

20.8.3 SC:VIC01.02.03 Corner Inlet

The southern SC includes the barrier islands, inlets and tidal deltas of Corner Inlet (Fig. 20.9), a 600 km^2 TD system that has acted as a major Pleistocene and Holocene sediment sink and has the best developed barrier islands in Australia. It contains an inner mainland Pleistocene barrier that extends for 45 km from the western Barry Beach to St Margaret Island (Bird 1993). This barrier is dissected by TD tributary estuaries linked to several small streams entering its northern shore, the largest the Franklin. The entire inlet is drained by a network of large tidal channels with extensive mud and sand flats which are exposed at low tide. Around the shore are high tide salt marshes and intertidal mangroves (*Avicennia marina*), and the mangroves are the southernmost in Australia and most poleward in the world (38.9°S). Much of the sediment appears to have come from the shelf and in situ, with little fluvial supply. In the southwest corner, transgressive dunes from Waratah Bay have overpassed the 8 km wide Yanakie isthmus and prograded up to 1.5 km across the flats and into the inlet.

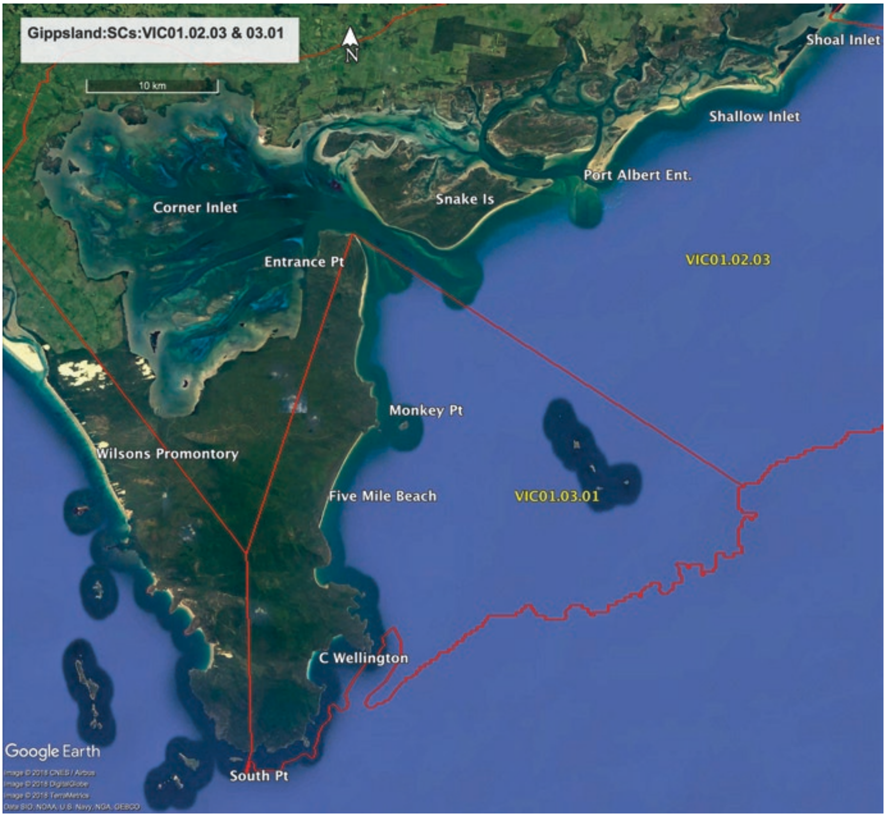

Fig. 20.9 SCs VIC01.02.03 and 01.03.01: Corner Inlet and eastern Wilsons Promontory. (Source: Google Earth)

The outer shoreline extends for 50 km from Shoal Inlet to Entrance Point. In between are five low barrier islands, including the large regressive Snake Island, separated by five dynamic tidal inlets. This is one of the more unusually SCs on the Australian coast, as within a matter of a few kilometre the WD Ninety Mile Beach, with just one narrow managed inlet for its entire 125 km, switches to a TM coast with five large inlets along the next 40 km of shore. The reason of this is twofold. First, wave height continues to decrease to <0.5 m as fetch decreases, with the winds south of Entrance Point blowing offshore, and second is the increase in tide range to 2.4 m, resulting in an RTR of ~5 and switch to a TM coast.

The coast is entire sedimentary with nine beaches occupying 46.8 km (94%) of the shore, the remainder the open water of the tidal inlets. The beaches reflect the decrease in wave height with dynamic LTT beaches in the east, switching to storm-generated LBT to the west, which remain inactive during the intervening calmer periods. Further west as waves continue to decrease, the TM R + LTT prevails. On Snake Island, the southern beach suddenly switches from TM R + LTT to TD B + RSF as it enters Corner Inlet and wave height drops.

The five barrier islands are arranged in two compartments, controlled by protruding ebb tide deltas. In the east is a curving 15 km wide embayment bordered by Shoal Inlet, Shallow Inlet (Fig. 20.10a) and Port Albert Entrance, with one barrier island extending east of Shoal Inlet and two barrier islands forming the embayment. Between the Port Albert Entrance and Entrance Point is the Snake Island a low (<10 m), 30 km^2 barrier composed of an 8 km wide series of regressive spits, beach ridges and foredunes, with the spits oriented to the east indicating the direction of sand transport. The island has a subaerial volume of 175 M m^3, with all the islands totalling 226 M m^3 (6650 m^3 m^{-1}). However, the massive ebb and flood tide deltas are expected to hold a similar volume of sediment. The barrier islands have low, in places unstable or no foredune and are prone to overwashing, with overwash flats extending 2.5 km across Clomel Island (Fig. 20.10b). This is a very dynamic system, with low waves but strong tidal flows, and prone to storm surges and overwashing, with all the island bordered by dynamic and migratory tidal inlets with deep migratory channels. However, none of the islands are inhabited, and there is no property at risk.

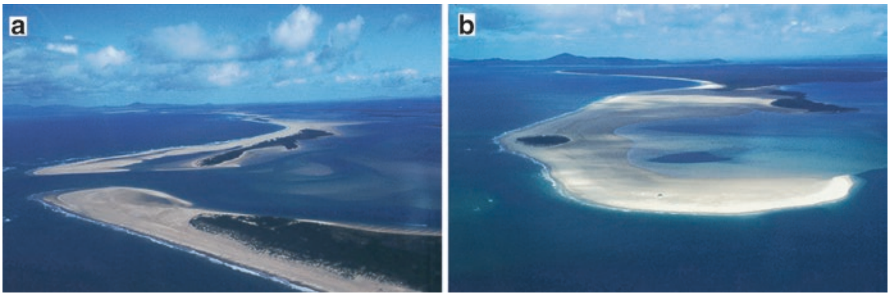

Fig. 20.10 (**a**) the protruding Shallow Inlet (VIC 79-80) and (**b**) overwash flats on Clonmel Banks (VIC 81). (Photos: AD Short)

20.8.4 PC Overview

This PC has an entirely sandy shore separated in the south by some tidal inlets. It commences in the south at Corner Inlet a TD sediment sink consisting of dynamic barrier islands and massive tidal deltas where on the order of 500 M m^3 of sand has accumulated, no doubt derived from the adjacent Bass Strait shelf. Wave energy increases to the east, and by Shoal Inlet, it is sufficient to develop the 125 km long WD Ninety Mile Beach, a long, narrow barrier receding in the south, stable in the centre-north, and acting as a conduit for northeasterly sands transport throughout, with little onshore deposition (5500 m^3 m^{-1}). At the northern end of the beach (Red Bluff-Ewings March), the coast begins to curve to the east exposing the shore to onshore southwest winds which begin developing an unstable foredune and numerous small blowouts. Further east at Cape Conran, Point Hicks and Rame Head, the dunes become more substantial longwalled parabolics and at Point Hicks are actively overpassing the headland. Finally, between Mallacoota and Cape Howe, a massive transgressive dune system with both longwalled parabolics and transverse dunes up to 60 m high extends for 25 km east to Cape Howe where sand is being overpassed into NSW. The subaerial transition in barrier and dune type are paraleled by the longshore sand transport which is eroding the southern end of Ninety Mile Beach, transiting through the central-northern section and along the south-facing Red Bluff to Rame Head, overpassing and very likely bypassing the headlands. The ultimate sink for this sand is the Cape Howe barrier and the SSB's off Gabo Island and extending north from Cape Howe.

This is a very dynamic coast due to the strong westerly winds and waves which drive the aeolian and longshore sand transport. Owing to an imbalance in transport, the southern 100 km of Ninety Mile Beach is receding to make up the balance. Further east, the beaches are either stable or impacted by dune activity, with no areas of contemporary progradation. This situation will worsen into the future, as more sand is needed to feed the predicted increase in longshore transport. It is likely more of Ninety Mile Beach will begin to erode, the foredune will narrow and in places disappear, and overwashing and inundation of the back barrier will increase. This will all be exacerbated by rising sea level which will raise both sea level and the lake level, leading to increased flooding of the low-lying backbarrier and interbarrier areas and the entire lake system. Fortuitously, there is little development on the open coast, with only the Seaspray surf club presently at risk. The greatest impact will be to the several coastal strip communities located at present behind protecting foredune, which will become increasingly exposed as the foredune retreats, and in particular, the already flood and inundation-prone areas of the lake system including parts of Lakes Entrance and Lochsport become more prone to inundation and flooding. In Corner Inlet, the barrier islands are already prone to overwashing, erosion and migration in association with the tidal inlets. This will also be exacerbated by rising sea level which will increase the tidal prism generating larger more dynamic inlets which in turn will rework the adjacent barrier islands, as well as leading to higher storm surges and more frequent overwashing and inundation.

20.9 PC:VIC01.03 Eastern Wilsons Promontory (SC:VIC01.03.01)

The southernmost PC extends south along the eastern side of Wilsons Promontory for 68 km between Entrance Point and South Point, the southern tip of the Australian continent (Fig. 20.9). It contains one SC (VIC01.03.01). The entire coast is located within Wilsons Promontory National Park and is dominated by sloping granite bedrock (Fig. 20.11a) which rises to 700 m inland and is densely forested. This is a low-wave energy ($H_b < 0.5$ m), lee coast with the prevailing southwesterly winds blowing offshore. Tide range is 2.4 m inside Entrance Point and 2 m at South Point.

The coast contains 19 generally embayed beaches (Fig. 20.11a) which total 27 km in length, occupying 40% of the shore; the remainder are rounded granite slopes (Fig. 29.11b) and boulders. The beaches are composed of quartz-rich sand (1.5% carbonate), which ranges in size from fine in the north to coarse and very coarse sand in the sheltered Refuge Cove. The beach states range from R in the sheltered bays particular where the sand is coarse to LTT on the more exposed longer northern beaches, with rips forming on the l8 km long Five Mile beach and southern Waterloo Bay beaches during periods of higher waves.

The southern beaches from Sealers Cove to Home Cove are all deeply embayed and are expected to be closed TCs with no sand transport out of the embayments. The longer Five Mile Beach is expected to experience some north transport, with two creek mouths deflected to the north, the northern Miranda Creek by 2.5 km. Sand is moving along the northern Three Mile-Hunter and Entrance Point beaches and bypassing Whale Rock. This is driven by both the north trending waves and flood tidal currents which from Whale Rock maintain large shore transverse sand waves with a wave length of 0.5 km, which grade into the deep 4 km wide tidal channel that extends for 8 km along the northern shore of Entrance Point beach (VIC 86-88). The sink for this sand is both Corner Inlet and the Entrance Point barrier.

There are five barriers along this SC starting with the large Entrance Point regressive plain in the north which has a subaerial volume of 38 M m^3 (6820 m^3 m^{-1}). Its

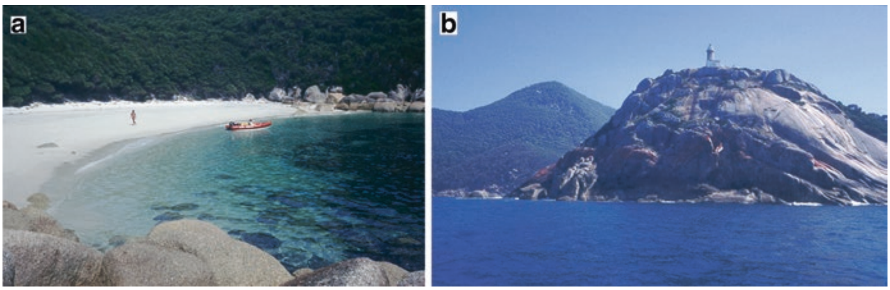

Fig. 20.11 (**a**) the deeply embayed beach in Refuge Cove (VIC 99) and (**b**) South East Point the massive granitic headland forming the southern tip of the Australian continent. (Photos: AD Short)

2.5 km wide plain contains up to 50 low beach-foredune ridges, the innermost of which may be Pleistocene, and the outmost appears to be continuing to prograde (Bird 1993). The alignment of the ridges has changed over time in response to the changing orientation and location of the tidal channel. Further south is the Five Mile Beach barrier, a 100–200 m wide, 8 km long-stable barrier with a volume of 13.5 M m^3 (1700 m^3 m^{-1}) that may be backed by an inner Pleistocene barrier. The other smaller barriers (Mount Hunter, Sealers Cove, Waterloo Bay) have regressed slightly and now appear to the stable. The total PC barrier volume is 80 M m^3 (2950 m^3 $year^{-1}$).

20.9.1 PC Overview

PC:VIC01.03 is contained entirely within Wilsons Promontory National Park, with the only development on the coast being walking trails and a few camping areas; otherwise, it is completely undeveloped and likely to remain that way. The beaches are generally stable with the wide Entrance Point barrier responding to changes in the Prince Albert Entrance. Rising sea level will increase the tidal prism of Corner Inlet and thereby reactivate its already dynamic inlets generating more changes in the inlets and adjacent shoreline including Entrance Point.

20.10 Regional Overview

The Gippsland region is an exposed and highly dynamic coast. In the east, sand is moving along the Croajingolong coast bypassing and overpassing the headlands to ultimately feed the Cape Howe dune systems which overpasses into NSW and the large SSB's that extend north from at least Gabo Island. The long Ninety Mile Beach is experiencing substantial easterly longshore transport from at least Seaspray, with the Seaspray beach receding into lagoonal peats. This transport is predicted to increase which will place stress on the entire system. Further south Corner Inlet has low, overwashed TM barrier islands separated by large dynamic tidal deltas, all of which are very vulnerable to existing storm surge and inundation and will become increasingly vulnerable with rising sea level and potential changes tide regimes. Only the southern Wilsons Promontory shore all located in a national park and dominated by granite is at low risk.

O'Grady et al. (2015) concluded as a consequence of the southward shifting subtropical ridge (STR) predicted in global climate change models, that the northern end of Ninety Mile Beach may experience noticeable changes in longshore wind, wave and ocean currents. In summer months, the southern shift in the STR should result in both increased summer westward wind-driven currents and westward wave forcing. During winter months, the contraction and increased intensity of the westerly storm belt linked to Southern Annular Mode (SAM) could possibly influence the transport. The overall impact should be an increase in easterly longshore sand transport, which will have significant impacts of the entire beach system, a conclusion also reached by Charteris et al. (2009). Rainfall is also predicted to decrease which Wheeler et al. (2010) concluded will lead to further growth of the Lake Entrance FTD, also assisted by the increased longshore transport and rising sea level, meaning more sand will be lost from the beach system into the FTD.

This is a vulnerable coastal system which with predicted rises in sea level and changing wind and wave climate will be most vulnerable along Ninety Mile Beach, particularly towards the south which can expect increase recession, dune breaching and overwashing, while overall rise in sea and lake level will increase flooding and inundation in the lakes. The undeveloped Corner Inlet barrier islands and inlet are also extremely vulnerable to changes sea level and tide regimes.

References

Beaman RJ (2005) A GIS study of Australia's marine benthic habitats. Ph.D. thesis, School Biogeography Environmental Studies, University of Tasmania

Bird ECF (1993) The coast of Victoria. Melbourne University Press, Melbourne, 324 p

Bryant EA, Price DM (1997) Late Pleistocene marine chronology of the Gippsland Lakes region, Australia. Phys Geogr 18:318–334

Charteris A, Sjerp E, McCowan A, Lawry E, Malcolm D (2009) Geomorphological threats of climate change on the Gippsland coast. In: Coasts and Ports, Wellington, New Zealand

Ferland MA, Roy PS (1997) Southeastern Australia: a sea-level dependent, cool-water carbonate margin. In: James NP, Clarke JDA (eds) Cool-water Carbonates. Society for Sedimenary Geology, Tulsa, pp 37–53

Hudson JP (1991) Late Quaternary evolution of twofold Bay, southern New South Wales. MSc thesis, Department of Geography, University of Sydney, Sydney, 210 p

Jeffrey M, Masters C, Fulland A (2009) Lakes entrance sand management program overview. In: Coast Ports 2009, Wellington, New Zealand, pp 450–456

McLennan R (1976) Geomorphology of the Snowy delta. In: Douglas JG, Ferguson JAS (eds) Geology of Victoria, vol 5. Geological Society of Australia, Melbourne, pp 325–327

McSweeney SL, Kennedy DM, Rutherfurd ID (2017) A geomorphic classification of intermittently open/closed estuaries (IOCE) derived from estuaries in Victoria, Australia. Prog Phys Geogr 41(4):421–449

O'Grady JG, McInnes KL, Colberg F, Hemer MA, Babanin AV (2015) Longshore wind, waves and currents: climate and climate projections at Ninety Mile Beach, southeastern Australia. Int J Climatol (wileyonlinelibrary.com). https://doi.org/10.1002/joc.4268

Oliver TSN, Kennedy DM, Tamura T, Murray-Wallace CV, Konlechner TM, Augustinus PC, Woodroffe CD (2018) Interglacial-glacial climatic signatures preserved in a regressive coastal barrier, southeastern Australia. Palaeogeogr Palaeoclimatol Palaeoecol. https://doi.org/10.1016/j.palaeo.2018.04.011

Reinson GE (1977) Hydrology and sediments of a temperate estuary – Mallacoota inlet, Victoria. Bur Min Resour Geol Geophys Bull 178, Canberra

Rosengren NJ (1978) The physiography of coastal dunes, east Gippsland, Victoria. MA thesis, University of Melbourne

Short AD (1996) Beaches of the Victorian Coast and Port Phillip Bay. Sydney University Press, Sydney, 298 p

Thom BG (1984) Sand barriers of eastern Australia: Gippsland – a case study. In: Thom BG (ed) Coastal Geomorphology in Australia. Academic Press, Sydney, pp 233–261

Thom BG, Roy PS, Short AD, Hudson J, Davis RA Jr (1986) Modern coastal and estuarine environments of deposition in southeastern Australia. Guide Excursion 4A, 12th International Sedimentological Congress, Canberra, 279 p

Wheeler P, Peterson J, Gordon-Brown L (2010) Flood-tide delta morphological change at the Gippsland lakes artificial entrance, Australia (1889–2009). Aust Geogr 41(2):183–216. https://doi.org/10.1080/00049181003742302

Wijeratne EMS, Pattiaratchi CB, Eliot M, Haigh ID (2012) Tidal characteristics in Bass Strait, southeast Australia. Estuar Coast Shelf Sci 114:156–165. https://doi.org/10.1016/j.ecss.2012.08.027

Wright LD, Nielsen P, Short AD, Coffey FC, Green MO (1982) Nearshore and surf zone morphodynamics of a storm wave environment: eastern Bass Strait, Australia. Coastal Studies Unit Tech. Rept 82/3, University of Sydney, 153 p

Chapter 21
East Tasmania Region

Abstract The east Tasmania region includes eastern Flinders Island and the eastern Tasmanian mainland between its northern tip at Cape Portland and its southern extremity at South East Cape, together with Maria and Bruny Islands a shoreline distance of 1097 km together with 407 km of island shoreline. The coast is dominated by its geology with rocky shore and numerous headlands occupying 65% of the coast and most of the beaches embayed between the rocky sections. The coast has a temperate humid climate with the prevailing westerlies flowing offshore. It is exposed to micro-tides and moderate southerly swell which drives northerly sand transport which is interrupted by the headlands and estuaries. A few small rivers and streams flow to the coast all entering estuaries. The beaches are composed of quartz-rich sand and are wave-dominated on the open coast, with tide-dominated beaches and tidal flats in the sheltered southeast bays. Barrier development is limited to low regressive ridges with just one area of moderate dune transgression, with sand also deposited into the estuarine flood tide deltas. This chapter describes the geology, climate and coastal process together with the beaches, barriers, sediment transport and sediment compartments.

Keywords East Tasmania · Flinders island · Maria island · Bruny Island · Wave-dominated · Beaches · Barriers · Sediment transport · Sediment compartments

21.1 Introduction

Tasmania is an island located between 39.5 and 43.5°S with an area of 64,519 km^2 and a 2237 km long coast. In this book it is divided into three natural regions: the east coast, west coast and north coast, each with a distinctive geology, orientation, processes and coastal systems. The three regions (TAS01, 02, 03) include Flinders, Maria, Burny and King Islands and are shown in Fig. 21.1a, and their ten PCs are shown in Fig. 21.1b. The east coast is described in this chapter, the west coast in Chap. 23 and north coast in Chap. 24.

The east coast of Tasmania is essentially a continuation of the southeast Australian mainland coast and geology, with the connecting Bass Basin drowned to form Bass

A. D. Short, *Australian Coastal Systems*, Coastal Research Library 32,
https://doi.org/10.1007/978-3-030-14294-0_21

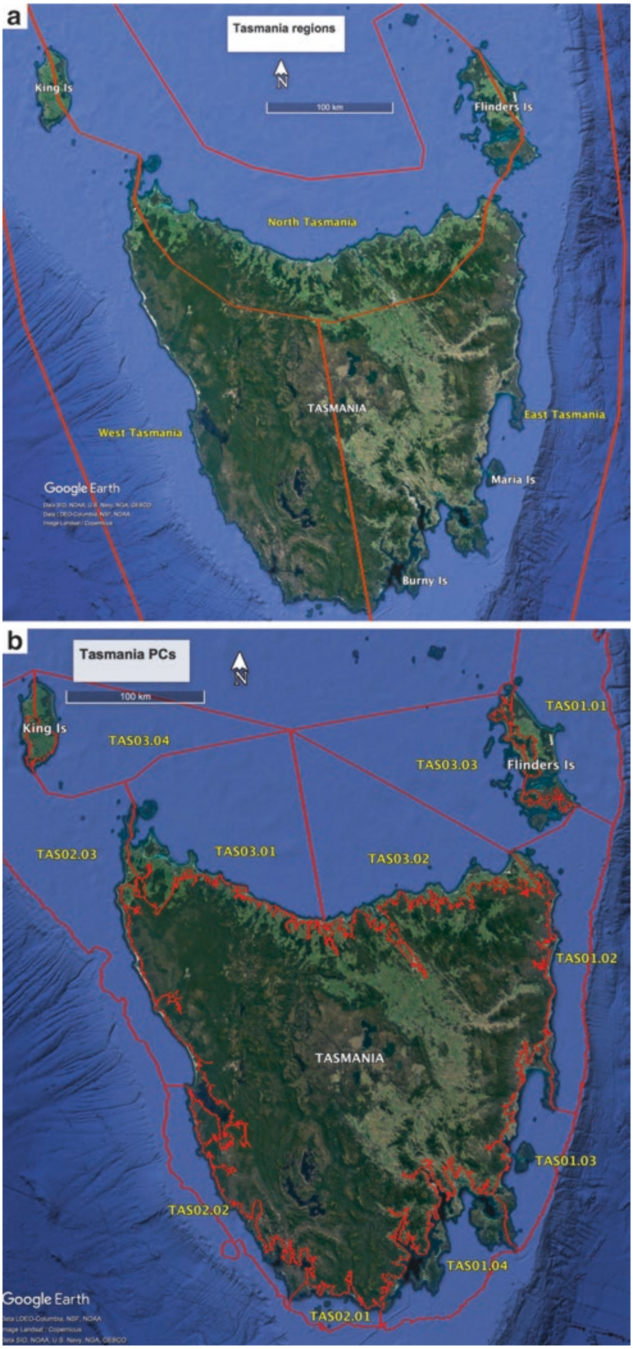

Fig. 21.1 Tasmania contains three regions – the east, west and north coast (**a**), which contains 10 PCs (**b**). (Source: Google Earth)

Strait and its many islands. The eastern region includes the east coast of the large Flinders and Cape Barren Islands and the east Tasmanian coast from Cape Portland, the northeast tip of the island, down to the southern tip at South East Cape, a shoreline distance of 1097 km. In addition, it includes Maria and Bruny islands with the three main islands (Flinders, Maria, Bruny) contributing an additional 407 km of shoreline.

21.2 JL 'Jack' Davies

Any discussion of the Tasmanian or even Australian coast must be undertaken with reference to the pioneering and very incisive work of JL 'Jack' Davies. Jack, a Welshman, came to Tasmania in the 1950s to take up the chair of geography at the University of Tasmania, moving to the new chair of geography at Macquarie University in the 1970s. Jack used the Tasmania coast to pioneer research into beach-foredune ridge development (Davies 1957, 1958a, 1961), wave refraction and beach alignment (Davies 1958b, 1960), sediment transport (Davies 1973a; Davies and Hudson 1987a) and coastal sediment compartments (Davies 1974, 1978; Davies and Hudson 1987b); and on the global stage, he was first to classify the worlds' wave climate and the coasts they impact (Davies 1964). Much of this was encapsulated in his outstanding book 'Global Variation in Coastal Development' (Davies 1973b, 1980). Jack's work initiated in Tasmania ultimately encompasses the entire Tasmanian (Davies 1975, 1978, 1985), Australian (Davies 1977) and world's coastline (Davies 1964, 1973b, 1980). A recent critical review of Jack's contribution to the debate and ultimately our understanding of the formation of beach-foredune ridge plains was written by Oliver et al. (2016).

21.3 Geology

Tasmania's geology can be divided into three sectors: the western terrane consisting of ancient Precambrian and Cambrian sedimentary and volcanic rocks, the central Tamar Fracture Zone which extends from the Tamar to the Derwent and the eastern Tasmania Terrane dominated by a mix of granite and sedimentary rocks overlain by dolerite up to 500 m thick (Fig. 21.2). The east Tasmania region is a continuation of the Lachlan Fold Belt whose Devonian granites dominate Flinders and Cape Barren Islands, and the Tasmania coast from Musselroe Point down to the Freycinet Peninsula, south of which the coast is a mix of Triassic sedimentary rocks overlain by Jurassic dolerite.

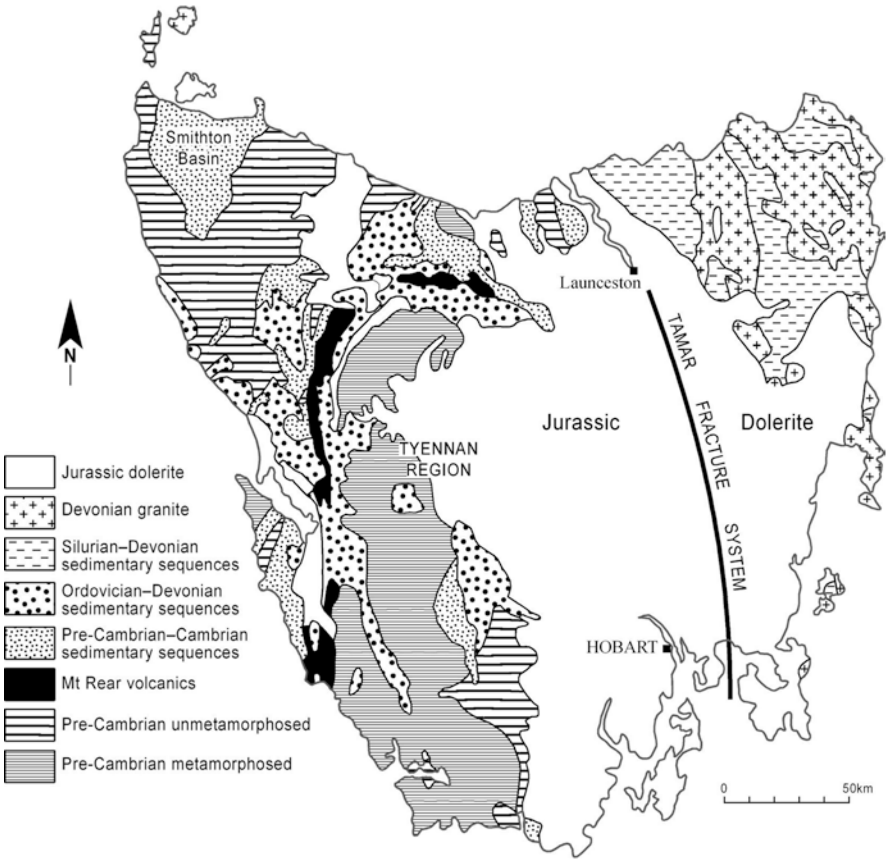

Fig. 21.2 Tasmanian geology with generally higher Pre-Cambrian rocks in the west, sedimentary rocks and granite in the northeast, and the massive area of Jurassic dolerite covering the centre and east to southeast

21.4 Neotectonics and Sea Level

Murray-Wallace and Goede (1995) examined a number of coastal sites across northern Tasmania including King and Flinders Islands. They found evidence for early to middle Pleistocene uplift on the islands, while on the north coast, last interglacial sea levels were found between +11 and +32 m above present sea level, but not on the islands. They attribute the uplift to neotectonics, which occurred early on the Bass Strait islands and later on the north Tasmanian coast. Their findings confirm the earlier work of Bowden and Colhoun (1984). The Holocene sea-level record follows that of the mainland with a rapid rise to around present sea level by 7.3 ka, followed by a possible late Holocene fall to present level ~3.5 ka (Oliver et al. 2017).

21.5 Rivers and Creeks

Along the east coast, the denudation of the granite and dolerite has produced a low to moderate relief undulating east coast, rising inland to several hundred-metre high tiers, mountains and hills which have been heavily dissected by 140 streams and about ten small rivers draining to the coast. Most of the rivers have small catchments of a few hundred square kilometres (e.g. Anson 296 km^2, George 606 km^2, Scamander 301 km^2, Carlton136 km^2, Coal (Pitt Water) 1029 km^2) and Esperance (339 km^2). The largest two are the Derwent (9718 km^2) and the Huon (3068 km^2) which both flow into elongated drowned river valleys with extensive bay head deltas. Along the coast the drowned valleys form estuaries with bay head deltas and provide accommodation space for the many beaches; however, none of the rivers are delivering bedload to the coast.

21.6 Sediments and Coastal Processes

Beach sediments along the east Tasmania coast are predominately well-sorted, medium- grained quartz-rich sand with local carbonate enrichment. They have a mean size of 0.32 mm (σ = 0.29 mm), with a mean carbonate content of 9%, but locally ranging up to 87% (Table 21.1). These are close to Davies (1978) who in his investigation of beach sand around Tasmania found the east coast had predominately well to moderately well-sorted, fine to medium sand (mean = 0.24 mm) with carbonate averaging 6%. Figure 21.3 shows the longshore variation in grain size and carbonate content. The source is ultimately from the granite and sandstones of the eastern ranges, with the sediment deposited on the shelf at lower sea levels and reworked onshore and longshore during and following the PMT. There is no evidence of fluvial supply of bedload to the coast at present.

Table 21.1 Tasmanian PCs and islands sand size and % carbonate

	TAS01 east	TAS02 west	TAS03 north	Flinders	King
n	31	3	8	20	15
Size (mm)	0.32	0.32	0.39	0.47	0.33
σ (mm)	0.29	–	0.42	0.40	0.15
sorting	0.50	0.44	0.69	0.64	0.45
% carbonate	9	23	18	35	46
σ (%)	19		15	33	39
% range	0–87	1–65	0–48	0–88	1–98

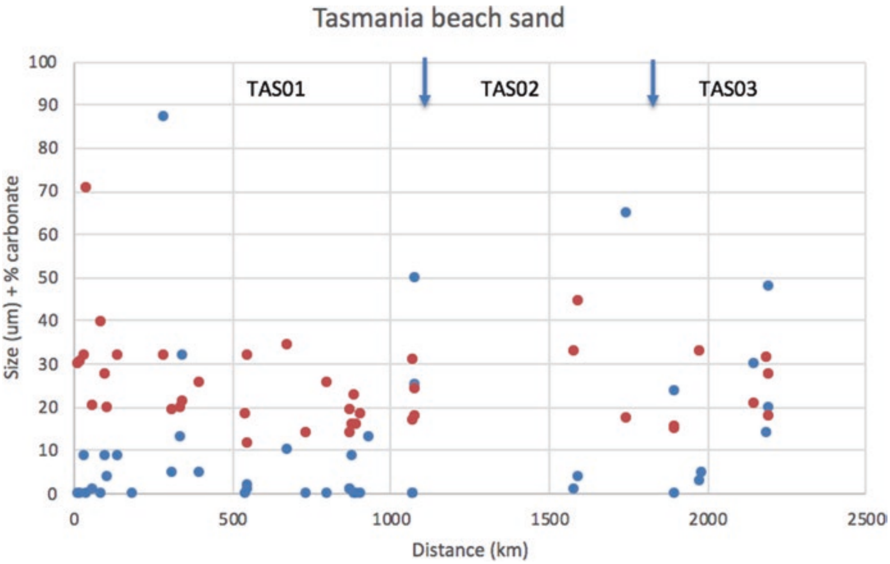

Fig. 21.3 Tasmanian beach sand size (red dot, µm) and percent carbonate (blue dot). Arrows indicate boundaries of the three PCs: the east (TAS01), west (TAS02) and north (TAS03) coasts. Distance clockwise from Cape Portland

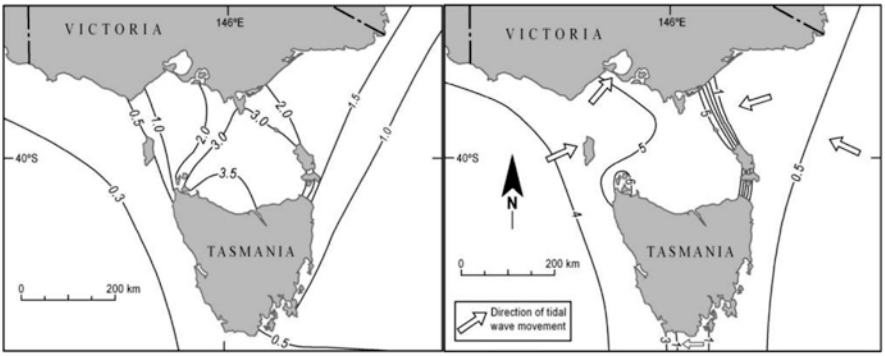

Fig. 21.4 Tasmania and Bass Strait co-range (m) and co-tidal (hours) lines. (Source: Short 2006)

The east coast has a micro-tidal tide regime with a mean spring range between 1.1 and 1.6 m with the tidal crest arriving along the coast almost simultaneously (Fig. 21.4).

The east coast receives waves from two major sources. The dominant waves are the refracted southwesterly swell generated by midlatitude cyclone south of Tasmania, which can arrive year-round, but substantially reduced in height as they refract and travel up the coast. Second, are higher easterly waves generated by east coast cyclones which tend to form several times during the year together with low easterly sea breeze in summer. Overall, waves arrive from the south through the east, averaging 1–1.5 m with a period of 10–14 s. These maintain a moderate wave climate (Fig. 1.12a), apart from sections sheltered by Maria Island. There are however no wave recording system on the east coast.

Wave energy increases along the more exposed sections of the southeast coast, between Cape Pillar and South East Cape, as it becomes increasingly exposed to the prevailing southwesterly swell (Fig 1.12a). Much of the coast is however indented and lies sheltered in Storm, Frederick Henry and Norfolk bays or in the D'Entrecasteaux Channel in lee of Bruny Island. Only lowered refracted swell enters Storm and Frederick Henry bays, while Norfolk Bay and the D'Entrecasteaux Channel receive only wind waves. A waverider buoy in Storm Bay recorded a mean H_b of 1 m, with a short period of 6–7 s, indicating the dominance of the local wind waves over the westerly swell. The local wave climate varies considerably around the southeast depending on the exposure to the refracted westerly swell, the orientation of the shoreline and the extent of fetch to produce wind waves. Within the bays more exposed west- and south-facing shores tend to receive higher wind waves than the more sheltered north- and east-facing shores. There is little monthly variability in the wave climate along the east coast, with variability increasing slightly on the more exposed open southeast coast (Fig. 1.12b).

Tasmania is exposed to persistent strong westerly winds particularly during winter. The winds are generated by the westerly flow between the sub-tropical high and midlatitude cyclones (Kalma and Chin 1988). Wind speeds are generally >6 m s^{-1} along the entire west and south coast. On the east coast, the highest wind speeds occur in the Eddystone Point region and along the south coast west from the Tasman Peninsula. Figure 21.5 shows the wind roses from four coastal locations, each show-

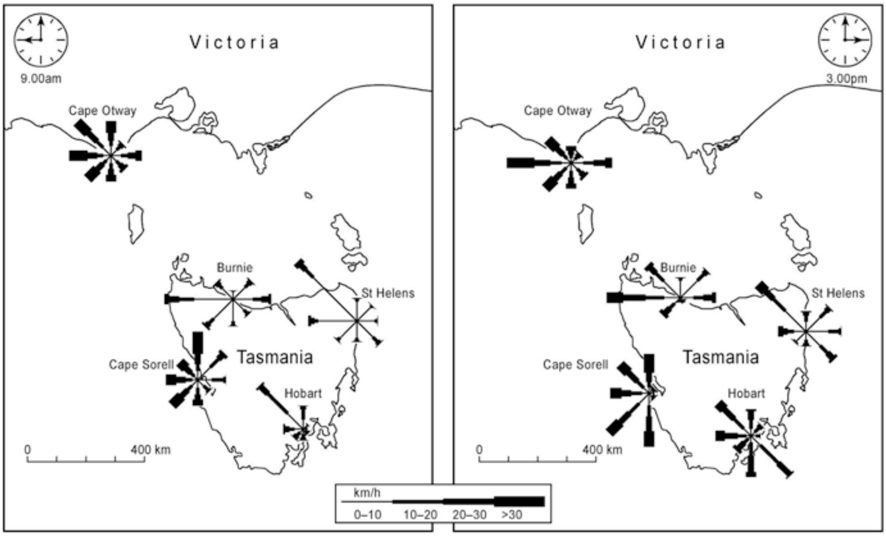

Fig. 21.5 Wind roses (9 am and 3 pm) for Tasmanian coastal sites and Cape Otway. (Source: Short 2006)

ing a dominance of the westerly winds, with easterly sea breeze along the east coast in the afternoon.

21.7 Beaches

The east coast is dominated by its geology with rocky shore occupying 65% of the coast and 565 generally short embayed beaches (mean length = 0.67 km), with the longest beach Nine Mile (13 km) at the head of Great Oyster Bay.The prevalence of rocky shore and the several large drowned river valleys-bays in the south shelter much of the shore resulting in a lower energy breaker wave climate than that of the southeast Australian coast, with H_o expected to be <1.5 m and dominated by southerly swell. The low to moderate waves combine with the micro-tides and medium sand to maintain a WD open coast; however within the many large southeast bays, wave height drops to <0.3 m, and TD conditions prevail. Along the open coast, the lower breaker waves maintain lower energy R and LTT beaches with 323 and 112, respectively, and a total length of 241 km (63%). On the more exposed locations, the higher energy rip-dominated TBR beaches number 67, with a total length of 112 km (29%). Unlike the central east and southern NSW regions, there are no RBB beaches owing to the lower waves. Within the bays there are 31 TD R+RSR and 32 B+SF and just three B+TMF, with a combined length of 20 km (10%) (Table 21.2). However most of the coast, particularly in the southeast, is predominately rocky. Short (2006) provides a description of all the beaches in this region.

21.8 Barriers

The east coast (excluding Flinders Island) has 117 barriers with a total length of 270 km, which represents just 25% of the coast. The very limited barrier development is a product of the lower wave energy; the embayed and often sheltered nature of much of the coast; lack of accommodation space; the sand deficient nature of the coast; very limited longshore transport; and the predominately offshore winds (Fig. 21.5). The barriers tend to be low, regressive, consisting of one or a few

Table 21.2 East Tasmania (PC:TAS01.01-03) beach types and states

BS	BS	n	%	Total km	% (km)	Mean (km)	σ (km)
4	TBR	67	11.9	112.2	29.3	1.7	2.6
5	LTT	112	19.8	105.7	27.6	0.9	1.8
6	R	323	57.2	135.4	35.4	0.4	0.7
10	B+RSF	31	5.5	12	3.1	0.4	0.3
11	B+SF	29	5.1	17.1	4.5	0.6	0.7
14	R+RF	3	0.5	0.6	0.2	0.2	–
		565	100	383	100	0.7	

Table 21.3 East Tasmania barrier dimensions

PC:TAS	TAS01.01	TAS01.02	TAS01.03	TAS01.04	Total
No.	13	44	28	45	130
Total length (km)	78.3	130.6	61.7	75.8	364.4
Mean min width	290	120	140	80	80–120
Mean max width	820	290	270	210	210–820
Mean height (m)	9	8	5	5	7
Area (ha)	4742	2495	1803	2392	11432
Unstable (ha)	20	524	154	133	831
Total volume (M m^3)	407	247	95	162	911
Unit volume (m^3 m^{-1})	5200	1893	1538	2142	2630

foredune ridges, with the only major transgressive systems on the southeast-facing Peron dunes, which only extend 700 m inland. The largest systems are regressive barriers located in generally large south-facing bays which offer the accommodation space. These include Nine Mile (25 ridges), Buxton (30), Rebhan (20) and Seven Mile (50). The barriers have a total area of 6690 ha, of which 881 ka (12%) is unstable, a quarter of this in the Peron dunes. They have a total volume of 504 M m^3, which represents a low 1880 m^3 m^{-1} (Table 21.3).

21.9 Sand Transport

Davies (1973a) investigated sediment transport and compartment boundaries around the entire Tasmanian coast. Along the east coast, he identified major boundaries at St Helens Point, St Patricks Foreland and the Freycinet Peninsula, with minor boundaries at Eddystone Point (probable), Long Point and Cape Lodi, while between Freycinet Peninsula and the west coast's Cape Sorrell, he classified this entire south-east-south-southwest coast as having individual beach compartments all bordered by obstacles to sand transport. Davies assessment was based on the rocky and often embayed nature of the coast, including the highly indented southeast coast, and the prominent east coast headlands. He found transport is at best limited, with limited transport possible in the northeast between Cape Portland and Bindalong, between St Helens Point and Bicheno, and along the western shore of Great Oyster Bay. He attributed the lack of longshore transport to the high degree of embaymentisation which produces numerous obstacles (headlands, etc.) to sand transport resulting in closed SCs and TCs; to the long period southerly swell which through wave refraction results in predominately swash-aligned beaches; the generally low tide range limiting the area of potential transport; and the low rate of contemporary sand supply which has enable the compartments to reach an equilibrium state.

The east coast region contains four PCs and 17 SCs (Table 21.4), which are discussed below including their potential for transport within and between each of the SCs.

Table 21.4 East Tasmania region, PCs and SCs

PC No.[a]	Name	Boundaries	Beach ID[b]	No. beaches	km[c]	Total (km)
East Tasmania						
TAS01.01.01	Flinders Is (E)	Stanley Pt-Pot Sellars Pt	Flinders 1-7	7	0–45	45
TAS01.01.02		Sellars Pt-Buffalos Beach	Flinders 8-28	21	45–109	64
TAS01.02			*Flinders 1-28*	*28*	*0–109*	*109*
TAS01.02.01		C Portland-Eddystone Pt	TAS 1-49	49	0–59	59
TAS01.02.02		Eddystone Pt-St Helens Pt	TAS 50-100	51	59–107	48
TAS01.02.03		St Helens Pt-Wardlaws Pt	TAS 101-125	25	107–151	44
TAS01.02.04		Wardlaws Pt-Friendly Pt	TAS 126-158	33	151–208	57
TAS01.02.05		Friendly Pt-Cape Sonnerat	TAS 159-160	2	208–254	46
TAS01.02		*C Portland-C Sonnerat*	*TAS 1-160*	*160*	*0–254*	*254*
TAS01.02.01		C Sonnerat-C Bougainville	TAS 161-254	94	254–366	112
TAS01.03.02		C Bougainville-C Bernier	TAS 255-284	30	366–414	48
			Maria Is 1-19	19	0–65	65
TAS01.03.03		C Bernier-C Frederick Hendrick	TAS 285-299	15	414–445	31
TAS01.03.04		C Frederick Hendrick-C Pillar	TAS 300-309	10	445–514	69
TAS01.03		*C Sonnerat-C Pillar*	*TAS 161-309+ Maria Is 1-19*	*149*	*254–514*	*260*
				19	*65*	*65*
TAS01.04.01		C Pillar-Outer North Hd	TAS 310-335	26	514–612	98
TAS01.04.02		Outer N Hd-C Contrariety	TAS 336-409	74	612–779	167
TAS01.04.03		C Contrariety-C Direction	TAS 410-414	5	779–789	10
		Deenes Pty-Tasman Hd	Bruny Is 1-25	25	0–75	75
TAS01.04.04		Tasman Hd-Hopwood Pt	Bruny Is 26-38	13	75–111	36

(continued)

Table 21.4 (continued)

PC No.[a]	Name	Boundaries	Beach ID[b]	No. beaches	km[c]	Total (km)
TAS01.04.05		C Direction-Rossel Pt	TAS 415-527	113	789–1042	253
		Hopwood Pt-Deenes Pt	Bruny Is 39-94	56	111–233	122
TAS01.04.06		Roissel Pt-South East Cape	TAS 528-565	38	1042–1097	55
TAS01.06			*TAS 310-565*	*256*	*514–1097*	*583*
			Bruny Is 1-94	*94*	*0–233*	*233*
TAS01.01–04	*East Tasmania*	*Region sub-total*	*TAS 1-565*	*565*	*0–1097*	*1097*
			Islands	*141*		*407*

[a]NCCARF compartment number
[b]ABSAMP beach ID
[c]Distance from Cape Portland

21.10 PC:TAS01.01 Flinders Island-East Coast

Flinders Island is located in eastern Bass Strait 55 km north of Cape Portland. The island has an area of 1376 km^2 and 235 km long coastline which can be divided into an east, south, west and north coasts. PC:TAS01.01 contains two SCs, the 45 km long northeast coast (SC:TAS01.01.01) and the 64 km long southeast-south coast (SC:TAS01.01.02) (Fig. 21.6), while the west and north coasts are part of the north Tasmania region and PC:TAS03.03, which are described in Chap. 24. The island has a core of Devonian granite which rises to 766 m high Mount Strzelecki in the south, with granite outcropping along the west coast of the island including the northern Stanley Point and southern Pigs Head Point. In contrast, the east coast is largely a 5–10 km wide low gradient coastal plain anchored by the central granite 200 m high Babel Island. The island has a population of 900 and one town Whitemark (200) and the small Lady Barren community (260). Apart from a couple of jetties, there is no property or infrastructure at risk.

Beach sand along the east coast is well-sorted, fine-grained and quartz-rich with generally <10% carbonate (Fig. 21.7). The wave climate is a continuation of the east Tasmanian coast and dominated by moderate to occasionally high southerly swell with larger waves from east coast cyclones. Spring tide range is 1.3 m. Winds are predominately moderate to strong offshore westerlies (Fig. 21.5).

21.10.1 SC:TAS01.01.01 Stanley Point–Sellars Point

SC:TAS01.01.01 extends for 45 km from the northern tip of the island at Stanley Point to the Sellars Point the low sandy tip of the large cuspate foreland formed in lee of Babel Island. This is a sedimentary shore with most of the compartment made

Fig. 21.6 Flinders Island is divided into four SCs. TAS01.02.01-02 occupy the east coast and are the subject of this section, while TAS03.03.01 the south coast and TAS03.03.02 the west and north coasts are discussed in Chap. 24. (Source: Google Earth)

up of seven near continuous beaches totally 41.5 km and occupying 92% of the coast. The beaches are all well exposed to Bass Strait waves, and except for a sheltered beach in lee of Holloway Point, are all rip-dominated TBR, with 150 beach rips usually operating. The 32 km long Foochow beach (FI 3) is tied to the northern Holloway Point extending southeast to two small granite outcrops, south of which

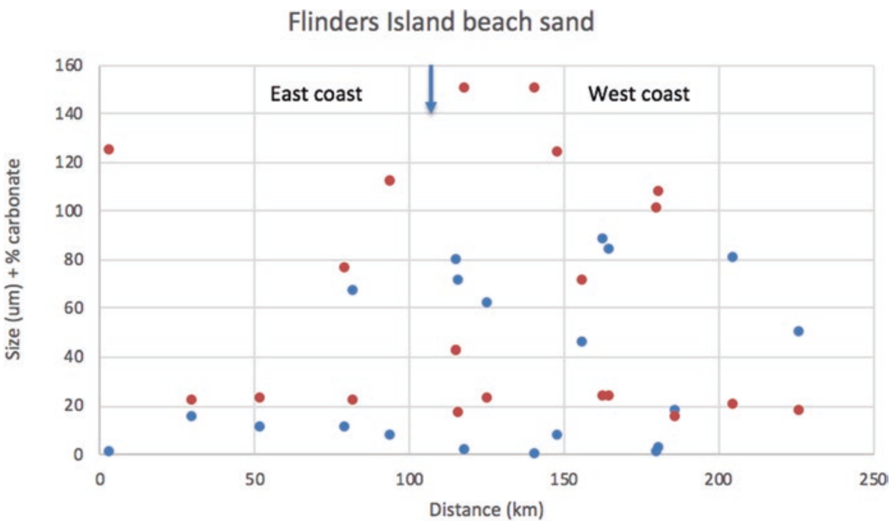

Fig. 21.7 Flinders Island beach sand size (red dot, μm) and percent carbonate (blue dot). Arrow indicates PC boundary (east TAS01.01, west TAS03.03). Distance clockwise from Stanley Point

Swimming beach (FI 6-7) curves for another 8 km south-southeast to the foreland. They are cut by three inlets: at North East River (Fig. 21.8a), Foochow and Patriarch. This low gradient, northeast-facing shore has acted as a major sediment sink for both onshore and longshore supplied sand. The foreland has prograded 2 km seaward and is capped by ~40 low ridges, which extend 8 km west to Red Bluff (Fig. 21.8c). North from the bluff and Patriarch Inlet, the barrier averages about 500 m in width capped by ridges its entire length (Fig. 21.8b) up to the northern North East River Inlet. The barrier is backed by a ~20 km wide belt of what appears to be longwalled parabolics very likely formed during the glacial maxima by strong westerly winds. These dunes appear depleted and are possibly reworked from Pleistocene coastal dunes that originated at a high stand of the sea in the western Marshall Bay. Similar coastal-glacial dune fields are present in Ringarooma Bay on the nearby northern Tasmanian coast (Bowden and Colhoun 1984) and to the north in Gippsland (Oliver et al. 2018).

The Holocene barriers have a volume of 213 M m^3 (5132 m^3 m^{-1}) making it one of the larger barrier systems on the Tasmania coast. Based on the orientation of the coast and ridges, the sand has moved both onshore from the shallow shelf and longshore (Fig. 21.8c) around the SC boundary at Sellars Point to supply the SC. This sand has been deposited in the barrier as well as moving northward to and probably around Hollaway Point where it is lost offshore into the Sisters Passage. Longshore transport rates would be expected to be on the order of a few 10,000 ‘s m^3 year^{-1}.

Fig. 21.8 (**a**) Holloway Pt and North East River inlet and the northern end of the long Foochow beach (FI 2); (**b**) regressive foredune ridge in the mid Foochow barrier (FI 2); (**c**) sand (arrows) bypassing Red Bluff (FI 5); (**d**) the blocked and overwashed Cameron Lagoon inlet; (**e**) east trending spits on Pot Boil Point and (**f**) sheltered Big River Cove beach (FI-27) with seagrass fringed sand flats which increase in width to the more sheltered west. (Photos: AD Short)

21.10.2 SC:TAS01.01.02 Sellars Point–Buffalo Beach

SC:TAS01.02.02 extends for 28 km from Sellars Point southeast to the low sandy Pot Boil Point, where the shore turns and trends west-southwest for 36 km to Buffalo Beach (FI 29) forming the northern shore of 3–8 km wide Franklin Sound, a total distance of 64 km and consisting of two distinct sections. This is a complex SC involving both southerly wave and easterly tidal sand transport along its eastern section, as well as possibly glacial aeolian overpassing from the west to east coast. The exposed east-facing eastern shore has a 28 km long WD TBR Planters beach (FI 8-9) broken only by the Cameron (Fig. 21.8d) and Logan lagoon inlets. It is backed by a regressive barrier up to 1 km wide running its full length, behind which is a 7 km wide mix of inner east-trending glacial dunes separated by lagoons and shallow lakes from the outer barrier. Sand for these glacial dunes would have to have originated in an inner Pleistocene barrier and/or lagoon in the north and possibly from the west coast (via Chew Tobacco Creek valley) in the south. The beach has acted more as a conduit for northward sand transport via Sellars Point to the Foochow barrier system and beyond. Pot Boil Point (Fig. 21.8e) is part of a large ebb tide delta, the 'boil' referring to both the east-trending strong tidal currents as well as waves breaking over the shallow delta which extends up to 10 km seaward. The combination of waves and strong easterly tidal currents has deposited a 6 km long, up to 2 km wide long series of regressive spits that extend into the adjoining SC (TAS03.03.01). The sound appears to be acting as a conduit for tide-driven sand transport from the west to east through the sound, some of which may then move northwards along the eastern Planters beach.

The eastern coast barriers have a total volume of 407 M m^3 (5200 m^3 m^{-1}) (Table 21.3), while the 40 km^2 tidal delta could contain on the order of 400 M m^3, making it a major sediment sink. However, as no detailed studies have been undertaken of the island's barriers and tidal deposits, all this remains to be resolved.

The southern south-facing shore forms the island's south coast and faces south into 3–8 km wide 25 km long Franklin Sound with a shoreline length of 36 km. This is the site of the small Lady Barron community and its pier, and a shorefront road extends along the central part of the coast. The sound shore is moderately exposed at its entrances, becoming increasingly sheltered away from the entrances as waves drop below 0.5 m and particularly in the central Adelaide Bay where only fetch-limited wind waves impact the shore. Spring tide range is 1.3 m increasing to 1.9 m at the western end of the sound and the southwestern tip of the island. Beach sand is more variable with sand ranging from fine to very coarse as well as having a greater range in carbonate (10–70%), both indicating a low energy system with little to zero longshore transport.

The southern sound shore consists of three parts: the eastern splay of recurved spits that extend from Dick Davey Shoal for 6 km to Pot Boil Point with WD R beaches; the central sound and island sheltered 7 km wide Adelaide Bay which contains four R beaches along its more exposed eastern shore, grading to B+SF; and then seagrass-covered sand flats along most of the central-western shore. To the west is the western granite shoreline that continues for 14 km to Buffalo Beach and contains 14 small (mean length = 0.4 km) moderately sheltered embayed beaches, all B+SF with seagrass fringing the edge of the flats. In each of the beaches, the sand flats increase in width to ~100–150 m to the more sheltered western end of each embayment (Fig. 21.8f). Some of the beach are backed by a few stable foredunes, with some minor dune transgression in lee of the more exposed westernmost beaches (FI 26-7) where densely vegetated dunes extending up to 500 m inland. These small low energy barriers have a total volume of 11.6 M m^3.

21.10.3 PC Overview

The east coast of Flinders Island is for the most part a broad low gradient sediment sink, as well as conduit for wind-, wave- and tide-driven sand transport. The east coast is entirely undeveloped, apart from access roads, and the present shorelines appear to be stable; however it is at risk to sea-level rising across the low gradient eastern plain, which would reactivate the tidal inlets, deltas and lagoons and raise groundwater across the low wet plain. In addition, changes in wave climate and tide regime would impact rates of sand transport along the eastern beaches and in the sound. At present there is no property at risk to coastal erosion or inundation (Tasmanian Govt 2016).

21.11 PC:TAS01.02 Northeast Coast

PC:TAS01.02 occupies the entire northeast coast of Tasmania extending from the northern tip at the low 10 m high Cape Portland south for 254 km to the steep granite cliffs of 100 m high Cape Sonnerat on Schouten Island (Fig. 21.1b). The coast initially trends 60 km southeast to Eddystone Point and then turns and trends essentially due south to the cape. It is a bedrock-controlled coast containing 160 beaches with an average length of 0.98 km, and a total length of 146 km, occupying 57% of coast, with the remainder primarily rocky shore dominated for the most part by massive sloping granite and boulders. In the northeast the coast rises slowly to 560 m high Mount Cameron located 25 km inland and is drained by the Ringarooma, Great Musselroe and Anson rivers, each of which is still in filling their coastal lagoons, together with a few small creeks. South of the Anson mouth, the coast rises to heights between 200 and 600 m within 5 km of the coast and is drained by a series of over 35 small creeks, with the George and Scamander the only rivers, which flow to a bay and lagoon, respectively. None of the rivers and streams appear to be delivering sand to the coast. The PC contains fives SCs.

21.11.1 SC:TAS01.02.01 Cape Portland–Eddystone Point

SC:TAS01.02.01 commences at Cape Portland and trends southeast to Eddystone Point (Fig. 21.9a) and consists of a series of slightly embayed northeast-facing beaches and barriers, anchored by generally low granite points (Fig. 21.10a), the highest 28 m Eddystone Point. The coast is undeveloped apart from vehicle access points and camping areas, the small estuarine community at Musselroe Bay (population 230) and a few shacks at Picnic Point. The Musselroe Conservation Area occupies 19 km of coast and the northern section of Mount William National Park another 7 km. There are 49 beaches extending near

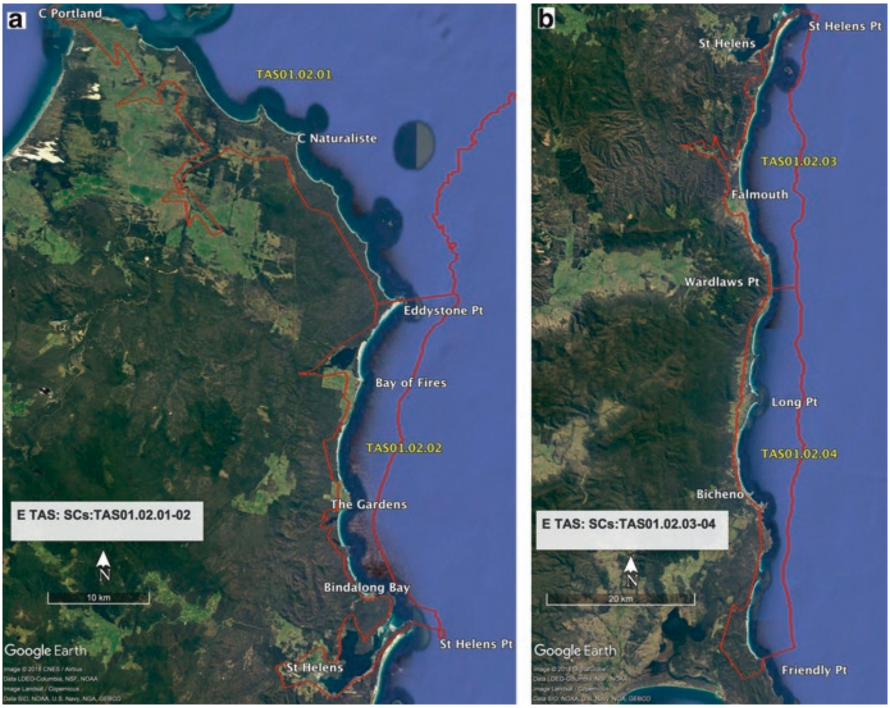

Fig. 21.9 (**a**) SC:TAS01.02-01 and 02 and (**b**) SC:TAS01.02.03-04. (Source: Google Earth)

continuously between, and often around, the low points, and make up 47.5 km (83%) of the shore, averaging 0.97 km in length. This is a low-lying northeast-facing shore, sheltered in part by its orientation together with Swan Island and clusters of inshore reefs. It is at most moderate energy WD shore, with waves along this north to northeast-facing shore average about 1 m and combining with the fine to medium sand to maintain R beaches between the more north-facing Cape Portland to Great Musselroe Bay, and LTT beaches down to Eddystone Point, with rips only occurring during and following periods of higher waves. The generally lower waves allow seagrass to grow close inshore along the sandy beaches.

The beaches are backed by a series of 17 low, narrow, generally stable barriers (Fig. 21.10b) with a total volume of 59 M m^3 (1328 m^3 m^{-1}) averaging 2.6 km in length. Between Cape Portland and Tea Tree Point, the west-facing sections of the curving beaches are backed by low active and stable transgressive dunes, activated by the strong westerly winds, with the sand overpassing the low headlands. In addition, the entire northeastern corner of the island is covered by glacial longwalled parabolic dunes which originated in the western Ringarooma Bay and reach as far south as Stumpys Bay, where they were investigated by Bowden and Colhoun (1984), a cross-island distance of over 50 km. The eastern end of these dunes would

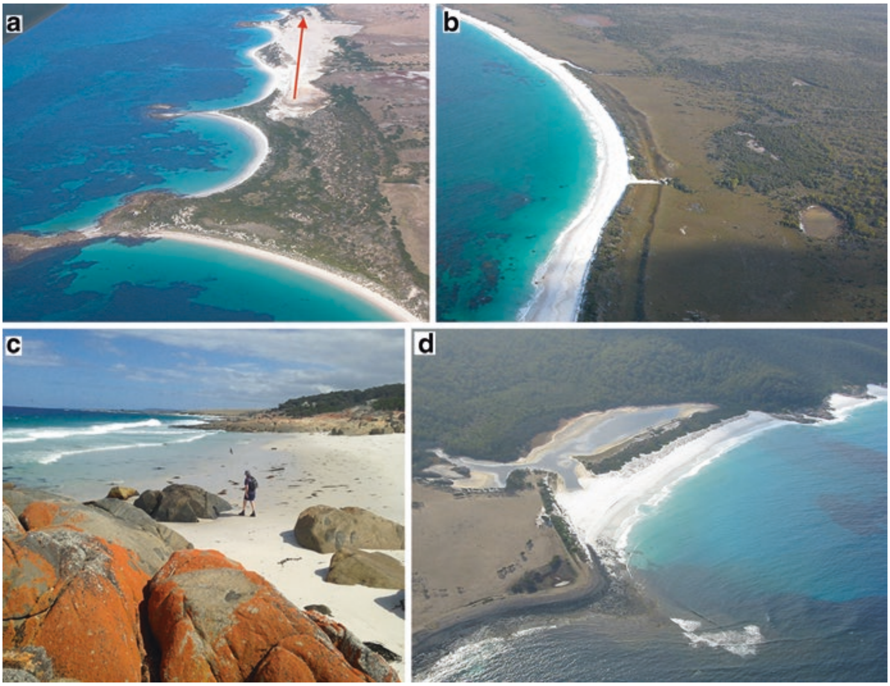

Fig. 21.10 (**a**) View east from Lanoma Point, with vegetated and active dunes overpassing (arrow) the low points and seagrass growing close inshore (TAS 5-8); (**b**) Narrow stable foredune and barrier at Cod Bay (TAS 36); (**c**) typical granite bounded beach (TAS 65) and (**d**) Gardens Lagoon a typical small east coast ICOL (TAS 69). (Photos: AD Short and W Hennecke)

have been reworked during the sea level transgression to contribute to the present east coast barriers.

While the winds are blowing the sand from west to east, the predominately refracted southerly waves should be moving sand longshore to the northwest, with bypassing of the subdued and often sandy headland to be expected. Rates however along the low energy LTT and particularly the R beaches would be small and interrupted by the headlands and reefs, and probably on the order of <10,000 m^3 $year^{-1}$, with limited backpassing (Fig. 21.10a) over the northern headlands.

21.11.2 SC:TAS01.02.02 Eddystone Point–St Helens Point

SC:TAS01.02.02 commences at Eddystone Point and trends due south to St Helens Point (Fig. 21.9a), a shoreline distance of 48 km (Fig. 21.8). In between is the famed Bay of Fires, a near continuous stretch of white quartz sandy beaches bordered by red lichen-encrusted granite slopes and boulders (Fig. 21.10c). Much of the coast lies in Mount William National Park, the Bay of Fires Conservation Area, Humbug Point Nature Recreation Area and St Helens Conservation Area. There is however limited coastal development at the small (The Gardens, the headland holiday community of Bindalong Bay (200)) and the fishing, service and holiday town of St Helens (2100) set at the head of Georges Bay.

The coast is a mix of the 25 beaches averaging 1.1 km and totalling 27.5 km (57%) separated by the granite points and headlands, particularly around The Gardens and south of Bindalong Bay. A series of small creeks and the George River reach the coast, five of the creeks forming coastal lagoons/ICOL's (Anson, Gardens (Fig. 21.10d), Big, Sloop, Grants,) while the river has deposited a sandy bayhead delta at the head of the 10 km long drowned Georges Bay. The beaches are mix generally shorter more embayed and sheltered R (mean length = 0.25 km) and LTT (0.7 km) with TBR on the longer (0.9 km) more exposed beaches. The coast has 11 barrier systems which occupy 22.5 km (47%) of the coast. They range from one to a few stable foredunes along the east to northeast-facing southern beaches, to minor dune transgression on the slightly more southerly facing northern end of the curving northern beaches (Anson Bay, Abbotsbury and Break Yorke) where north-trending dunes extend up to 500 m inland. They have a volume of 46 M m^3 (2026 m^3 m^{-1}).

Longshore sand transport is limited in this SC owing to the areas of low wave energy, seagrass meadows extending close to shore, rocky sections and headlands with rock reef extending offshore and some deeply embayed beaches. While there may be some intra-beach transport to the north, there appears to be little if any transport between the beaches, with Eddystone Point expected to be a closed boundary.

21.11.3 SC:TAS01.02.03 St Helens Point–Wardlaws Point

SC:TAS01.02.03 extends south from the prominent St Helens Point for 44 km to Wardlaws Point (Fig. 21.9b), which is located on a 12 km long section of rocky coast at the foot of Mt Elephant which rises to 760 m 6 km inland. Most of the coast is located in the St Helens and Scamander conservation areas and the southern Four Mile Creek coastal reserve, with the small coastal communities of Beaumaris (300), Scamander (500) and Falmouth (200) located behind and/or in between the reserves. The coast is a mix of 25 beaches occupying 29 km (65%) of the coast and rocky granite shore, with inlets/ICOL's at Dianas Basin, Scamander and Henderson Lagoon. There is presently no property or infrastructure at risk.

The longer northern section north from Falmouth is almost a continues strip of predominately exposed longer TBR beaches (mean length 1.6 km) with sand extending around the base of some of the rocky sections, with a few short (0.2 km) R beaches south from Falmouth, in all 25 beaches occupy 29 km (65%) of the coast. It is likely sand is moving northwards along this section (Fig. 21.11b) and being lost into the three inlets, with the ultimate sink being the more exposed, higher energy east-southeast facing Peron dunes (Fig. 21.11a) at the northern end of the SC, the

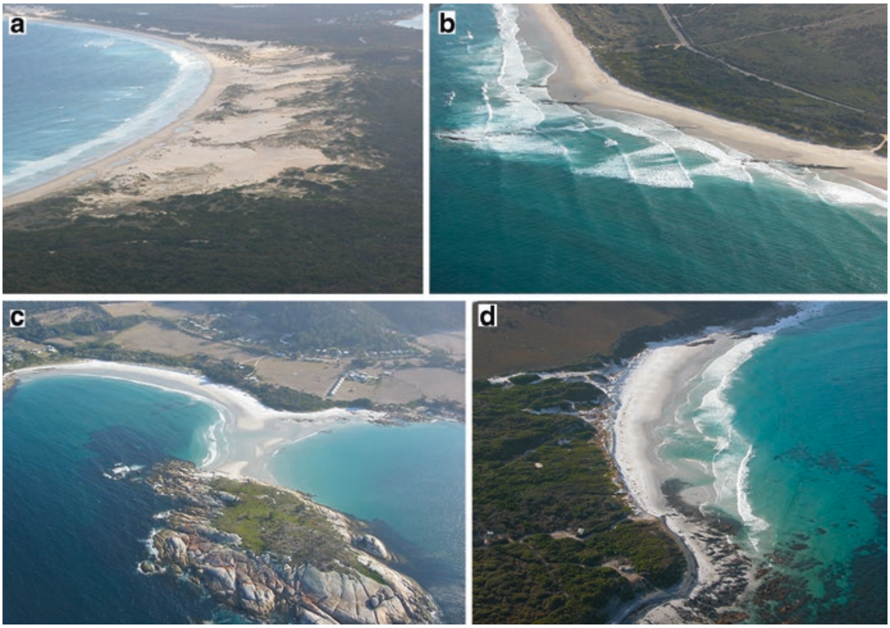

Fig. 21.11 (**a**) Peron dunes the largest transgressive dunes on the east coast (TAS 103); (**b**) waves refracting around Ring Rocks, Beaumaris (TAS 111) and driving northerly sand transport; (**c**) tombolo in lee of Diamond Island with Redbill Beach to left (TAS 142-143) and (**c**) well-developed beach rips on Courland Bay beach (TAS 150). (Photos: AD Short and W Hennecke)

largest transgressive barrier on the east coast with dunes extending up to 0.7 km inland. The Peron barrier has a volume of 68 M m^3 (7940 m^3 m^{-1}), with the other six barriers which range from stable foredunes to minor now stabilised dune transgression totalling 25 M m^3, and an overall per metre volume of 3558 m^3 m^{-1}.

21.11.4 SC:TAS01.02.04 Wardlaws Point–Friendly Point

SC:TAS01.02.04 continues almost due south from Wardlaws Point for 57 km to Friendly Point (Fig. 21.9b) with its relatively straight (crenulation ration 1.16) easterly orientation exposing it to the prevailing waves. The coast contains five curving east-facing slightly embayed beaches each bordered and separated by steep, sloping granite. Most of the shore is occupied by the Little Creek Coastal Reserve and the Lagoons, Seymour and Denison Rivulet conservation areas and the northern section of Freycinet National Park, with the only major development around the popular fishing and tourist town of Bicheno (900). The coast is a mix of 33 sandy beaches and usually sloping granite rocks together with a few granite boulder beaches. The beaches total 39 km (69%) of coast and range from shorter R (0.15 km) to longer

LTT (0.64 km) and the longer more exposed TBR (2 km) (Fig. 21.11d) which also dominate by beach length (86%). There are also a few small creeks, a single coastal Templestone Lagoon and a well-developed tombolo in lee of Diamond Island (Fig. 21.11c).

There are six barriers along this SC occupying 33 km (58%). They are all narrow (~200 m) and consist of a stable to semi-stable foredune with minor dune transgression, the most extensive extending 300 m inland and rising to 25 m high on the southern Friendly beaches. The barriers have a total volume of 32 M m^3 with a low per metre volume of 1095 m^3 m^{-1}. The low volume can be attributed to the lack of accommodation space on this generally straight shore with rising slopes behind. There may be some longshore transport on the longer Lagoon, Dennison and Friendly beaches, but there appears to be no transport around the headland and rock sections between the TCs (i.e. Ironhorse-Hughes points, Long Point, the Bicheno coast and Courland Point).

21.11.5 SC:TAS01.02.05 Friendly Point–Cape Sonnerat

SC:TAS01.02.05 occupies the southern section of the PC is largely a steep rocky coast, with the entire coast located in the Freycinet National Park and is no development apart from camp sites. The 46 km of coast extends from Friendly Point to Cape Sonnerat at southern tip of Schouten Island. The only beaches are the small Bluestone Bay and the longer Wineglass Bay with a combined length of 1.8 km occupying just 4% of the coast, the remainder of the coast consists of steeply sloping granite rising to 100–400 m (Fig. 21.12a). The sheltered curving Wineglass Beach (Fig. 21.12b) is a classic R beach with usually well-developed beach cusps. It is backed by a narrow stable foredune which forms the eastern side of 1.5 km wide low sandy isthmus that connects the Freycinet Peninsula to the mainland. The small barrier has a volume of 1.2 M m^3 (670 m^3 m^{-1}). The bay is a totally closed TC with the small barrier indicating limited and now ceased onshore sand supply.

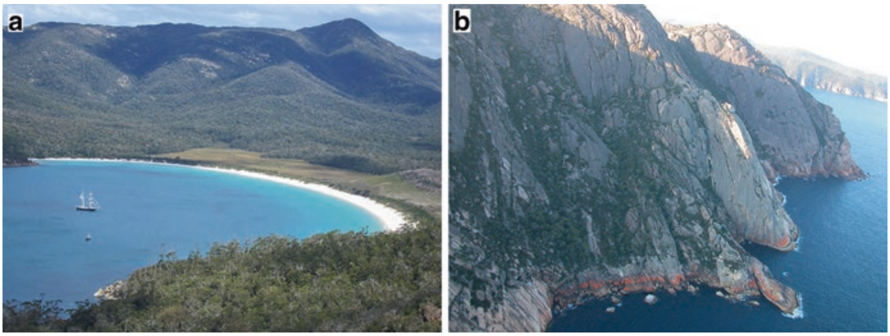

Fig. 21.12 (**a**) Wineglass Bay (TAS160) is a sheltered reflective beach; and (**b**) the bare granite slopes of The Hazards rise to over 400 m (Photos: AD Short)

21.11.6 PC Overview

PC:TAS01.02 is a low to moderate wave energy mix of generally short sandy beaches and sloping granite shore, headlands, boulders and reefs, with limited development and most of the coast located in national parks and reserves. The coastal hinterland generally rises in from the coast, with the only low-lying areas for the most part undeveloped coastal lagoons and the larger George Bay, with essentially no property or infrastructure presently at risk to erosion, apart from St Helens and Scamander which are located on reasonably low ground and prone to future fluvial and marine inundation. While this coast will be impacted by rising sea level and changing wave climate, it will for the most part be left alone, with attention focused on those areas at risk to present and future inundation as well as some sections where coastal erosion will threaten properties in the future (Tasmanian Govt 2016).

21.12 PC:TAS01.03 Cape Sonnerat–Cape Pillar

PC:TAS01.03 is an irregular 260 km long section of the southeast coast located between Cape Sonnerat and Cape Pillar, the southeast corner of the island and includes Maria Island (Fig. 21.1). It has a crenulation ratio of 2.6 and is dominated by its geology which is a mix of Devonian granite on the Freycinet Peninsula and Jurassic sedimentary rocks and dolerite along the coast (Fig. 21.2), with the isthmus-linked Maria Island a combination of sedimentary and dolerite rocks. Rocky shore occupies 65% of the coast, with 149 small beaches (mean length = 0.61 km) the remainder. The coast can be divided into four parts, the northern south-facing Great Oyster Bay (SC:TAS01.03.01); the central Maria Island and the sheltered mainland shore in its lee (SC:TAS01.03.02); the curving Marion Bay (SC:TAS01.03.03); and the southern rugged east coast of the Tasman Peninsula (SC:TAS01.03.04), each of which is described below.

Spring tides remain micro (1.1–1.3 m) along the coast, while breaker wave height is low to at best moderate and spatially variable owing to the number of bays and sheltering by the peninsula and island. As a consequence, the shore is dominated by small R beaches, with 91 R beaches averaging 0.4 km in length and occupying 40 km (43% by length), followed by LTT (41 beaches, mean 1.1 km, total 45 km, 50%), and just a handful of more exposed TBR (7 beaches, mean 0.9 km, total 6.4 km, 7%). The predominance of rocky shore and low wave energy is also reflected in the low number and small size of the barriers in this PC. A total of 28 barriers occupy 61.7 km of shore (24%). They tend to be low, narrow and stable, together with a few regressive systems. They total 95 M m^3 (1538 m^3 m^{-1}) both the lowest values in the east Tasmania region (Table 21.3).

21.12.1 SC:TAS01.03.01 Great Oyster Bay: Cape Sonnerat–Cape Bougainville

SC:TAS01.03.01 contains Great Oyster Bay, with the western shore of the Freycinet Peninsula-Schouten Island forming its eastern boundary, the peninsula linked to the mainland by a low isthmus (Figs. 21.13; 21.14a) and linked by Nine Mile Beach to the south-trending mainland coast. The bay is 17 km wide at its mouth and extends north for 30 km with rocky shore and low energy embayed beaches along its two arms and the PCs largest barrier Nine Mile at the head of the bay. There is a scattering of small communities around the northern and western bay shore, the larger settlements at Coles Bay (500) and Swansea (600), both located on high ground. Most of the eastern arm is located within Freycinet National Park and the Coles Bay Nature Reserve. Two larger estuaries and 26 small upland creeks reach the bay shore, predominately along its western arm, some forming small usually blocked lagoons at their mouths. The Great Swanport barrier estuary in lee of Nine Mile beach has an area of 3600 ha and a well-developed ebb and flood tidal delta (Fig. 21.14b), while the drowned Swanport River flows into the 7 km long Little Swanport estuary, with a large bay head delta and ebb and flood tidal delta, but no sand supply to the coast.

The SC has a shoreline length of 112 km between Cape Sonnerat and Cape Bougainville and contains 94 predominately low energy R (64) and LTT (25) beaches, with just three more exposed TBR beaches located on southeast-facing

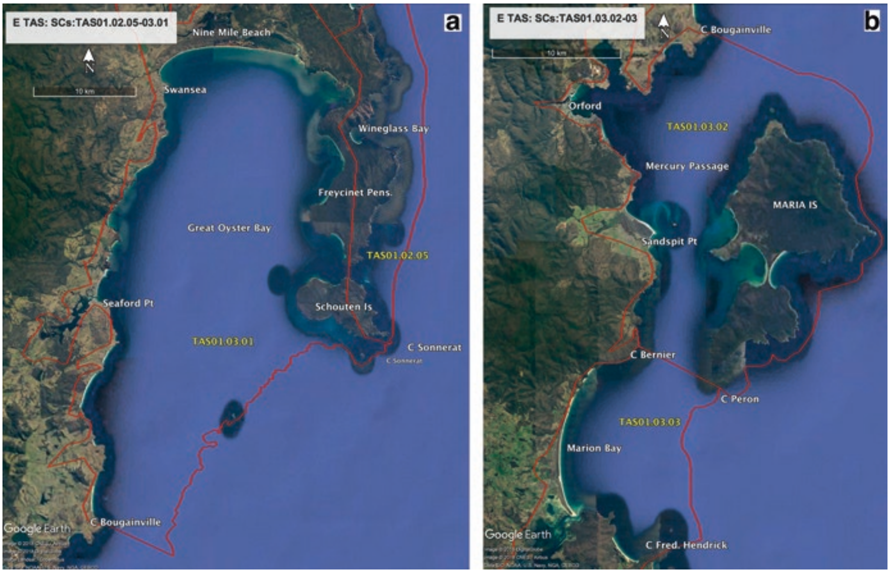

Fig. 21.13 (**a**) SC:TAS 01.03.01 Great Oyster Bay and (**b**) SC:TAS01.03.02-3 Maria Island. (Source: Google Earth)

Fig. 21.14 (**a**) View east across the Hazards beach (TAS 170) to Wineglass Bay located either side of the isthmus that connects the Freycinet Peninsula to the mainland; (**b**) Great Swanport ebb tide delta (TAS 190-1); (**c**) the drift aligned Swansea beaches (TAS-193) indicative of northerly sediment transport and (**d**) Plain Place beach (TAS-253) is typical of this coast with a LTT backed by a stable foredune and a small ICOL. (Photos: AD Short and W Hennecke)

shores. The beaches occupy 53.5 km (48%) of the coast the remainder generally sloping rocky shore. There are 17 barrier systems which occupy 35 km (13.5%) of the shore. They are all regressive systems ranging from one to several foredunes (Fig. 21.14d), the largest Nine Mile which is 1.5 km wide and capped by 25 foredune ridges, which in the centre have been reworked by transgressive dunes extending 700 m inland, suggesting that progradation and probably sediment supply have ceased. Thom et al. (1981) drilled and carbon dated the barrier ridges and found the dates 'not very useful' owing to age of contamination. They obtained only one reasonable date of 4.5 ka. Nine Mile has a volume of 60 M m^3 (4380 m^3 m^{-1}), with the remaining small barriers totalling just 11 M m^3 (503 m^3 m^{-1}).

The predominately southerly waves move into the bay and run along its east and western shore (Fig. 21.14c), generating limited and continuously interrupted northward sand transport to the ultimate sink at Nine Mile beach. There is evidence of some headland sand bypassing, but given the low wave energy and many rocky sections and headland, this is expected to be limited.

21.12.2 SC:TAS01.03.02 Cape Bougainville–Cape Bernier/ Maria Island

SC:TAS01.03.02 extends from Cape Bougainville to Cape Bernier on the mainland (Fig. 21.13b), a distance of 48 km and includes the whole of hourglass-shaped Maria Island (Fig. 21.15a), with an island shoreline of 65 km (Fig. 21.13b). The only settlements are at Triabunna (1050) at the head of Spring Bay and Orford (550) at the Prosser River mouth. This is a highly variable coast dominated by the drowned Spring and Prosser bays in the north and regressive Rheban Spit barrier in the centre. There are several small upland creeks draining to the coast and the small Prosser River (743 km^2) which enters the middle of Prosser Bay and may be delivering sand to the adjoining Orford barriers. The coast has 30 generally small low energy predominately R beaches totalling 14.5 km (30%), with an average length of just 0.47 km. Then remainder of the coast is predominately sloping dolerite. The only wave study at Triabunna Harbour (Chappell 1975) reported most waves were long period swell (15–20 s) between 0.8 and 1 m high with the highest waves arriving between October and March.

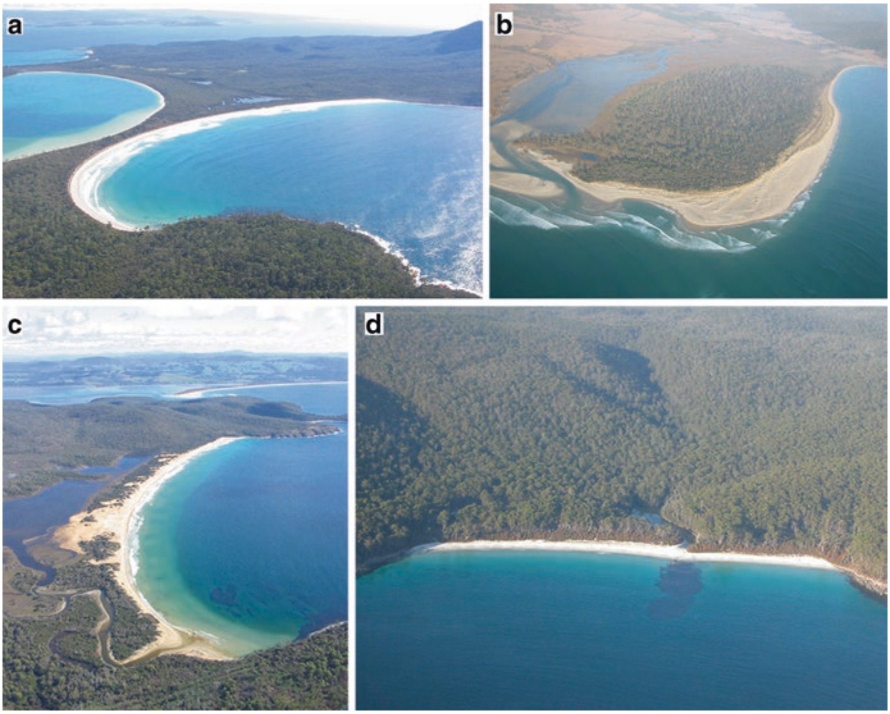

Fig. 21.15 (**a**) The McRae isthmus linking the two sides of Maria Island (MI 3–4); (**b**) wave refracting around Sandspit Point (TAS 276) a regressive barrier-spit; (**c**) Two Mile Beach (TAS 299) showing rip channels and active dune transgression and (**d**) Fortescue Bay (TAS 309) with a patch of gravel deposited by the creek in centre. (Photos: AD Short and W Hennecke)

There are just five barrier systems along this generally low energy coast; the largest Rheban Spit at the mouth of Sandspit Rivulet has a volume of 7.5 M m^3 (1364 m^3 m^{-1}). The spit has built eastward up to 1 km and is capped by a series of more than 20 low beach-foredune ridges, with southerly waves moving up the bay refracting around the spit transporting sand to the north (Fig. 21.15b). The spit was first mapped by Davies (1958b) who noted ongoing southward transport of sediment down the spit was leading to erosion of the northern half and truncation of the southern ridges followed by accretion. He proposed it has switched from a drift-aligned to swash-aligned shore. Thom et al. (1981) also investigated the spit and suggested that changes in swell direction may be responsible for the changing alignment. They also dated the inner ridges at ~5.5 ka, the central ridges between 4.9 ka and 4 ka and outer ridges at ~3.3 ka, with the outermost ridges not dated. The rivulet has infilled its lagoon and may be delivering limited bedload to the coast. In addition, southerly waves and strong tidal currents have deposited a large north-trending tidal shoal between the spit and the small Lachlan Island, which may also be a source of sediment from Mercury Passage. The remaining four barriers consist of one or two low stable foredunes and have a volume of just 1.6 M m^3 (315 m^3 m^{-1}).

Maria Island consists of two granite peaks: the northern 731 m high and the southern 324 m, with their granite slopes dominating the island and its 65 km long shoreline, with the entire island a national park. The peaks are linked by the low sandy 3 km long McRaes Isthmus (Fig. 21.15a), which has a volume of 18 M m^3 (3345 m^3 m^{-1}). The remainder of the island contains 19 small beaches occupying 19 km (26%) of the shore and nine small barriers totalling 1.8 M m^3, with most located along the northwestern shore of the northern peak. The isthmus has received sand from both the higher energy eastern shore and lower energy western shore, with greatest progradation (0.6 km) occurring on the western side. The eastern side has experienced past minor dune transgression, and both sides appear to be presently stable, suggesting the sediment supply on both sides has been exhausted.

21.12.3 SC:TAS01.03.03 Cape Bernier–Cape Frederick Hendrick

SC:TAS01.03.03 contains the larger Marion and smaller North bays, both curving east-facing beaches and barriers bordered by the high steep Cape Bernier, Cape Paul Lamanon and Cape Frederick Hendrick (Fig. 21.13b). The SC has a shoreline length of 31 km and contains 15 beaches dominated by the two bay beaches (8 km and 3 km long), in all totalling 14.8 km (48%) the other half of the coast generally steeply sloping dolerite. There are no coastal towns or communities in the SC. A few small creeks drain the slopes with Bream Creek deflected 5 km southward on Marion Beach indicative of the direction of longshore transport. Likewise, North Bay's Swan Lagoon also exists at the southern end of the bay. The main drainage is associated with the drowned Blackman Bay which is connected to the sea through the 200 m wide Marion Narrows, wedged between the tip of the barrier and rocky slopes to the south. The beaches are moderately sheltered by their location within the bays with wave energy also decreasing southward within the bays. The main bay beaches are LTT, with eight LTT beaches totalling 12.8 km in length (86%), followed by a couple of TBR and five small R. There are two low barriers the longer Marion Bay and Two Mile beaches, the latter with limited dune transgression (Fig. 21.15c), with volumes of 9.6 and 3.5 M m^3 (1170 m^3 m^{-1}), respectively. In contrast, the Narrows has a large tidal delta with the flood delta extending 4 km into the bay and the ebb 1.5 km seaward, with an area of 12 km^2 and volume on the order of 50 M m^3.

The bay has acted as a sediment sink for sand driven into the bay by wave and tidal flows to be deposited on the beaches and tidal deltas, with refracted southerly waves moving southward along both main beaches

21.12.4 SC:TAS01.03.04 Cape Fredrick Hendrick–Cape Pillar

SC:TAS01.03.04 contains the eastern shore of the rugged Tasman Peninsula, extending for 69 km from Cape Frederick Hendrick to Cape Pillar (Fig. 21.16). Apart from a few houses located at either end of Pirates Bay, there is little development on the coast, most of which is contained in the Tasman Peninsula Forest Reserve and the Eaglehawk and Cape Pillar state reserves. Beaches occupy just 5.8 km (8%) of the coast and are located in three separate embayments: the northern Lagoon Bay, the central Pirates Bay and southern Fortescue Bay (Fig. 21.15d). Most are small-sheltered R beaches apart from two longer TBR beaches which occupy most of the Pirates Bay beaches. There are four small barriers associated with the three bays, the largest the Pirates Bay (1 M m^3) with a stable foredune that rises to 20 m, while the other two have low stable foredunes totalling 0.75 M m^3 (390 m^3 m^{-1}). Each of the bays has acted as a sediment trap for the limited sand that has entered the bays.

21.12.5 PC Overview

PC:TAS01.03 is a generally sheltered rocky shore containing lower energy WD beaches and small regressive barriers, with only two substantial barriers at Nine Mile and Sandspit. Sand has moved northward into Great Oyster Bay, northwards in Mercury Passage and westward into the southern bays. However relatively little has been deposited in the low energy barrier systems, with more deposited in the few tidal deltas and on the Maria Island isthmus. There is limited coastal development with just a few small towns and communities and extensive areas of reserves. There is little at present risk, with future risk more related to rising sea level and inundation of the estuaries and wetlands than coastal erosion.

Fig. 21.16 SC:TAS01.03.03-04 and SA:TAS01.04-01-02. (Source: Google Earth)

21.13 PC:TAS01.04 Cape Pillar to South East Cape

PC:TAS01.04 occupies the southeast corner of Tasmania extending in a highly indented fashion from Cape Pillar (Fig. 21.17a), the southeastern corner, to the southern tip at South East Cape (Fig. 21.1), a direct distance of 100 km but shoreline distance of 583 km and a crenulation ratio of 5.8. The coast includes several large bays, estuaries and peninsulas plus 233 km long Bruny Island and is divided accordingly into six irregular SCs, which are discussed below. This is some of the most and least developed sections of the Tasmania coast, with the capital Hobart (200,000) situated on the Derwent River, with a regional predominately coastal population of another 20,000 including the towns of Kingston and Sorrell. The southern Huon-Bruny Island district has a total population of 19,000, with most of the small coastal communities numbering in the hundreds.

The coast has highly variable exposure to the predominant southern swell, ranging from high energy on exposed locations to sheltered TD shores within

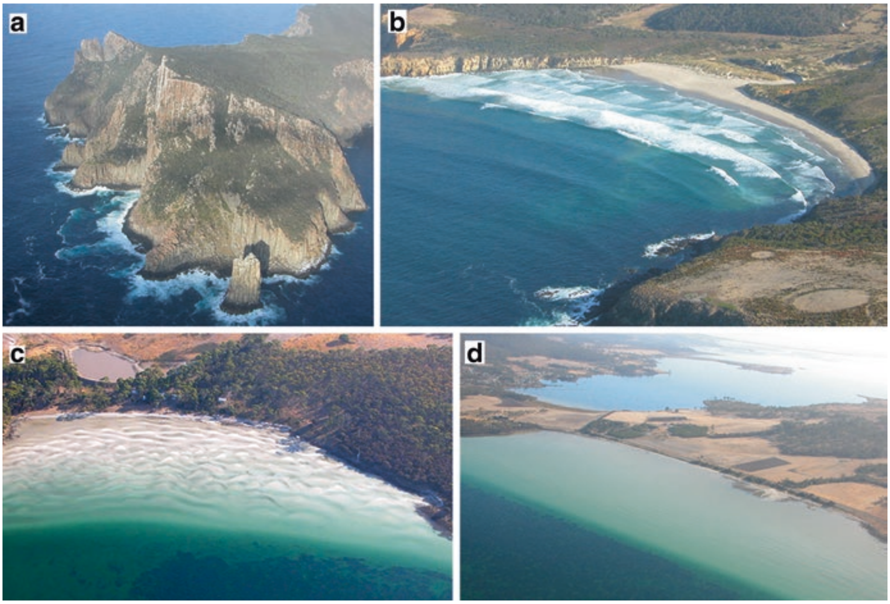

Fig. 21.17 (**a**) Cape Pillar is composed of vertical dolerite columns and rises 250 m; (**b**) high energy Roaring Beach (TAS 335); (**c**) the TD B+RSF Dalton beach (TAS 372) and (**d**) the 1.2 km wide ridged sand flats at Dunalley (TAS 377). (Photos: AD Short)

some of the bays. Spring tides remain micro ranging from 1.3 to 1.5 m (Fig. 21.4). Winds at Hobart are predominately northwesterlies in the morning, with some afternoon onshore south to southeasterlies (Fig. 21.5); however in general the westerly winds prevail and are strongest along the coastal strip between the Tasman Peninsula and Southwest Cape. Beach sand is generally moderately well-sorted, fine to medium quartz-rich sand (mean = 0.39 mm, carbonate = 15%) (Table 21.1 and Fig. 21.3). In the D'Entrecasteaux region, Davies (1978) found the beach sand was generally well sorted, fine (0.18 mm) with 5% carbonate. While there are 350 beaches, they occupy just 187 km (22%) of the coast, the bulk of the coast dominated by its heavily dissected and drowned geology (dolerite and sedimentary rocks) (Fig. 21.2) and their bedrock slopes, cliffs and rock platforms (Fig. 21.17a). The sheltered nature of much of this PC is reflected in the dominance of low energy R and LTT and TD beaches, with 207 R beaches (mean length = 0.37 km), 18 LTT (1.2 km) and 101 TD beaches mainly B+RSF and B+SF, which occupy 53 km of the coast (9%). There are 24 TBR which occupy 35 km (6%) of the more exposed section of the coast, as opposed to 153 km (26%) for the sheltered beaches. Likewise, the 45 barriers are generally small in size with a total volume of 162 M m^3 (2142 m^3 m^{-1}) (Table 21.3), more than half of this contained in the large Seven Mile Beach barrier. In general sand transport has been driven by the southerly swell northwards into the predominately south-facing bays (Maingon-Port Arthur, Storm-Fredrick Henry and the Derwent), the

D'Entrecasteaux Channel and Adventure and Cloudy on Bruny Island. More details are presented in the following six SCs (Table 21.4).

21.13.1 SC:TAS01.04.01 Cape Pillar–Outer North Head

SC:TAS01.04.01 occupies the 98 km long rugged and indented southern and western shore of the Tasman Peninsula (crenulation ratio = 2.7) with much of the coast located in the Cape Pillar and Cape Raoul state reserves, with Port Arthur (500) the only settlement of any note. The compartment extends for 98 km between Cape Pillar and Outer North Head (Fig. 21.16), most of it steep rocky shore with just 26 predominately sheltered R beaches and only two exposed TBRs (one the aptly named Roaring Bay, Fig. 21.17b), with a combined length of 11.5 km (12%). There are just four barrier systems totalling 12 M m^3 (2000 m^3 m^{-1}), the largest the climbing transgressive dunes extending for 0.7 km in from Roaring Bay, with a volume on the order of 10 M m^3. This is a rugged and generally steep rocky shore, with the small settlements around Port Arthur sheltered from ocean waves, with the only risk being future sea-level rise.

21.13.2 SC:TAS01.04.02 Outer North Head–Cape Contrariety

SC:TAS01.04.02 encompasses the large landlocked Norfolk Bay and the more open Fredrick Henry Bay, whose 21 km wide entrance between Outer North Head and Cape Contrariety opens into Storm Bay (Fig. 21.16) and receives refracted Southern Ocean swell (Davies 1958b). The compartment has an indented shoreline length of 167 km with a crenulation ratio of 8:1. The Coal (1029 km^2) and Carlton (136 km^2) rivers are the only major drainage into the bays, the Coal flowing into the Pitt Water barrier estuary behind Seven Mile Beach and the Carlton flowing into a drowned river valley. Neither are delivering sand to the coast.

There are 74 generally sheltered to very sheltered WD and TD beaches spread around the bay shores, with a total length of 45.5 km (27% of coast). They are dominated by the low energy R (24) and LTT (6) in Fredrick Henry Bay, with just two longer TBRs at the popular Carlton and Clifton surfing beaches. The very sheltered Norfolk Bay is dominated by R+RSF (27; Fig. 21.17c) and B+SF (15). The B+RSF average 9 ridges ($\sigma = 7$) close to the Australian average of 7, with widest at Dunalley having 28 ridges (Fig. 21.17d).

There are just 12 barriers located around the shore mainly in the outer Norfolk Bay and Fredrick Henry Bay, with a total length of just 31 km (18%). They have a combined volume of 120 M ^{3} (3914 m^3 m^{-1}) but are dominated by the large south-facing Seven Mile barrier at the head of Fredrick Henry Bay, with a volume of 96 M m^3. Thom et al. (1981) drilled and dated the Seven Mile ridges and found the dates were anomalously old (~10 ka) which they believe is due to mixing of older shells and recommended further dating to resolve the issue. This was undertaken by Oliver et al. (2017) who also investigated the barrier chronology and found it was initiated 7.3 ka when sea level reached at or near its present level. The barrier was possibly supplied by reworking relict terrestrial dunes sediments (Donaldson 2010) which were extinguished by 6.7 ka. This was followed by a pause to 3.6 ka following which progradation recommenced, with the new source from the floor of the bay, possibly aided by a slight fall in sea level. It then prograded up to 4 km into the bay as a swash-aligned beach-barrier until 1 ka. The outer ridges are now being reworked with some dune transgression. They also proposed that the exposed bay floor was a source of sand for southeast trending glacial parabolic dunes in the Carlton area.

Fredrick Henry Bay has acted as a major sediment sink and source with sand entering the bay and moving both longshore along the western shore and across the bay floor to the northern shore. Thom et al. (2018, Fig. 6) summarised the result of Byrne (2006) and Shand and Carley (2011) to develop a conceptual model of sand transport into the bay. They show that between 9500 and 13 000 m^3 $year^{-1}$ is being transported along the western receding Roches beach (Sharples 2010) and up to 60,000 m^3 $year^{-1}$ delivered to Seven Mile Beach from the bay floor. Bay sand is also being delivered to Carlton Beach and moving into the outer reaches of Norfolk Bay. In Norfolk Bay most of the beaches are very low energy separate TCs; however there has been enough sand mobilised to build the tidal sand flats which average 200 m in width and range from 50 to 500 m and enough wave energy to maintain the ridged sand flats (Fig. 21.7c and d)

21.13.3 SC:TAS01.04.03 Cape Contrariety–Tasman Head (Bruny Island-East)

SC:TAS01.04.03 contains the 10 km long south-facing end of South Arm, between Cape Contrariety and Cape Direction and the 75 km long eastern more exposed shore of Bruny Island, essentially the northern and western shore of Storm Bay (Fig. 21.18). The south-facing shores are exposed to moderate southerly swell entering the bay, with refracted waves reaching the east-facing shores, while spring tide range is 1.5 m at Hobart. A waverider buoy located in Storm Bay (CSIRO 2001) recorded a mean wave height of 1.2 m with a slight winter maximum up to 2 m, with a period ranging from 6 to 8 s, indicating it was recording more wind waves than swell. The exposed South Arm shore receives southerly wave averaging over 1 m and contains five rip-dominated TBR beaches including Calvert and the longer Hope Beach (South Arm Neck), the latter connecting Cape Direction to the mainland.

Bruny Island consists of a northern and southern half connected by the narrow 10 km long Neck, a sandy isthmus. On the eastern side of the island, the sandy Neck (Fig. 21.19a) is part of Adventure Bay, a curving 25 km long predominately sandy bay, with a 12 km wide entrance, and site of the largest community (150) of the island. The eastern shore of the island has 23 beaches which occupy 18.6 km (24%),

Fig. 21.18 SC:TAS01.04.03-06. (Source: Google Earth)

of the shore, most (16 km) located in Adventure Bay, the remainder sloping dolerite and sedimentary rocks. The beaches consist of 18 small embayed R on the northern and southern rocky sections with a mean length of 0.4 km and more exposed TBR on the longer Adventure Bay beaches (mean length 1.6 km) including the 10.3 km long Neck Beach and on a few of the southern more exposed pocket beaches.

The two South Arm barriers occupy 7.3 km of the shore and have a volume of 18 M m^3 (2465 m^3m^{-1}). They have received sand delivered from the Storm Bay sea bed deposited initially as narrow regressive barriers followed by minor dune trans-

Fig. 21.19 (**a**) view south of the Neck from its 20 m high foredune (BI 12); (**b**) the Lauderdale canal and part of the 1.6 km wide sand flats (TAS 439); (**c**) sandy foreland at Nutgrove Beach (TAS 454) appears to be transporting sand northwards and (**d**) small recurved gravel spit at Three Hut Pt (TAS 500) indicative of slow northward transport. (Photos: AD Short and W Hennecke)

gression. All the Bruny Island barriers are located in Adventure Bay and range from now stable dune transgression in the north (Miles Beach) to 10–20 m high stable foredunes along most of the Neck and southern beaches. They have a total volume of 10 M m^3 (622 m^3m^{-1}). It is likely that sand was transported from Storm Bay floor into Adventure Bay with limited northerly transport along the Neck Beach to supply the Miles Beach dunes; otherwise longshore transport within this compartment is very limited.

21.13.4 SC:TAS01.04.04 Bruny Island-South

SC:TAS01.04.04 is a small 36 km long compartment that takes in the southern shore of Bruny Island (Fig. 21.18). It basically consists of two rocky sections linked by the Cloudy Bay beaches in the centre. Steep dolerite cliffs rise to 300 m along the eastern Tasman Head coast and to 100 m on the western Cape Bruny. Ten small embayed

R beaches are found amongst the rocky sections, with the central Cloudy Bay containing three longer beaches totalling 6 km and ranging from LTT to TBR, and the western Lighthouse Beach TBR. There are three stable transgressive barriers extending up to 2.5 km inland in the east of the bay that have a total volume of 21 M m^3 (3088 m^3 m^{-1}). The main Cloudy Bay barrier impounds the 6 km^2 Cloudy Bay Lagoon, a barrier estuary with a permanent opening at its more sheltered western end. It has a 1.5 km^2 flood tide delta with a volume on the order of 15 M m^3. The U-shaped south-facing Cloudy Bay has acted as a sediment sink for sand delivered by the southerly waves. It appears that after initial barrier formation including some dune transgression and formation of the flood tide delta, the system has stabilised suggesting a cessation of shelf sand supply.

21.13.5 SC:TAS01.04.05 D'Entrecasteaux Channel

SC:TAS01.04.05 is another highly indented compartment which includes the lower Derwent River, Ralphs Bay, the D'Entrecasteaux Channel and the western coast of Bruny Island (Fig. 21.18). On the mainland it commences at Cape Direction and extends north into the Derwent and then down its irregular sheltered western shore to Tasman Head, a distance of 253 km, together with the 122 km long western shore of Bruny Island, a total shoreline of 375 km, the longest SC in Tasmania. This SC is feed by the larger Derwent and Huon rivers and smaller Esperance each of which enter drowned river valleys and supply no sand to the coast. The coastline is essentially a series of drowned valleys which provides a highly indented and irregular shoreline (crenulation ration = 4.7), all sheltered by Bruny Island from ocean waves. There are a total of 169 small sheltered beaches scattered along the mainland and island shore with an average length of 0.5 km and total length of 80 km (21%), the remainder of the shore largely sloping vegetated bedrock and some open water across the bay mouths. The beaches are a mix of low energy WD and TD, with 110 R and 21 B+RSF, 35 B+SF and three R+RF, with south-facing Roaring Bay the most exposed (Fig. 21.20a). The longest beach is the western side of the Neck, the 8 km long curving Isthmus Bay with its 800 m wide sand flats containing both ridged sand flats and shore transverse sand waves that may be indicative of sand transport.

There are a total of 31 small barriers, 11 on the west coast of Bruny Island and 20 on the mainland. Most consist of a low foredune or two, with the largest in Ralphs Bay located inside of South Arm where a series of low beach ridges have prograded 500 m into the bay (Fig. 21.19b). The island barriers total 2.5 M m^3 (300 m^3m^{-1}) and the mainland 6.2 M m^3 (275 m3 m^{-1}). The low energy and embayed nature of many of the beach, together with seagrass growing close to shore severely restricts sand transport, with perhaps some limited northerly transport along some of the western Hobart shore beaches between Blinking Billys Point and Lords Beach (Fig. 21.19c). For the most part, however, there appears to be limited northerly longshore transport, rather sand has slowly moved into the small bays

Fig. 21.20 (**a**) Roaring Bay beach (TAS 510) a partly sheltered LTT-TBR; (**b**) Elliott Beach (TAS 535) has sand bypassing the point (arrow) to partly fill the bay; (**c**) Southport Lagoon and its large tidal delta, with Big Lagoon beach to the left (TAS 540-1) and (**d**) Cockle Creek, inlet and beach (TAS 560) is a small stable barrier located deep in Rocky Bay. (Photos: AD Short)

(Fig. 21.19d) to build the beaches and barriers, with the greatest sand accumulations in the Isthmus and Ralphs bays tidal flats, the latter up to 2.5 km wide.

21.13.6 SC:TAS01.04.06 Russel Point–South East Cape

SC:TAS01.04.06 is the southernmost SC extending for 55 km from Russel Point, opposite the southern end of Bruny Island, to the southern tip of Tasmania at South East Cape (Fig. 21.18). This is an irregular southeast-facing shore containing both sheltered bay shores and a few exposed beaches. Most of the coast is contained within the Southport Lagoon Wildlife Sanctuary, the Recherche Bay State Recreation Area and the southern tip in the Southwest National Park. The only community is at Southport (150). Most of the coast is rocky with densely vegetated slopes, with 38 small beaches averaging 0.44 km in length and occupying 15.5 km (28%) of shore. Most of the beaches are small sheltered R averaging 0.3 km, together with five LTT and six TBR all located around the more exposed Southport Bluff and Big and Little Lagoon.

There are seven barrier which occupy just 9.5 km of coast (17%) and have a total volume of 6.5 M^3 (677 m^3 m^{-1}), all consisting regressive low foredune ridges. The largest, Big Lagoon barrier, is a 7 km long spit that has extended to the northeast across the entrance to Big Lagoon, a barrier estuary, and which has prograded on both the ocean and lagoon sides. An ~8 km^2 flood tide delta (Fig. 21.20c) fills the eastern half of the lagoon with a volume on the order of 80 M^3. A smaller tidal delta is located in the Southport Narrow which links to the drowned Hastings Bay. The small Cockle Creek barrier (Fig. 21.20d) is the southernmost in the State, also housing the southernmost community. This SC has received wave supplied shelf sand to partly infill and block the Southport Lagoon and for some to move westward along the northern bluffs towards the Narrows (Fig. 21.20b).

21.13.7 PC Overview

PC:TAS01.04 is a large and highly irregular and indented section of coast containing a series of drowned valleys which have formed bays, peninsulas, estuaries and islands, with a total shoreline length of 816 km, just 23% of which contains small predominately sheltered WD and TD beaches, with the bulk of the coast steep and rocky. While the coast faces south and Storm Bay allows waves to penetrate well inshore, most of the shores are aligned north-south or sheltered and exposed only to local wind waves, resulting in a generally low energy shore, as indicated by the fact that 82% of the beaches sheltered and just 18% more exposed. Likewise, the barrier volumes are relatively small, as it is typical of the region. There is limited longshore sand transport with most of the coast dominated by closed SCs and TCs including the larger Fredrick Henry-Norfolk and Storm bays. It does however contain the city of Hobart and the surrounding region, the most developed section of coast and estuaries in Tasmania whose risk level is discussed below. The main impacts on this coast will be related to the rising sea level which will reactive the estuaries and their flood tide deltas, generating more sand loss to the estuaries, activate shoreline recession and inundate low-lying areas.

21.14 Regional Overview

The east Tasmanian region, including eastern Flinders, Maria and Bruny Islands, is a low to moderate energy lee shore, with the dominant winds blowing offshore. The moderate waves have delivered relatively small volumes of sand to the coast to build numerous beaches but generally small barriers, with only one significant transgressive barrier system (Peron dunes). Davies (1973a, 1978) found there is a high degree of compartmentalisation with low rates of longshore transport with sediment trapped

Table 21.5 Tasmanian coastal erosion and inundation hazards by region, including high-, medium- and low-risk hazard bands

	Erosion no.	%	Inundation no.	%
Northeast	420	9.0	275	7.9
Southeast	834	17.9	630	18.1
Hobart	1705	36.5	1195	34.3
West	44	0.9	180	5.2
Northwest	978	20.9	895	25.7
Launceston	685	14.7	270	7.8
King Is	4	0.1	35	1.0
	4670	100	3480	100

Data from: Tasmanian Govt (2016)

within usually embayed compartments and with most transport being transverse to the shore and into dunes, rather than longshore. The geology dominates the entire coast which generally rises inland from the shore. Apart from Hobart, development is spread thinly and sporadically along the coast, with the majority of the coast located in a large number of parks and reserves. As a consequence, there is a generally low level of risk, with the greatest threat being from inundation of low-lying areas due to sea-level rise. The predominately rocky open coast in contrast will be more resilient.

Tasmanian Government (2016) provides a state-wide overview of the exposure to coastal hazards including sea-level rise, erosion and inundation. It includes tables listing of the number of residential building envelopes by coastal hazard band, LGA and locality. It was found state-wide that there were 4670 residential building envelopes at risk to erosion and 3480 at risk to inundation. In terms of coastal erosion hotspots where a number of residential houses are at risk, the greatest number is located in the Hobart region (1705) particularly at Lauderdale, Cremorne and Opossum Bay. Likewise, 1195 sites in the Hobart region are exposed to inundation. The report shows the risk is spread right around the Tasmanian coast and tends to be higher in the more developed regions, as indicated by Table 21.5. Maps of potential coastal erosion and inundation for the entire state are also available at https://nationalmap.gov.au

References

Bowden AR, Colhoun EA (1984a) Quaternary emergent shorelines of Tasmania. In: Thom BG (ed) Coastal geomorphology in Australia. Academic Press, Sydney, pp 313–349

Byrne G (2006) Roches Beach Lauderdale – coastal erosion study. Report to Clarence City Council by Vantree Pty Ltd

Chappell JF (1975) Wave study, Triabunna Harbour, east coast Tasmania. In: 2nd Australian conference on coastal and ocean engineering, Gold Coast, Institution of Engineers Australia, pp 26–29

CSIRO (2001) https://data.gov.au/dataset/wave-data-from-csiro-waverider-buoys-deployed-in-tasmanian-waters-1985-1993
Davies JL (1957) The importance of cut and fill in the development of beach ridges. Aust J Sci 20:51–54
Davies JL (1958a) Analysis of height variation in sand beach ridges. Aust J Sci 21:51–52
Davies JL (1958b) Wave refraction and the evolution of shoreline curves. Geogr Stud 5:1–13
Davies JL (1960) Beach alignment in southern Australia. Aust Geogr 8:42–44
Davies JL (1961) Tasmanian beach ridge systems in relation to sea level changes. Pap Proc R Soc Tasmania 95:35–40
Davies JL (1964) A morphogenic approach to world shorelines. Zeits fur Geomorphologie 8:127–142
Davies JL (1973a) Sediment movement on the Tasmanian coast. In: 1st Australian conference on coastal engineering, Sydney, Institution of Engineers Australia, pp 43–47
Davies JL (1973b) Geographical variation in coastal development. Longmans, London, 204 p
Davies JL (1974) The coastal sediment compartment. Aust Geogr Stud 12:139–151
Davies JL (1975) Beach sand and waves energy in Tasmania. Pap Proc R Soc Tasmania 105:58
Davies JL (1977) The coast. In: Jeans DN (ed) Australia: a geography. Sydney University Press, Sydney, pp 134–151
Davies JL (1978) Beach sand and wave energy in Tasmania. In: Davies JL, MAJ W (eds) Landform evolution in Australasia. Australian National University Press, Canberra, pp 158–167
Davies JL (1980) Geographical variation in coastal development, 2nd edn. Longmans, London, 212 p
Davies JL (1985) Tasmania. In: Bird ECF, Schwartz ML (eds) The World's Coastline, vol 1. Van Norstrand Reinhold Co, New York, pp 975–997
Davies JL, Hudson JP (1987a) Differential supply and longshore transport as determinants of sediment distribution on the North coast of Tasmania. Mar Geol 77:233–245
Davies JL, Hudson JP (1987b) Sources of shore sediment on the north coast of Tasmania. Proc R Soc Tasmania 121:137–151
Donaldson P (2010) Facies architecture and radar stratigraphy of the Seven Mile spit somplex, Tasmania. School Earth Science, University of Tasmania, Hobart, 147 p
Kalma JD, Chin AK (1988) Windspeed maps for Tasmania and their use in wind energy assessment. Aust Geogr Stud 26:264–278
Murray-Wallace C, Goede A (1995) Aminostratigraphy and electron spin reconnaissance dating of Quaternary coastal neotectonism in Tasmania and Bass Strait islands. Aust J Earth Sci 42:51–67
Oliver TSN, Thom BG, Woodroffe CD (2016) Formation of beach-ridge plains: an appreciation of the contribution by Jack L. Davies. Geogr Res 55:1–16. https://doi.org/10.1111/1745-5871.12193
Oliver TSN, Donaldson P, Sharples C, Roach M, Woodroffe CD (2017) Punctuated progradation of the Seven Mile Beach Holocene barrier system, southeastern Tasmania. Mar Geol 386:76–87
Oliver TSN, Kennedy DM, Tamura T, Murray-Wallace CV, Konlechner TM, Augustinus PC, Woodroffe CD (2018) Interglacial-glacial climatic signatures preserved in a regressive coastal barrier, southeastern Australia. Palaeogeogr, Palaeoclimatol, Palaeoecol 501:124–135. https://doi.org/10.1016/j.palaeo.2018.04.011
Shand TD, Carley J (2011) Investigation of trial groyne structures for Roches Beach, Report to Clarence City Council by Water Research Laboratory. University of New South Wales, Sydney
Sharples C (2010) Shoreline change at Roches Beach, south-eastern Tasmania, 1957–2010. Report to Antarctic Climate and Ecosystems Co-operative Research Centre. University of Tasmania, Hobart
Short AD (2006) Beaches of the Tasmanian coast and islands. Sydney University Press, Sydney, 353 p

Tasmania Govt (2016) Coastal Hazards Technical Report: mitigating natural hazards through land use planning and building control. Department of Premier and Cabinet, Tasmanian Government, Hobart, 125 p

Thom BG, Bowman GM, Gillespie R, Temple R, Barbetti M (1981) Radiocarbon dating of Holocene beach-ridge sequences in south-east Australia. Department of Geography, University of New South Wales, Royal Military College, Duntroon, 36p

Thom BG, Eliot I, Eliot M, Harvey N, Rissik D, Sharples C, Short AD, Woodroffe CD (2018) National sediment compartment framework for Australian coastal management. Ocean Coast Manag 154:103–120

Chapter 22
Great Southern Division

Abstract The Great Southern division spans 8055 km of coast from the southern tip of Tasmania across the south coast to Cape Leeuwin, the southwest tip of the continent. This is a generally exposed south-facing shore with the open coast receiving persistent moderate to high southerly swell and strong south through westerly winds, together with more sheltered areas along the north Tasmanian coast, Western Port, Port Phillip, northern Kangaroo Island and the SA gulfs. The climate ranges from the Mediterranean in the south to semi-arid in the Bight, and rivers are few, usually dry or absent. Tides are micro on the open coast increasing to meso in some of the sheltered area. Sediments are derived from shelf carbonate on the open coast and seagrass meadows in the sheltered areas, with carbonate-rich sediment dominating most of the coast. Beaches are wave-dominated on the open coast and tide-modified and tide-dominated in the sheltered sections. Barriers range from regressive to massive Holocene dune transgression including numerous clifftop dunes, most blanketing Pleistocene dune calcarenite. This chapter reviews the geology, coastal processes, sediment, biological processes, beaches and barrier of the division.

Keywords Southern Australia · Southern Ocean · Coastal processes · Waves · Micro-tides · Meso-tides · Beaches · Barriers

22.1 Introduction

The Great Southern division is the longest and most dynamic of Australia's seven coastal divisions. It spans a massive 8055 km from South East Cape at the southern tip of Tasmania, across Bass Strait, then from Wilsons Promontory along the central-western Victorian coast, all of the South Australian coast, including Kangaroo Island, the Great Australian Bight and the south Western Australian coast to the southwest tip of the continent at Cape Leeuwin (Fig. 22.1). The entire coast faces into the Southern Ocean and its prevailing and persistent southwest swell and strong westerly wind stream. It is a coast that has been battered by high waves and winds for millennium, a battering that is expressed in its high energy beaches, massive sand transport and massive dunes and barrier systems. There are, however, also

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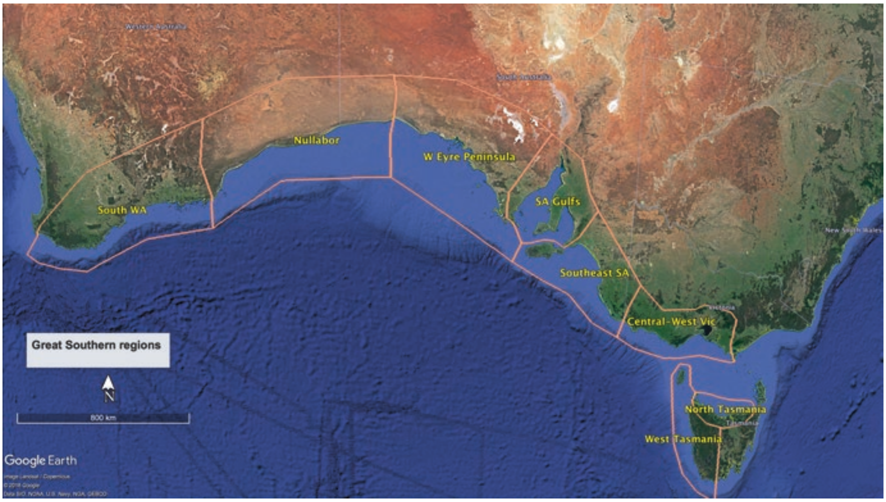

Fig. 22.1 The Great Southern division and its eight regions. (Source: Google Earth)

sheltered sections in northern Tasmania, Western Port and Port Phillip, the SA gulfs, some of the Eyre Peninsula bays and parts of the western Nullarbor coast, where other processes come into play. The division contains 8 regions, 30 PCs (Table 22.1) and 106 SCs, all of which are discussed in the following 8 chapters (Chaps. 23, 24, 25, 26, 27, 28, 29 and 30). Chapters 1 and 16 also provide an overview of the geology, climate and coastal processes along the southern Australian coast, which are briefly summarised in this chapter.

22.2 Geology

The geology in the east commences with the rugged Kanmantoo Fold Belt in western Tasmania which continues up through western Victoria, with the Bass and Otway basins in between (Figs. 1.2 and 1.3). The large Murray Basin lies between the Kanmatoo Fold Belt and the Adelaide Fold Belt which extends from Kangaroo Island up through the SA gulfs. The more ancient Gawler Craton extends across the Eyre Peninsula, with the flat Nullarbor Plain separating it from the ancient Yilgarn Craton in the south of Western Australia, which is fringed along the south coast by the Bremer Basin. The coast is dominated both by its bedrock geology and the more recent Quaternary dune calcarenite which blankets most of the exposed high energy coast, forming rock, reefs, islets, islands, bluffs, cliffs and lithified barriers, all part of the world's greatest temperate carbonate province (Short 2013).

Table 22.1 Great Southern division, 8 regions and 30 PCs

PC No.[a]	Name	Boundaries	Beach ID[b]	No. beach	km[c]	Total km
West Tasmania						
TAS02.01	SW Tasmania	South East C-South West C	TAS 566-614	49	1097–1227	130
TAS02.02	West Tasmania	SW C-C Sorell	TAS 615-789	175	1227–1540	313
TAS02.03	W Tas+W King Is	C Sorell-C Wickham	TAS 790-964	175	1540–1798	258
			KI 46-80	35	96–196	100
North Tasmania						
TAS03.01	NW Tasmania	Hunter Is-Regatta Pt	TAS 965-1138	174	1798–2012	214
TAS03.02	North Tasmania	Regatta Pt-C Portland	TAS 1139-1269	131	2012–2237	225
TAS03.03	W Flinders Is	C Sir John-Stanley Pt	FI 29-133	105	FI 109–235	126
TAS03.04	E King Is	C Wickham-Stokes Pt	KI 1-15	45	KI 1–96	96
Central and western Victoria						
VIC03.01	Central Victoria	South Pt-Pt Lonsdale	VIC 107-280	174	449–760	311
	Port Phillip		PP 1-132	306	0–260	260
VIC03.02	Surf Coast	Pt Lonsdale-C Otway	VIC 281-410	130	763–902	139
VIC03.03	West Victoria	C Otway-Pt Danger	VIC 411-560	152	902–1232	330
			SA 1-2	2	0–14	14
Southeast SA						
SA01.01	SE of SA	Danger Pt-C Jaffa	SA 3-147	145	14–216	202
SA01.02	The Coorong	C Jaffa-Middleton Rocks	SA 148-149	2	216–428	212
SA01.03	S Fleurieu	Middleton Rocks-C Jervis	SA 150-186	27	428–502	74
		NE Kangaroo Is	KI 45-57	50	KI 76–113	111
SA01.04	Kangaroo Is	C Willoughby-C Borda	KI 58-145	88	KI 113–345	232
SA gulfs						
SA02.01	Kangaroo Is	C Borda-C Spencer	KI 146-44	73	KI 345–76	190
	SA gulfs		SA 187-391	322	SA 502–945	443
SA02.02.	SA gulfs	C Spencer-C Catastrophe	SA 392-803	412	945–1924	979

(continued)

Table 22.1 (continued)

PC No.[a]	Name	Boundaries	Beach ID[b]	No. beach	km[c]	Total km
W Eyre Peninsula						
SA03.01	Eyre Peninsula	C Catastrophe-C Radstock	SA 804-1092	289	1924–2401	477
SA03.02	Eyre Peninsula	C Radstock-Pt Peter	SA 1093-1305	213	2401–2770	369
SA03.03	Eyre Peninsula	Pt Peter-Hd of Bight	SA 1306-1441	136	2770–3067	297
Nullarbor coast						
SA03.04	Nullarbor Cliffs	Hd of Bight-Wilson Bluff	SA 1442–1454	13	3067–3273	206
WA01.01	Roe Plain	Wilson Bl-Twilight Cove	WA 1–16	29	0–308	308
WA01.02	Baxter Cliffs	Twilight Cove-Pt Culver	WA17–18	2	308–450	142
WA01.03	Bilbunya coast	Pt Culver-C Palsey	WA 19–52	34	450–638	188
Southeast WA						
WA02.01		C Palsey-Shoal C	WA 53-186	134	638–966	328
WA02.02		Shoal C-Red Is	WA 187-277	91	966–1116	150
WA03.01		Red Is-Herald Pt	WA 278-387	110	1116–1436	320
WA03.02	King George Sd	Herald Pt-Bald Hd	WA 388-411	24	1436–1467	31
WA04.01		Bald Hd-Pt Nuyts	WA 412-522	111	1467–1636	169
WA04.02		Pt Nuyts- Pt D'Entré.	WA 523-569	47	1636–1704	68
WA04.03		Pt D'Entré.-C Leeuwin	WA 570-617	48	1704–1818	114
		Division total		**3764**		**8055**

[a]NCCARF compartment number
[b]ABSAMP beach ID
[c]Clockwise distance from state borders or northern tip of islands

22.3 Climate

The southern coast is influenced by the sub-tropical high in the north and the migratory midlatitude cyclones (subpolar lows) to the south, the highs bringing calmer drier conditions, while the lows deliver cooler weather, frontal precipitation and westerly winds. The lower latitude Great Australian Bight (~31–34°S) coast is dominated by the high and has semi-arid (BSk) conditions across the central Bight. The east and west coasts extend into higher latitudes and come under the increasing influence from the lows with winter rainfall and a Mediterranean climate (Csb) prevailing across central-western Victoria (38–39°S) through to Streaky Bay in South Australia (32°S) and on the southern Western Australian coast (34–35°S). Further south in Tasmania (39–43°S), the climate is dominated more by the lows and is both cooler and more humid with a temperate humid climate (Cfb) and year-round rainfall (Fig. 1.5a and b; Fig. 1.8; Table 16.2). From the east rainfall ranges from a high 1320 mm at Strahan to 530 mm at Adelaide to a low of 275 mm at Eucla and then increases westwards to 617 mm at Esperance and 960 mm at Cape Leeuwin. Daily mean temperatures range from a summer daily mean of 15 °C in Tasmania to 20 °C across the Bight and in winter from 10 °C in Tasmania to 15 °C across the Bight (Fig. 1.5c, d). Winds are predominately westerly, ranging from due west in Tasmania to southwest across the Bight.

22.4 Coastal Processes

The coast is for the most part micro-tidal (<2 m), with meso-tides up to 3 m occurring in Bass Strait (north Tasmania and central Victoria) and in the upper St Vincent and Spencer gulfs, while the south Western Australian coast has the smallest tides in Australia (~0.5 m) (Fig. 1.15; Table 16.3). Then entire open coast receives wave generated by the midlatitude cyclones that track continuously across the Southern Ocean south of Australia (Fig. 16.3), together with local westerly wind and sea breeze waves. Combined they deliver a very energetic deepwater wave climate with waves averaging 3 m on the west coast of Tasmania and 2–2.5 m along much of the southern coast (Figs. 1.11, 1.12a and 16.4). The entire open coast is WD, with TM and TD conditions in the more sheltered meso-tidal areas.

22.5 Shelf Waves

Two types of shelf waves impact the southern coast (see Sect. 16.4.4). Progressive waves move from east to west with periods of 5–20 days and commonly reach 0.5 m and can be as high as 1.5 m (Provis and Radok 1979). As the open coast is micro-tidal, the shelf waves are a major component of the actual water level and can exceed the tide range. The second type, standing waves, are produced by seasonal shifts in the pressure systems and can cause the water level to be raised or lowered a few decimeters for period of days to weeks along long sections of the coast.

22.6 Ocean Currents

The strong cool Antarctic Circumpolar Current passes well south of the continent, with weaker currents closer to the coast driven by the westerly winds (Fig. 1.18). The warm Leeuwin Current which flows down the western coast rounds Cape

Leeuwin and can break into series of easterly trending warm core eddies, some of which make it all the way to Bass Strait and western Tasmania.

22.7 Sea Surface Temperature

Figure 1.17 shows the summer and winter Southern Ocean SST, which range from a low of 12 °C during winter in Tasmania to a high of 22 °C during summer in the SA gulfs. Across most of the southern coast, temperatures range from 14 to 16 °C in winter and 18 to 20 °C in summer.

22.8 River and Estuaries

The only river of note on this coast is the Murray-Darling, Australia's largest river system, which rises in the eastern highlands (Fig. 1.9), but which, owing to massive water extraction, cannot maintain an open river mouth and which is not presently delivering sand to the coast. Most other rivers and creeks are small, with many flowing into usually blocked coastal lagoons and a 2100-km-long section of the Bight having no rivers or creeks whatsoever (Fig. 1.9).

22.9 Coastal Sediments

The entire Great Southern division, apart from southwest Tasmania and southwest WA, is a carbonate-rich province (Fig. 1.10) with the sediment derived from the inner shelf benthic flora and fauna and in sheltered waters from seagrass meadows (Sect. 16.5.3). Along most of the mainland coast, carbonate ranges from 60% to 80%, decreasing to between 20% and 30% along the more humid TAS and southwest WA coasts where quartz sand dominates. Grain size is predominately fine to medium and well sorted.

22.10 Sediment Transport

Most of the open coast beaches are swash-aligned with predominately on-offshore transport and little longshore transport. There has been massive onshore transport into the Murravian Gulf since the Pliocene (Murray-Wallace and Woodroffe 2014) (Fig. 1.28) with each sea level high stand adding more sand. Today longshore transport is limited to the lower energy north-south trending shores in the SA gulfs and into some of the western Eyre Peninsula bays and on parts of Kangaroo Island. These will all be discussed in the following chapters.

22.11 Sea Level

Figure 1.42 presents general sea level curves for the Australian coast. The last interglacial attained a sea level ~2 m above present along the south WA, Eyre Peninsula and adjacent regions (Murray-Wallace and Belperio 1991), while tectonics in the SA gulfs and western VIC causes regional variability, reaching 10 m in St Vincent Gulf and 16 m near Mount Gambier. During the Holocene the PMT reached its present level ~6.4 ka followed by variable regression of between 1 and 3 m, the regional variation also due to regional tectonism which is causing slow uplift in western Victoria-southeast of SA (Murray-Wallace et al. 2002) and northern Tasmania (Murray-Wallace and Goede 1995). In the tectonically active upper Spencer Gulf, Belperio et al. (1984) detected a 2.5 m higher mid-Holocene sea level. In southern WA, Baker et al. (2005) found that for the south and southwest coasts' regional sea level rose to peaks at 6.5 and 4.2 ka followed by sharp ~1 m falls at 5.2 and 3.8 ka. Because of the regional synchronicity, they found no evidence of local tectonism or hydro-isostatic influence.

22.12 Biological Processes

Biological processes have played a major role in the development of the southern coast owing to the predominance of carbonate-rich sand derived from inner shelf and seagrass meadows biota (Short 2013) (see Sects. 16.5.3 and 16.5.4). The shelf provides a range of benthic flora and fauna whose detritus is eroded by waves and transported shoreward from depths out to 70 m (Fig. 16.9), arriving at the shore as fine though coarse, white though brown sand (Fig. 16.10). In the sheltered gulfs and bays, seagrass meadows also supply epifauna as shell detritus to the shore (Fig. 16.8). One species of mangroves (*Avicennia*) occurs on the southern coast and is restricted to Western Port in Victoria and the SA gulfs and western bays, with none in Tasmania or the south WA coast. Extensive temperate seagrass meadows are found in all sheltered locations including the SA gulfs, Eyre Peninsula bays and sheltered parts of the Nullarbor coast. The dunes vegetation is well adapted to the climate, and even in the semi-arid Bight region, 90% of the dunes are vegetated and stable.

22.13 Beach Systems

The Great Southern division has 3734 beaches which occupy 4672 km (58%) of the coast, with an average length of 1.2 km (Table 22.2). West TAS has the shortest (mean = 0.6 km) and lowest proportion of beaches at 31% and the southern SA the highest at 68%, a figure which includes Australia's longest beach, the 194 km long Coorong. The open coast beaches are exposed to the full force of the southwest Southern Ocean swell which prevails year-round (Fig. 16.4). The waves and

Table 22.2 Great Southern beaches by region

Region	Number	Length (km)	Mean length (km)	% coast
West Tasmania	434	247	0.6	31
North Tasmania	425	383	0.9	58
C-W Victoria	588	601	1.0	57
SE of SA	285	517	1.8	68
SA gulfs	734	1028	1.4	64
Western Eyre	638	639	1.0	56
Nullarbor	65	484	7.3	57
SE of WA	565	773	1.4	66
Total	3734	4672	1.2	58

micro-tides combine with the fine to medium sand to maintain a full range of WD beaches including several 500 m wide multibar D systems (Fig. 22.2a). In the sheltered sections of Kangaroo Island, the meso-tidal upper SA gulfs and sheltered bays on the Eyre Peninsula, a range of TM and particularly TD beach dominate (Fig. 22.2b). The beaches and their transport systems are presented in the Chaps. 23, 24, 25, 26, 27, 28, 29 and 30, while Short (1996, 2001, 2005, 2006) provides a description of all the southern coast beach systems.

22.14 Barrier Systems

This is a high wave and wind energy coast which is reflected in the nature and size of the barriers. The division has a total of 602 barrier systems which occupy 3836 km (48%) of the coast and have an area of 8078 km^2 (Table 22.3). They range from regressive beach and foredune ridge systems (Fig. 22.3a), some up to 5 km wide, to massive primary and secondary dune transgression in place extending tens of kilometres inland. The dunes include hundreds of kilometres of clifftop dunes (Fig. 22.3b), most of which have had their source beaches and ramps completely eroded, stranding them on top of the cliffs. The barriers include most of Australia's largest barrier systems by volume and volume per metre (Table 22.3), with the southeast of WA region averaging 58,254 m^3 m^{-1}, the highest regional volume in Australia (Appendix 34.2). Most of the barriers are stable (82%); however there are a number of predominately unstable systems along the southeast SA, Eyre Peninsula and Nullarbor coasts.

22.15 Division Summary

The Great Southern division is the largest in Australia spanning 8055 km of coast and exposed to persistent high waves and strong westerly winds. The coast is predominately tectonically stable with last interglacial deposits and landforms spread along the entire coast, with most now onlapped or overlapped with extensive

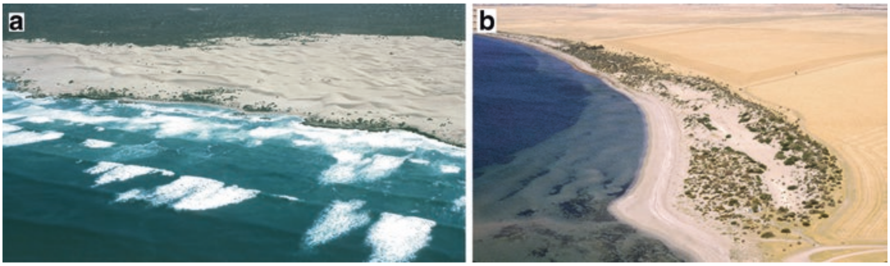

Fig. 22.2 (**a**) High energy D at Coymbra (SA 1419), with low calcarenite bluffs and backing transgressive dunes and (**b**) low energy beach at Perforated Rocks in Streaky Bay (SA 1179) with ridged sand flats fringed by seagrass and a partly stable blowout, with farmland almost to the shore. (Photos: AD Short)

Table 22.3 Great Southern barriers by region

Region	No.	Volume (M m^3)	Length	Volume (m^3 m^{-1})
West Tasmania	88	6585	228	28,877
North Tasmania	94	3757	257	14,647
C-W Victoria	73	13,975	262	53,340
SE of SA	26	21,141	479	44,100
SA gulfs	99	2769	619	4473
Western Eyre	84	20,245	711	28,457
Nullarbor	16	16,705	522	32,000
SE of WA	122	44,151	758	58,254
Total	602	129,328	3836	33,714

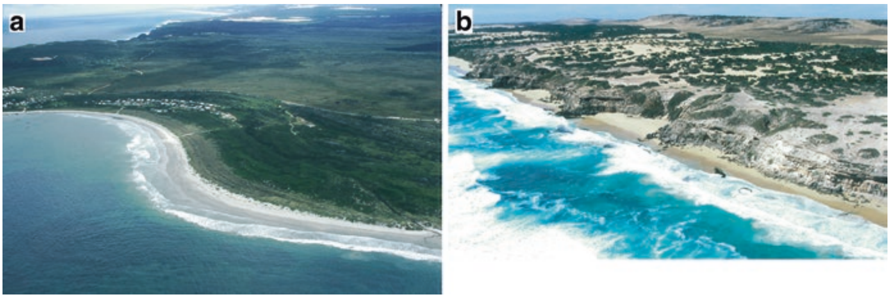

Fig. 22.3 (**a**) Low energy LTT beach and regressive foredune ridges at Windy Harbour (WA 568) and (**b**) parabolic clifftop dunes on top of 30 m high calcarenite bluffs at Convention Beach (SA 979–982). (Photos: AD Short)

Holocene deposits. Sediments are largely derived from the shelf, and in sheltered areas seagrass meadows, and are deposited as beach-barrier systems that occupy much of the coast, with often massive transgressive dunes including clifftop dunes dominating the open coast and regressive systems in more sheltered areas. Apart from the major cities of Melbourne and Adelaide and several regional coastal centres much of the coast in lightly to undeveloped with in places hundreds of kilometre of undeveloped coastline together with extensive section of national parks and reserves.

References

Baker RGV, Haworth RJ, Flood PG (2005) An oscillating Holocene sea-level? Revisiting Rottnest Island, Western Australia, and the Fairbridge eustatic hypothesis. J Coast Res SI 42:3–14

Belperio AP, Hails JR, Gostin VA (1984) The stratigraphy of the coastal carbonate banks and Holocene sea levels of northern Spencer Gulf, South Australia. Mar Geol 61:297–313

Murray-Wallace CV, Belperio AP (1991) The last interglacial shoreline in Australia – a review. Quat Sci Rev 10:441–461

Murray-Wallace C, Goede A (1995) Aminostratigraphy and electron spin reconnaissance dating of Quaternary coastal neotectonism in Tasmania and Bass Strait islands. Aust J Earth Sci 42:51–67

Murray-Wallace CV, Woodroffe CD (2014) Quaternary sea-level changes: a global perspective. Cambridge University Press, Cambridge, 484 p

Murray-Wallace CV, Banerjee D, Bourman RP, Olley JM, Brooke BP (2002) Optically stimulated luminescence dating of Holocene relict foredunes, Guichen Bay, South Australia. Quat Sci Rev 21:077–1086

Provis DG, Radok R (1979) Sea-level oscillations along the Australian coast. Aust J Mar Freshwat Res 30:295–301

Short AD (1996) Beaches of the Victorian Coast and Port Phillip Bay. Sydney University Press, Sydney, 298 p

Short AD (2001) Beaches of the South Australian coast and Kangaroo Island. Sydney University Press, Sydney, 346 p

Short AD (2005) Beaches of the Western Australian Coast: Eucla to Roebuck Bay. Sydney University Press, Sydney, 433 p

Short AD (2006) Beaches of the Tasmanian Coast and Islands. Sydney University Press, Sydney, 353 p

Short AD (2013) Australia's temperate carbonate coast: sources, depositional environments and implications. In: Martini P, Wanless HR (eds) SP388 Sedimentary coastal zones from high to low latitudes: similarities and differences. Geological Society of London SP388, London. https://doi.org/10.1144/SP388.5

Chapter 23
West Tasmania Region

Abstract The west coast of TAS is the most exposed on the Australian coast. It has a humid cool temperate climate and is exposed to the full force of the Southern Ocean westerly waves and winds which batter the predominately rocky shore. The 700 km long coast extends from Tasmania's southern tip at South East Cape to the northwestern tip at Woolnorth Point and includes the western coast of King Island. It is a sparcely developed coast, with the southern half located in national parks and conservation areas and little development elsewhere. A few small rivers reach the coast and sediment and are predominately quartz-rich. Waves average 2–4 m, and tides are micro resulting in entirely wave-dominated beaches. Most beaches are embayed between rocky sections and average only 0.6 km in length, with many also sheltered in rocky bays resulting in lower-energy beach states. Barriers back a quarter of the rocky shore and are predominately transgressive dunes with a few small regressive systems in sheltered areas. This chapter described the coast, its beaches, barriers, sediment transport and sediment compartments.

Keywords West Tasmania · Southern Ocean · King Island · Coastal processes · Beaches · Barriers · Sediment transport · Sediment compartments

23.1 Introduction

The west coast of TAS is one of the most exposed, wildest, remotest and least developed sections of the Australian coast, with the entire southern half contain in the Southwest National Park and Conservation Area and much of the northern half in the Arthur-Pieman Protected Area. The region extends up to the west coast for 701 km from South East Cape to Woolnorth Point and another 100 km from Stokes Point to Cape Wickham on King Island, a total shoreline of 801 km (Fig. 21.1a). The entire coast faces generally west into the full force of the Southern Ocean waves and winds, which daily deliver long swell averaging 2–3 m, predominately strong westerly winds (Fig. 21.5) and rainfall reaching up to 2400 mm (Fig. 1.5) all which have battered the coast for millennium.

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https://doi.org/10.1007/978-3-030-14294-0_23

Fig. 23.1 The doleritic South East Cape the southern tip of Tasmania. (Photo: AD Short)

There are no towns on the coast, with the only regional towns being Strahan (650 population) in Macquarie Harbour and Marrawah (400) in the north, together with very small coastal/fishing/shack communities at Trial Harbour (25), Granville Harbour (30) and Temma (10). Likewise, access to the coast is limited to these and nearby locations.

The west coast geology is an extension of the Kanmantoo Fold Belt (Fig. 1.2) and is largely composed of resilient Precambrian sedimentary, metasedimentary and volcanic rocks (Fig. 21.2). Geology plays a major role along the coast controlling the orientation and forming numerous rock reefs, islets, small islands, points and headlands (Fig. 23.1) and contributing directly to the predominately rocky shoreline which occupies 554 km (69%) of the coast.

The climate is oceanic (Cfb, Fig. 1.8), with year-round frontal and orographic rainfall. Precipitation rises from ~1200 mm at the coast to over 2400 mm on the West Coast Range (Fig. 1.5a, b) that reached to over 1000 m. Mean monthly maximum temperature ranges from 18 °C in summer to 12 °C in winter (Fig. 1.5c, d).

23.2 Rivers and Creeks

The west coast rises to the West Coast Range whose crest is usually located with 50 km of the coast and reaches heights averaging several hundred metres. The range is drained by numerous small streams and a few small- to moderate-sized rivers. There are on the order of 140 creeks and small rivers reaching the coast, most with a catchment of just a few hundred square kilometres. The only larger systems are the

Macquarie Harbour catchment, and the Pieman and Arthur rivers. The main rivers from the south are Lousia, Old, Spring (125 km^2), Davey, Giblin (350 km^2), Lewis (211 km^2), Urquhart, Wanderer (351 km^2), Spero (154 km^2), Macquarie Harbour (Gordon and King, 7049 km^2), Henty (530 km^2), Little Henty (359 km^2), Pieman (3925 km^2) and Arthur (2496 km^2). Most of the rivers flow into drowned river valleys depositing bay head deltas and delivering no sand to the coast, however Davies (1973) did find that the Wanderer, Henty, Pieman, Pedder and Arthur are delivering limited amount of quartz sand to their mouths. Also, any of the smaller streams and groundwater drain across the beaches, saturating the beaches and inducing greater instability across the beach and backbeach.

23.3 Sediments and Processes

The west coast has a range of sediment types, with the mean size ranging from fine to medium, and carbonate from 1% to 65% (Fig. 21.3), all indicative of localised sources and lack of longshore sand transport. Davies (1973, 1978) in the most detailed study of west coast beach sand found the beach sand remarkably uniform in sorting and size, with the south, southwest and northwest coast all dominated by well-sorted, fine sand (mean = 0.23 mm). He found however two carbonate provinces. South of Conical Rocks (just south of the Pieman River), the sand is quartz-rich (13% carbonate, while to the north, they are carbonate rich (24%) being composed of shell particles including detritus from sponges, echinoderms, foraminifera and bryozoan. He also found the Wanderer, Henty, Pieman, Pedder and Arthur rivers are delivering limited amounts of terrigenous sand to the coast and diluting the otherwise carbonate-rich sand. This sand however remains near the mouths with little longshore transport, apart from the Hentry rivers which supply quartz sand to the long Ocean Beach.

The entire coast is micro-tidal, with spring tides ranging from 0.8 m at the southern Bramble Cove (Port Davey) to 1.2 m at Granville Harbour. It is also exposed to one of the world's highest energy wave climates, derived from the high-energy southwest swell generated by midlatitude cyclones that track continuous south of Australia (Fig. 16.3). The Cape Sorell waverider recorded an average daily $H_s = 3$ m and $H_{max} = 5$ m, with a period from 12 to 15 s. The waves gradually increase in height during winter to a September maximum ($H_s = 4$ m, $H_{max} = 6$ m), decreasing between November and January ($H_s = 2$ m, $H_{max} = 4$ m). The net result is year-round high waves (2–4 m) (Fig. 16.4). The combination of high waves and microtides result in an RTR ~ 0.5 and entirely WD coast and beaches. Breaker wave height is however highly variable owing to the prevalence of inshore rocks, reefs and islets, lowering the waves in many locations, on an otherwise high-energy coast.

Figure 21.5 illustrates the dominance of westerly winds at Cape Sorell which is typical of the west coast. Kalma and Chin (1988) found that the entire west coast including King Island is exposed to strong westerly winds and has the highest wind speeds in TAS with winds generally >6 m s^{-1} and reaching to 8–9 m s^{-1}.

23.4 Beaches

The persistent high waves along this coast maintain some of Australia's highest energy beaches, including Ocean Beach (Strahan) which is both the highest energy beach in Australia and the longest (33 km) and highest energy on the west Tasmanian coast. In addition, there are many beaches sheltered by the numerous rocks, reefs and headlands, resulting in small, deeply embayed lower-energy R being the greatest by number (242) but as they average only 0.3 km in length occupy just 70 km (28%) of the coast, while there are 126 higher-energy TBR averaging 0.7 km which occupy 90 km (37%) of the coast and two longer RBB (10%) and the dissipative Ocean Beach (13%) (Table 23.1). In all, there are 434 beaches (including western King Island) which occupy 247 km (31%) of the coast, the details of which are provided in Short (2006).

23.5 Barriers

There are 88 barrier systems along the coast which occupy 228 km (28%) of the coast. They are smallest along the rugged and indented southwest coast (PC:TAS02.01) (104 M m^3, 4350 $m^3\ m^{-1}$) where 14 barriers occupy just 24 km (18%) of the coast. They increase in number and size up the west coast (PC:TAS02.02) (496 M m^3, 14,476 $m^3\ m^{-1}$) with 35 barriers occupying 34 km (11%) of the coast, and are largest along the northern west coast including King Island. The northwest 'mainland' coast (SC:TAS02.03.01-06) has 28 barriers with a volume of 3832 M m^3 (32,042 $m^3\ m^{-1}$), while western King Island (SC:TAS02.03.08) was 11 barriers with a volume of 2153 M m^3 (43,070 M m^3) (Table 23.2) and combined representing 91% of the total west coast barrier volume. The geology is more subdued in the northwest, and King Island provides greater accommodation space with the transgressive dunes becoming more extensive. The higher per metre volumes are on par with the more exposed Great Southern regional volumes and the divisional average of 33,714 $m^3\ m^{-1}$ (Table 22.3). These systems are examined in more details in the following PCs and SCs.

Table 23.1 West Tasmanian and King Island beach types and states

BS	BS	n	No. (%)	Total km	Km (%)	Mean (km)	σ (km)
1	D	1	0.2	33.0	13.3	33	–
3	RBB	1	25.0	25.0	10.1	25	–
4	TBR	126	29.3	90.2	36.5	0.7	1.4
5	LTT	64	14.8	29.5	11.9	0.5	0.6
6	R	241	55.7	69.7	28.2	0.3	0.35
		434	100.0	247.4	100.0	0.6	–

Table 23.2 West Tasmania region and PC/SC barrier dimensions

PC/SC:TAS	02.01	02.02	02.03.01-06	02.03.08 King Is	West Tas
No.	14	35	28	11	88
Total length (km)	24	34	120	50	228
Mean min width	90	240	400	1000	–
Mean max width	330	600	1500	500	–
Mean height (m)	16	16	15	20	–
Area (ha)	586	4500	18,690	10,780	34,556
Unstable (ha)	54	330	3732	177	4293
Total volume (M m^3)	104	495	3832	2153	6584
Unit volume (m^3 m^{-1})	4350	14,476	32,042	43,070	28,877

23.6 Sand Transport

There have been no specific studies of sand transport on the west coast apart from Davies (1973, 1978) who inferred transport based on the beach sand characteristics. He found that the entire west coast south of Cape Sorell consists of closed TCs, while to the north, there is limited transport with major obstacles at Cape Sorell, Conical Rocks and Cape Grim and minor obstacles at Sandy Cape and Bluff Hill. He concluded that longshore transport is minimal and if it does occur would be from south to north. Most of the beaches are short (mean = 0.6 m) and bordered by rocks, reefs and headlands resulting in a dominance of low-energy R beaches, all of which inhibits sand transport. Also, most of the beaches are swash aligned with the wave approaching normal to shore. The only morphological evidence of longshore transport is along the long Ocean Beach where the Henty and Little Henty rivers are deflected to the south by up to 10 km, indicative of southerly transport on this beach.

The west coast contains three PCs and 13 SCs (Table 23.3, Fig. 21.1b), each of which is discussed below.

23.7 PC:TAS02.01 South East Cape to South West Cape

The southernmost west coast PC/SC commences at South East Cape (Fig. 23.1), the southern tip of the island and trends west for 130 km to South West Cape, the southwest tip of the island (Fig. 23.2). This is a steep, rugged, rocky south-facing coast with many cliffs and steep slopes rising between 100 and 300 m. In between are more than a dozen headland-bordered south-facing bays exposed to the full force of the Southern Ocean waves and winds (Fig. 23.3). The bays contain 49 beaches which average 0.55 km in length and occupy just 27 km (21%) of the predominately rocky shore. They range from high-energy TBR on the exposed beaches to LTT and R when sheltered by headlands and orientation. Most are small bay head beaches, with just three longer barrier systems in larger valleys where they

Table 23.3 West Tasmania region, PCs and SCs

PC No.[a]	Name	Boundaries	Beach ID[b]	No. beach	km[c]	Total km
West Tasmania						
TAS02.01.01	South Tasmania	Southeast C-SouthWest C	TAS 566-614	49	1097–1227	130
TAS02.02.01	SW Tasmania	Southwest C-Hilliard Hd	TAS 615-630	16	1227–1264	37
TAS02.02.02	Bathurst Hbr	Hilliard Hd-Davey Hd	TAS 631-666	36	1264–1320	56
TAS02.02.03		Davey Hd-low rocky Pt	TAS 667-705	39	1320–1405	85
TAS02.02.04		Low rocky Pt-C Sorell	TAS 706-789	84	1405–1540	135
TAS 02.02		*SW C-C Sorell*	*TAS 615-789*	*175*		*313*
TAS02.03.01	Macquarie Hbr	C Sorell-Braddon Pt	TAS 790-791	2	1540–1545	(170)
TAS02.03.02	Ocean Beach	Ocean Beach	TAS 792-795	4	1545–1578	33
TAS02.03.03		Ocean Beach-Ahrberg Bay	TAS 796-816	21	1578–1609	31
TAS02.03.04		Ahrberg Bay-Sandy C	TAS 817-846	30	1609–1657	48
TAS02.03.05		Sandy C-Bluff Hill Pt	TAS 847-910	64	1657–1724	67
TAS02.03.06		Bluff Hill Pt-Woolnorth Pt	TAS 911-964	54	1724–1798	74
TAS02.03.07	Hunter Island	Hunter Island (west coast)		–	–	(32)[d]
TAS02.03.08	King Island (west)	Stokes Pt-C Wickham	KI 46-80	35	96–196	100
TAS02.03		*C Sorell-C Wickham*	*TAS 790-964*	*175*	*1540–1798*	*258*
			KI 46-80	*35*	*96–196*	*100*
		Region sub-total		*434*		*801*

[a]NCCARF compartment number
[b]ABSAMP beach ID
[c]distance clockwise from Cape Portland
[d]not discussed

form mid-bay barriers (Prion 5 km, Louisa 2.3 km (Fig. 23.3d), and Cox Bight 5.3 km. There are a total of 14 barriers, with most consisting of a large foredune, except for the west-facing South Cape Bay where the remnants of the beaches (TAS 566-7) are backed by well-vegetated parabolic clifftop dunes extending up to 3 km inland and to elevations of 60 m. The barriers have a total volume of 104 M m^3 (4350 m^3 m^{-1}) (Table 23.2), the largest being the South Cape Bay dunes (80 M m^3). The generally few beaches and barriers and their small volume can be attributed to

Fig. 23.2 The southwest corner of Tasmania and SCs TAS02.01.01 and 02.02.01. (Source: Google Earth)

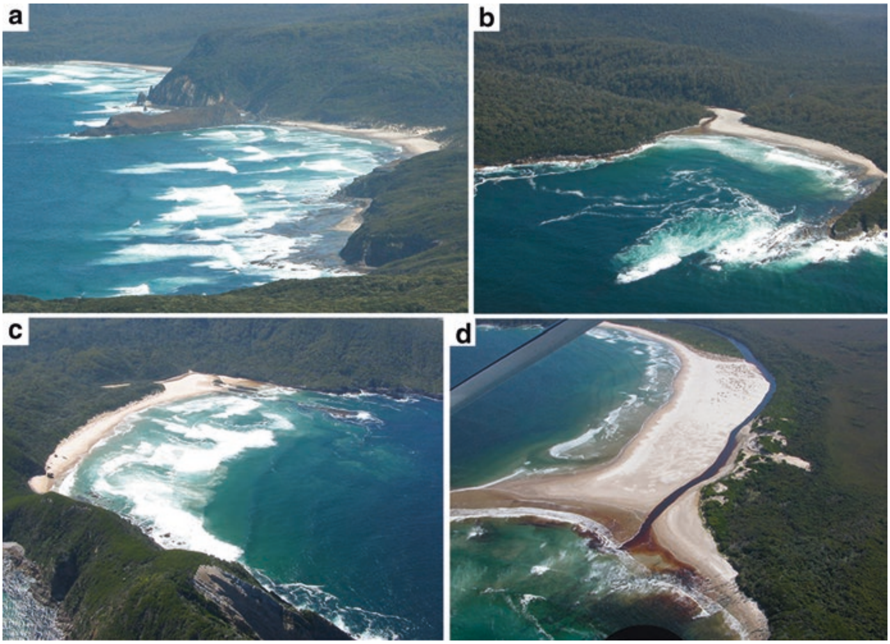

Fig. 23.3 (**a**) View west of South East Cape and South Cape Bay beaches TAS 566–568; (**b**) partly sheltered beach (TAS 569) at mouth of South Cape Rivulet; (**c**) high-energy rip-dominated Surprise Bay (TAS 571) and (**d**) Louisa beach and its deflected river mouth (TAS 584). (Photos: AD Short and W Hennecke)

a lack of accommodation space, predominately southerly orientation, steep nearshore-inner shelf and possibly a lack of shelf sand.

23.8 PC:TAS02.02 South West Cape–Cape Sorrell

The west coast of Tasmania commences at South West Cape and trends north-northwest for 570 km to Woolnorth Point. It is divided roughly in half into two PCs 02.02 and 02.03. PC:TAS02.02 commences at South West Cape and extends for 313 km to Cape Sorell at the entrance to Macquarie Harbour (Fig. 21.1b) and contains four SCs. The entire PC is located in the Southwest National Park and Southwest Conservation Area, with no development or settlements in the region other than provisions for bushwalkers. The coast and hinterland is undeveloped and in a natural state. The PC faces into the full forces of the southwest waves and westerly winds which maintain a high-energy WD coast, containing 175 generally small embayed beaches (mean length = 0.4 km) which occupy 71.2 km (23%) of the shore, the remainder rugged and rocky.

23.8.1 SC:TAS02.02.01 South West Cape–Hilliard Head

SC:TAS02.02.01 is a 37 km long section of rocky west-facing coast that extends from South West Cape to Hilliard Head, which marks the southern entrance to the large Port Davey (Fig. 23.2). Most of the coast is steep and rocky, rising steeply in places to 600 m, with small deeply embayed R beaches wedged into sheltered gaps in the rocks, the 16 beaches totalling 7.4 km (20%). There are just three longer exposed beaches in Window Pane (1.5 km), Noyhener (2 km) and Stephens (2.4 km) bays which are high-energy rip-dominated TBR-RBB. Each is also backed by both stable and active parabolic dunes. In Window Pane Bay, the now well-vegetated dunes extend 1.5 km inland and climb to a height of 250 m, while the Stephens Bay active dunes have overpassed the southern Chatfield Point and reached Noyhener Bay where the dunes combine and extend in some place 3 km inland, the two barriers having volumes of 30 and 70 M m^3, respectively.

23.8.2 SC:TAS02.02.02 Hilliard Head–Davey Head

SC:TAS02.02.02 commences at Hilliard Point and includes the large Port Davey-Bathurst Harbour downed valleys and its 56 km of outer bay shoreline, with the northern boundary being the northern entrance to the bay at Davey Head (Fig. 23.2). The Port Davey Marine Reserve includes all the bay and extends up to 20 km inland into Bathurst Harbour with an area of 180 km^2. This is a predominately rocky shore

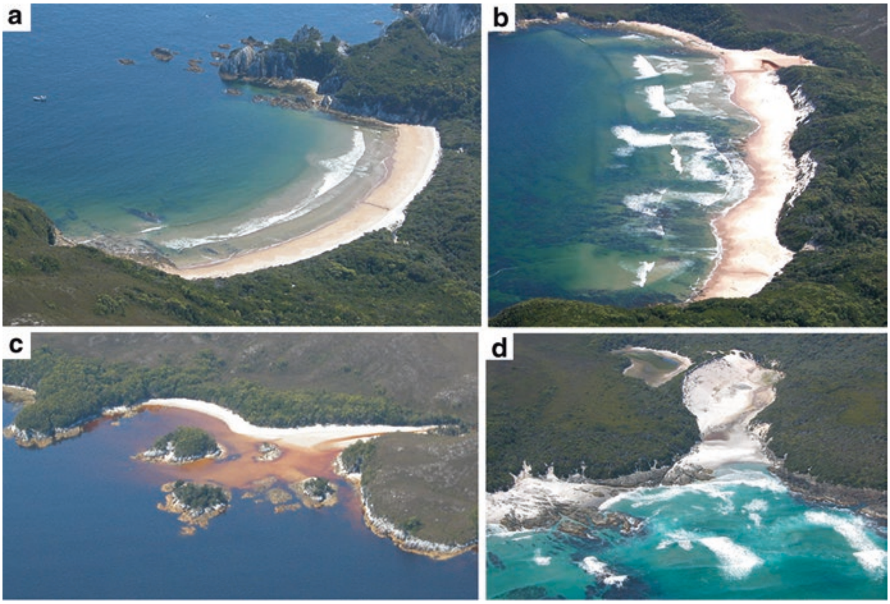

Fig. 23.4 (**a**) Partly sheltered LTT Norman Cove (TAS 631) located just inside the entrance to Port Davey; (**b**) west-facing rip-dominated Tooglow beach backed by a high foredune (TAS 642); (**c**) sheltered R beaches and sand flats at the mouth of Coffin Creek (TAS 649) located inside Port Davey; and (**d**) exposed Sandblow Bay with the beach and dune destabilised by both the waves and the creek (TAS 676). (Photos: AD Short)

with 40 km of rock (71%). There are 36 predominately small (0.46 km) sheltered R beaches located around the inner bay shore (Fig. 23.4c), with some LTT beaches near the entrance (Fig. 23.4a) and just two more exposed TBR beaches including Tooeglow beach (TAS 642; Fig. 23.4b) which while located 17 km inside of bay faces due west through the 14 km wide bay entrance and receives high westerly swell. There are six small barriers, all mainland beaches with a foredune which have a total volume of just 1.3 M m^3. Any sand within the bay resides on the bay floor with little being deposited on the few beach systems owing to the low wave energy.

23.8.3 SC:TAS02.02.03 Davey Head–Low Rocky Point

SC:TAS02.02.03 continues north from Point St Vincent for 85 km to the protruding Low Rocky Point (Fig. 23.5). This is another rock-dominated shoreline containing several open bays (South East Bight, Sandblow (Fig. 23.4d), Alfhild, Wreck, Towterer (Fig. 23.6a), Mulcahy, Nye and Elliott) containing beaches and barriers. There are a total of 39 beaches which occupy 15.3 km (18%) of the coast. Most are small, sheltered R beaches wedged in amongst the rocks with an average length of just 0.24 km. The longer bay beaches (mean = 0.82 km) face south through west and

Fig. 23.5 SC:TAS02.03.03. (Source: Google Earth)

have higher energy TBR-RBB beaches with both stable and active, southeast-trending, parabolic and long-walled parabolic dunes. The transgressive barriers have a volume of 238 M^3 (30,512 $m^3\ m^{-1}$) and in Towterer Bay (Fig. 24.6a) extend up to 6 km inland.

23.8.4 SC:TAS02.02.04 Low Rocky Point–Cape Sorell

SC:TAS02.02.04 commences at Low Rocky Point from where the coast trends relatively straight north-northwest for 135 km to Cape Sorell, which marks the southern entrance to Macquarie Harbour (Fig. 23.7a). This is a rocky coast with an elevation generally between 20 and 50 m which rises moderately inland to higher elevations.

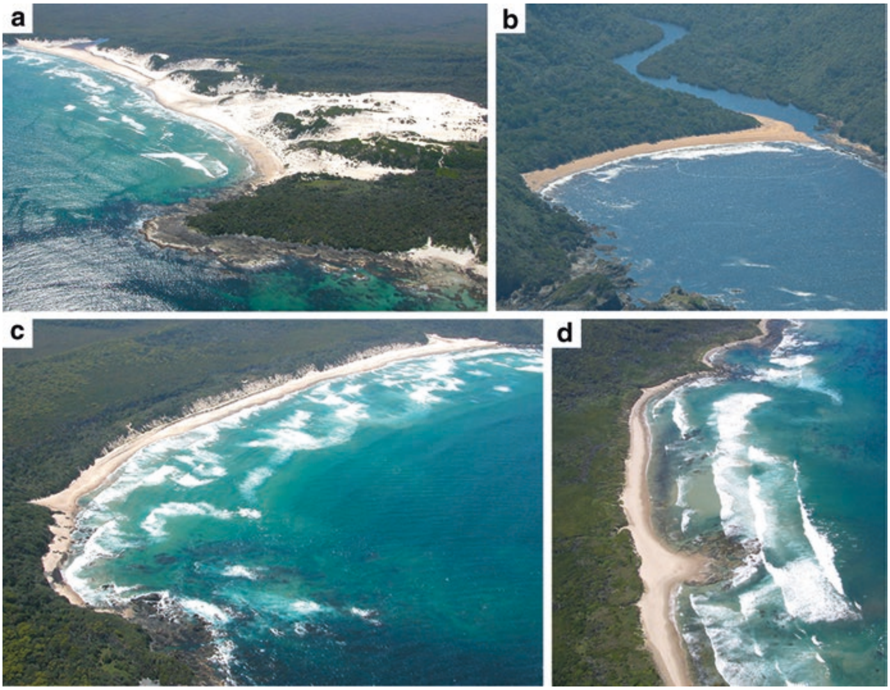

Fig. 23.6 (**a**) The exposed high-energy Towterer beach and active dune system (TAS 684); (**b**) the sheltered Wanderer River mouth at Christmas Cove (TAS 725); (**c**) exposed high- energy double rhythmic bar system at Endeavour Bay (TAS 728); and (**d**) the rocky and rip-dominated Whitehorse beaches (TAS 735 and 736). (Photos: AD Short and W Hennecke)

There are however a number of open bays (Endeavour, Spero, Hibbs, Warna, Birthday, Edwards) and numerous indentations along this predominately rocky coast, within which are located 84 beaches. The beaches occupy 32 km (24%) of the shore, with the majority (49) small, embayed R beaches with a mean length of 0.3 km, together with nine LTTs (0.44 km). There are also 26 exposed TBR-RBB beaches, which while longer (0.5 km) are still relatively short with only the Endeavour Bay beach >1 km at 2.1 km in length (TAS 728).

There are 19 barrier systems occupying 17 km (12.5%) of the coast, most of which consist of a single high foredune, while seven have generally stable well-vegetated parabolic dunes, the longest at Dunes Creek (TAS 778) extending 2 km inland. The barriers have a total volume of 152 M m^3 (8987 m^3 m^{-1}) and for the most part (87%) are well vegetated and stable. The largest area of instability in the north at Iron Creek where the active dunes have extended up to 1.5 km inland and deflated down to the bedrock. The Endeavour Bay foredune is backed by what appears to be a 600 m wide overwash plain and 300 m wide swamp-filled back-barrier depression. A number of small rivers have dynamic river-mouth spits at their

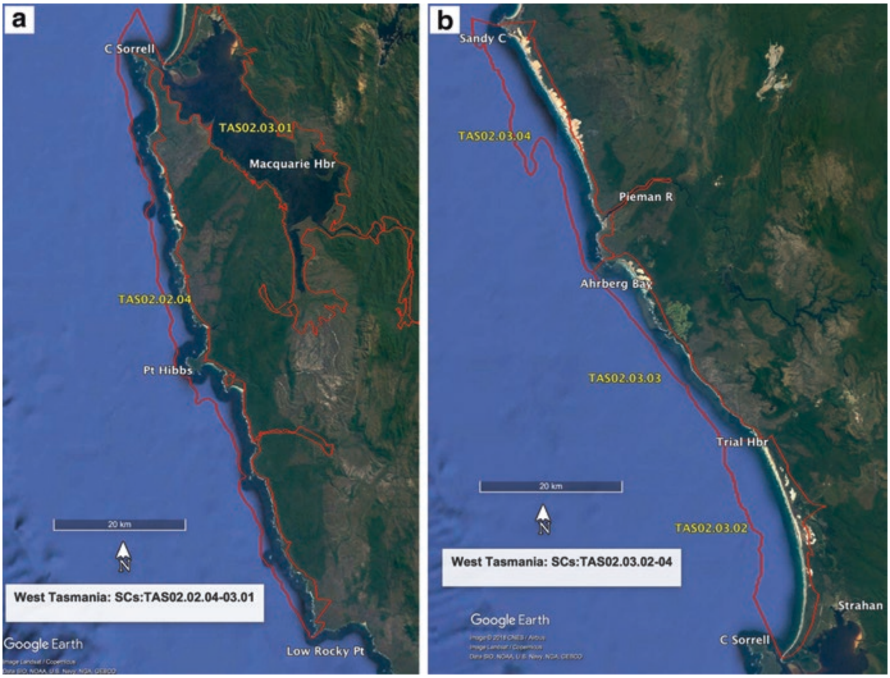

Fig. 23.7 (**a**) SCs TAS:02.02.04 and 02.03.01 and (**b**) SCs TAS03.02-04. (Source: Google Earth)

entrances, including the Wanderer, Spero, Hibbs Lagoon, Griffith and Modder, while other rivers like the deeply incised Lewis, Mainwaring, Urquhart enter narrow, winding drowned valleys.

23.8.5 PCs Overview

PCs TAS02.01 and 02.02 occupy the south and southwest coast of Tasmania, a predominately rugged and rocky shore containing 224 beaches which occupy just 21% of the coast, all located in either bays or indentations in the rugged shore, with barriers totalling just 600 M m^3 in volume (10,000 m^3 m^{-1}). While this is a high-energy shore, there has been relatively little barrier development owing to a combination of lack of accommodation space and the steep inshore gradients. Where bays and beaches do face into the west to northwest winds, some substantial transgressive dune fields have developed. Most of these are now well vegetated, with some stranded as clifftop dunes indicating that most transgression probably accompanied the PMT and stillstand, with minimal activity since. This also implies a cessation of sediment supply indicating that the shelf sources have been depleted and/or lie at too great a depth for onshore mobilisation.

23.9 PC:TAS02.03 Cape Sorrel to Cape Wickham (King Island)

PC:TAS02.03 occupied the northern half of Tasmania's west coast including the west coast of King Island, extending for 258 km from Cape Sorrell to Woolnorth Point, then along the western King Island coast for 100 km from Stokes Point to Cape Wickham, a total length of 358 km. Most of the coast between the Pieman River and Marrawah is located in the Arthur Pieman Protected Area, with no coastal towns, other than Strahan in Macquarie Harbour, and just a few small fishing shack communities at Trial Harbour, Granville Harbour, Temma and Arthur River. There is only vehicle access to the coast at Ocean Beach (Strahan), the above communities and between Temma and Marrawah. The coast is orientated west-southwest into the prevailing southwest waves and westerly winds, with micro-tides and high wave and wind energy conditions throughout.

23.9.1 SC:TAS02.03.01 Macquarie Harbour

SC:TAS02.03.01 contains Macquarie Harbour a large drowned rectangular-shaped bay which extends for 33 km to the southeast and averages 8 km in width an area of ~300 km^2 (Fig. 23.7a). It is feed by the larger Gordon and King rivers, with latter delivering mining tailings from the Queenstown mine to build a substantial delta at its mouth, with an intertidal area of 5 km^2. The mine closed in 1994, and now the rebuilt railway down the King River is a major tourist attraction. There are just two adjoining beaches located at the mouth of the harbour, one the man-made Pilot beach (TAS 790; Fig. 23.8a) which has prograded 300 m northwards against the 1.1 km long entrance training wall. The harbour is a sink for sediment delivered by the several rivers and also for marine sand that has built a flood tide delta that extends for ~6 km into the harbour and has an area of ~20 km^2. The narrow 0.35 km wide entrance is known as Hells Gate both for the difficulty in navigating the wave swept ebb tide delta at the mouth, which includes some rocks and islets, as well as reference to its days as the entrance to the infamous Sarah Island penal settlement.

23.9.2 SC:TAS02.03.02 Ocean Beach

SC:TAS02.03.02 commences on the northern side of the harbour entrance at low sandy Braddon Point, the southern tip of Ocean Beach (Fig. 23.7b). It curves to the north then northwest for 33 km to the northern end of the beach near the mouth of the Little Henty River and a kilometre south of Trial Harbour. Ocean Beach is the longest beach on the west coast and the most exposed and highest energy beach in Australia, with waves averaging 3 m (H_{max} = 5 m) throughout the year. The beach is

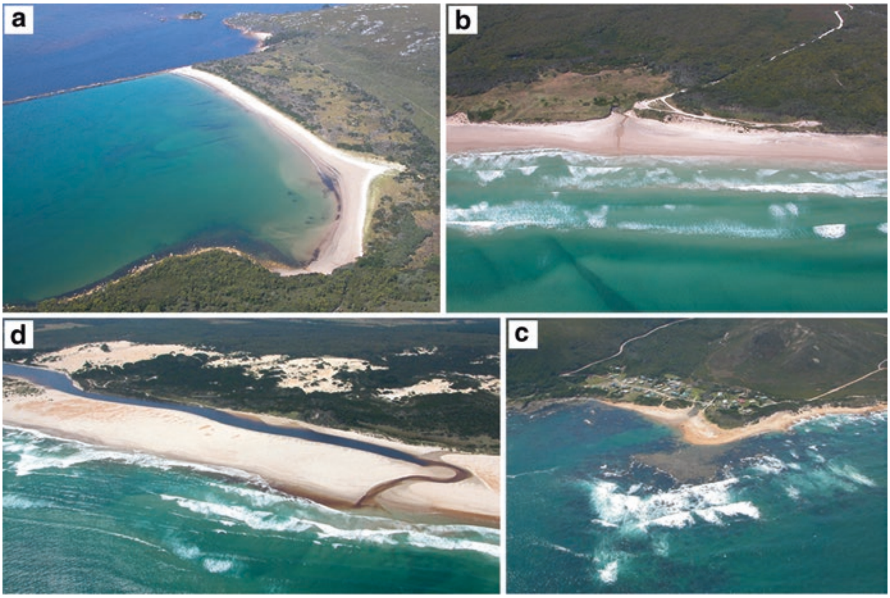

Fig. 23.8 (**a**) The sheltered Pilot beach at the mouth of Macquarie Harbour has built out against the training wall (TAS 790); (**b**) Ocean Beach with its three bars on a calm day (TAS 792); (**c**) the deflected mouth of the Henty River (TAS 793) and (**d**) the small Trial Bay shack community (TAS 798). (Photos: AD Short)

composed of fine to medium sand which combine with the persistent high waves to maintain surf zone that averages 500 m in width but extends to up 1 km in high seas, with a 2–3 bar system, containing a D outer bar and TBR-RBB inner bar (Fig. 23.8b), the latter cut by rips averaging 600 m in spacing, with up to 50 large rips usually active along the beach. The Henty and Little Henty rivers cross the northern end of the beach, both deflected to the south for several kilometres (Fig. 23.8c). Davies (1973) suggested the rivers are recycling the dune sand that is blown into their channel and delivering it back to the coast, combined with perhaps some terrigenous material. The deflection of the river mouths, combined with a series of south trending recurved spits at the southern end of the beach, terminating at Braddon Point, indicates that sand is transported southward along the beach and probably lost into the flood tide delta. Ocean Beach has been monitored by C Sharples (pers. comm.) since 1948. He found that after 30 years (1950–1980) of reasonable stability, there has since been marked and ongoing erosion at a rate of 0.8 m year^{-1} along the entire beach. Whether this is a cyclical or long-term trend remains to be seen.

The beach is backed by a transgressive barrier with both stable and some active dunes (the famous Henty Dunes) extending up to 3 km inland and to elevations of 40 m. They have a volume of 1500 M m^3 (46,875 m^3 m^{-1}), making it the largest barrier system in Tasmania and one of the highest per metre volumes in Australia.

23.9.3 SC:TAS02.03.03 Trial Harbour–Ahrberg Bay

SC:TAS02.03.03 begins at the rocks at the northern end of Ocean Beach and trends northwest past Trial Harbour (Fig. 23.8d) for 31 km to Ahrberg Bay (Fig. 23.7b). The southern half of the SC to Granville Harbour is rocky and steep, rising rapidly to 100 m. North of the harbour, the gradient decreases, and rock reefs litter the inshore extending up to 1 km seaward, as far as Four Mile beach (Ahrberg Bay), beyond which is a continuous 6.2 km long beach up to the rocks of that form the northern point. The coast is a mix of the rocky shore, a series of small sheltered R beach in lee of the reefs and the longer Four Mile Beach, which while continuous is crossed by eight small streams. The well-exposed beach has 500–700 m wide double bar surf zone, with well-developed inner TBR with rips spacing on average every 400 m. The beach is backed by both active and stable transgressive dunes up to 40 m high (Fig. 23.9a) that extend to the southeast for up to 2 km where they are truncated by the streams, and the sand returned to the beach. The barrier has a volume of 360 M m^3 and a high per metre volume of 58,065 $m^3\ m^{-1}$.

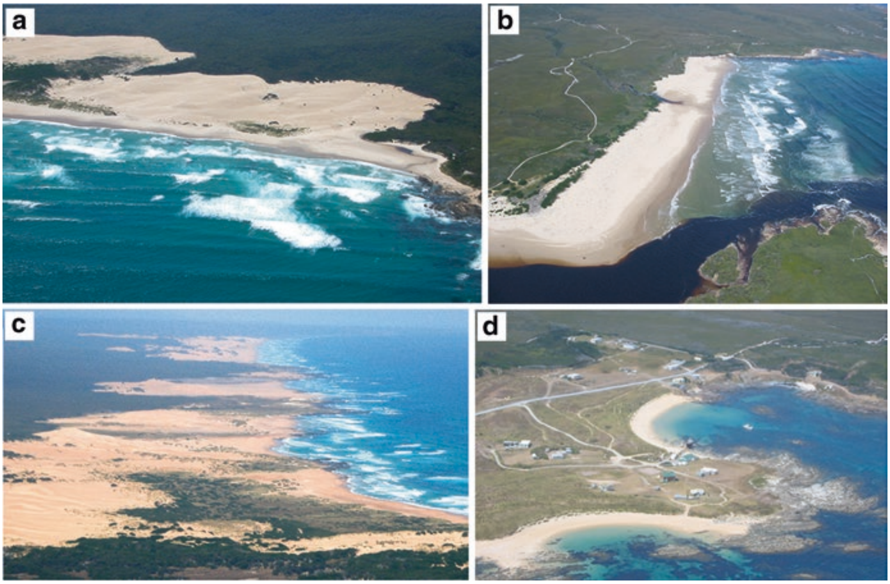

Fig. 23.9 (**a**) The southern end of Four Mile beach (TAS 816) with southeast-trending transverse dunes); (**b**) the Pieman River mouth (TAS 820); (**c**) view south along the exposed Blue Lagoon beaches and dunes (TAS 844) and (**d**) the small community at Temma and its sheltered boat harbour (TAS 874). (Photos: AD Short and W Hennecke)

23.9.4 SC:TAS02.03.04 Ahrberg Bay–Sandy Cape

SC:TAS02.03.04 extends relatively straight for 48 km to the north-northwest from the rocks at the northern end of Ahrberg Bay to the low Sandy Cape (Fig. 23.7b). In between is a southern rocky section containing Conical Rocks point, the deep incised and drowned mouth of the Pieman River and Rupert Point. North of the point is a more continuous straight section of rocky shore for 5 km, and then 20 km of near continuous straight beaches up to the lee of Sandy Cape. The only beach of note in the south is at the mouth of the Pieman River (Hardwicke Bay; Fig. 23.9b), an exposed high-energy double bar system with the river channel hugging the northern rocks. Davies (1973) found that based on sediment texture, the deep-drowned river is delivering some sand to the coast. The northern beach section consists of remnants of a once continuous beach. The beach actually begins at Rupert Point with surf zone bars fronting the 5 km long rocky section, followed by the continuous 10 km long beach (TAS 825) which is cut by 14 small streams, then a 10 km long section containing 20 small beaches separated by rocks and reefs and crossed by streams draining from the backing Norfolk Range. In all, it has a 25 km long beach-surf zone section with a continuous RBB outer bar located ~700 m offshore and TBR inner bar, while the inner surf zone and shoreline is a mix of sand and rock. These beaches are no doubt the remnant of a once more continuous beach, as the entire section is backed by stable transgressive dunes extending up to 2 km inland and a second-phase of active and stable dunes up to 1 km inland (Fig. 23.9c). At present, roughly 50% of the dunes are unstable. Then entire system has a volume of 525 M m^3 (28,405 m^3 m^{-1}). This entire SC appears to be a separate TC which is slowly receding owing to loses to the dunes, with no evidence of longshore transport. Davies (1973) also found that Conical Rocks divided the quartz-rich southern beaches from the carbonate-enriched northern beaches, marking a change in sediment origin and texture.

23.9.5 SC:TAS02.03.05 Sandy Cape–Bluff Hill Point

SC:TAS02.03.05 commenced at Sandy Cape and trends north-northwest for 67 km to Bluff Hill Point (Fig. 23.10a) with the small communities of Temma (Fig. 23.9d) and Arthur River (Fig. 23.11a) located in the north. In between are two boundary sandy beaches (Kenneth Bay and Arthur beach) with predominately rocky shore along the remainder. In total, there are 64 beaches which occupy 41 km (61%) of the shore. Most are short (0.38 km) sheltered R beaches amongst the rocky shore. There are in total 45 small sheltered beaches along the 25 km long central rocky section, apart from Hazards Bay (TAS 870) which is drained by two large rips, while the deeply embayed Temma beach (TAS 873) is used as a small boat harbour. In addition, there are 18 longer (1.32 km) more exposed TBR beaches located to either end of the compartment. The southern 12 km long Kenneth Bay beach has medium sand

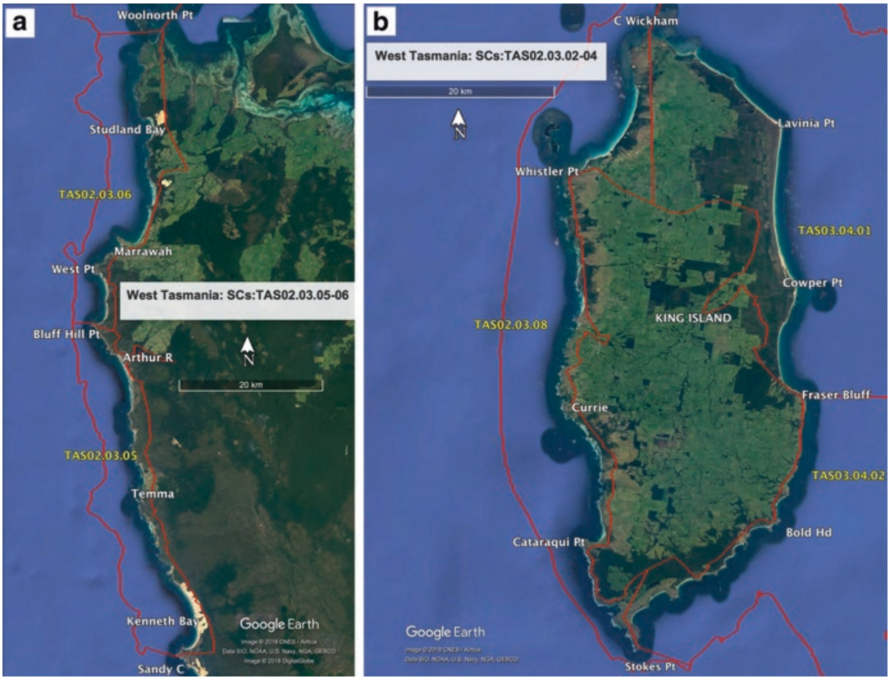

Fig. 23.10 (**a**) SCs TAS02.03.04-06 and (**b**) King Island – SCs TAS02.03.08 and TAS03.04.01. (Source: Google Earth)

and very well-developed 500 m wide high-energy TBR with rip spaced ~500–600 m, while the northern 5 km long Arthur beaches have finer sand and a 600 m wide double bar system with rips every ~400 m on the inner bar.

Kenneth Bay is backed by a very active 1 km wide transgressive barrier (220 M m^3, 18,333 m^3 m^{-1}) crossed by four streams draining from the Norfolk Range, while the northern Arthur barrier has largely stable parabolic-long-walled parabolic dunes trending northeast and extending up to 3 km inland (289 M m^3, 46,666 m^3 m^{-1}). The barriers occupy 35 km (52%) of the coast with a total volume of 795 M m^3 (22,721 m^3 m^{-1}).

23.9.6 SC:TAS02.03.06 Bluff Hill Point–Woolnorth Point

SC:TAS02.03.06 is located along the northernmost section of the west coast, extending for 74 km from Bluff Hill Point to the northwest tip at Woolnorth Point (Fig. 23.10a). The coast trends north and consists of a series of open west-facing bays (Mawson, Ann, Studland, Valley) separated by a series of headlands and rocky sections. There is public access to the coast at West Point and Marrawah beach; otherwise, it is inaccessible by private vehicle. There are a total of 54 beaches with

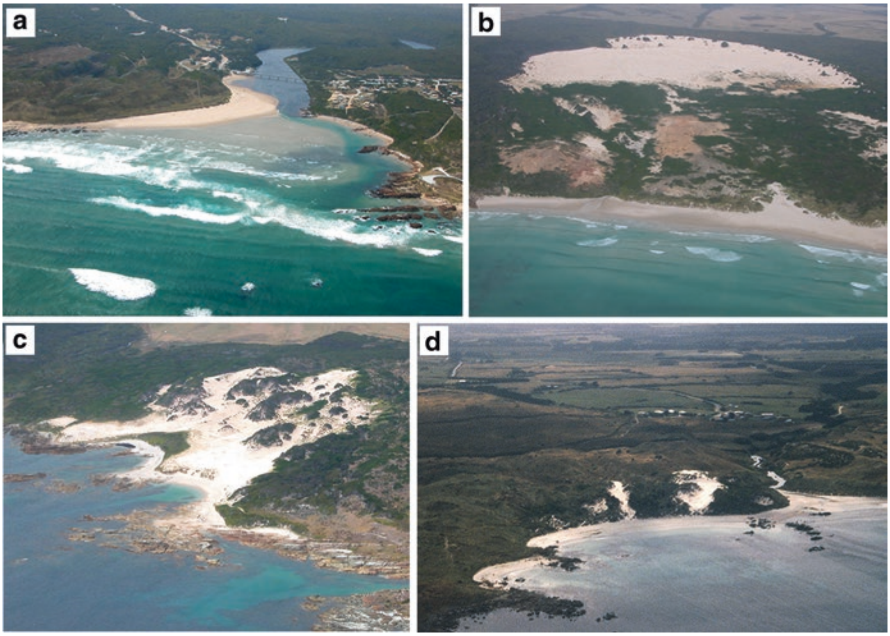

Fig. 23.11 (**a**) The dynamic mouth of the Arthur River (TAS 903); (**b**) massive parabolic dune at Mount Cameron beach (TAS 933); (**c**) climbing parabolic dunes at the sheltered Calm Bay (TAS 948) and (**d**) climbing blowouts at King Island's Little Porky beach (KI 65). (Photos: AD Short)

a mean length of 0.51 km which occupy 37% of the shore. Most beaches are sheltered R-LTT and located in amongst the rocky sections; however, by length, the longer TBR (mean = 0.97 km) dominate, with 18 TBR beaches all located in the more exposed bay sections. The coast however remains dominated by sedimentary rocks. Beach sediments remain fine to medium sand with variable carbonate. At Marrawah beach however, the carbonate reaches 65% which has contributed to the formation of massive beachrock at the southern end of the beach, just down from the carpark.

A total of eight barriers occupy 24 km (32%) of the shore, all located in lee of the higher energy bay beaches. They have a total volume of 645 M^3 (26,875 m^3 m^{-1}), the largest of which are the Ann Bay (Marrawah) and Studland systems, both with volumes of 160 M m^3 (45,714 m^3 m^{-1} and 43,243 m^3 m^{-1}, respectively). The barriers consist of either vegetated transgressive parabolic dunes (Fig. 23.11b), active (blowouts, Fig. 23.11c) and/or stable dunes, extending between 1 and 3 km inland, and climbing up the backing bedrock slopes to elevations between 30 and 85 m. Presently, 520 ha or 16% of the dunes are unstable. While most of the sand transport on this coast appears to be onshore, at the northern tip, there are large apparently east-trending sand shoals located either side of Woolnorth Point which may be driven by a combination of waves and tides and indicative of sand moving eastward around the point and into the neighbouring PC.

23.9.7 SCs:TAS02.03.07-08 King Island–West Coast

SCs:TAS02.03.07-08 are located along the western shores of Hunter and King Islands. Hunter island has a 32 km long, predominately rocky western shore and is partly blanketed by stable vegetated transgressive dunes. The larger King Island is similar with a wave and wind-battered western shore that extends for 100 km between the southern tip at Stokes Point and the northern tip at Cape Wickham (Fig. 23.10b). The only coastal settlement and community is at Currie (800) where the small boat harbour is located. In between are 35 beaches occupying 26 km (26%) of coast with an average length of 0.74 km. The bulk of the shore is rocky with 30 small sheltered R and LTT set in amongst the rocks and reefs, with an average length of 0.48 km, while on the most exposed sections there are five longer TBR with an average length of 2.35 km, the longest 8.7 km long Yellow Rock beach (KI 78). Almost the entire west coast has been blanketed by now well-vegetated massive Holocene transgressive dunes (Fig. 23.11d) extending due west up to 4 km inland and to elevations of 100 m. They appear to have been deposited in successive phases of dune transgression, very likely in the early to mid-Holocene. The Holocene dunes have a volume of 2153 M m^3 (43,070 m^3 m^{-1}) and cover an area of 108 km^2 of which just 2% is presently unstable.

The Holocene dunes overlie older Pleistocene dunes which extend in places 1–2 km further inland (Fig. 23.12a). The King Island dune systems were studies by Jennings (1957a, b, 1967a, b) who also noted the Pleistocene (Old Dunes) and Holocene (New Dunes) transgressive dunes, controls on their orientation (Fig. 23.12b), the northern dune lake systems, and clifftop dunes between Cataraque and Surprise points on cliffs between 30 and 50 m high.

Jennings (1959, 1961) also reported evidence of higher last interglacial shorelines with a boulder beach at 37–46 m and beachrock at 20 m, the high elevation is a result of neo-tectonism, as subsequently reported by Murray-Wallace and Goede (1995).

The west coast beach sands range from fine to coarse and from 1% to 98% carbonate (mean = 46%, σ = 36%) indicating considerable local variation in source and texture (Fig. 23.13) and consequently lack of longshore interchange and transport. The transport appears to be predominately onshore to supply the dunes. The source of the sand is undoubtedly the adjacent shoreface-inner shelf with 50% of the sand of carbonate origin.

23.9.8 PC Overview

PC:TAS02.03 trends north-northwest up the northern west coast of TAS for 258 km and another 100 km along the west King Island coast. This is a wave- and wind-battered coast which underwent most of its Holocene evolution during and immediately following the PMT, when beaches and barriers were deposited and dune

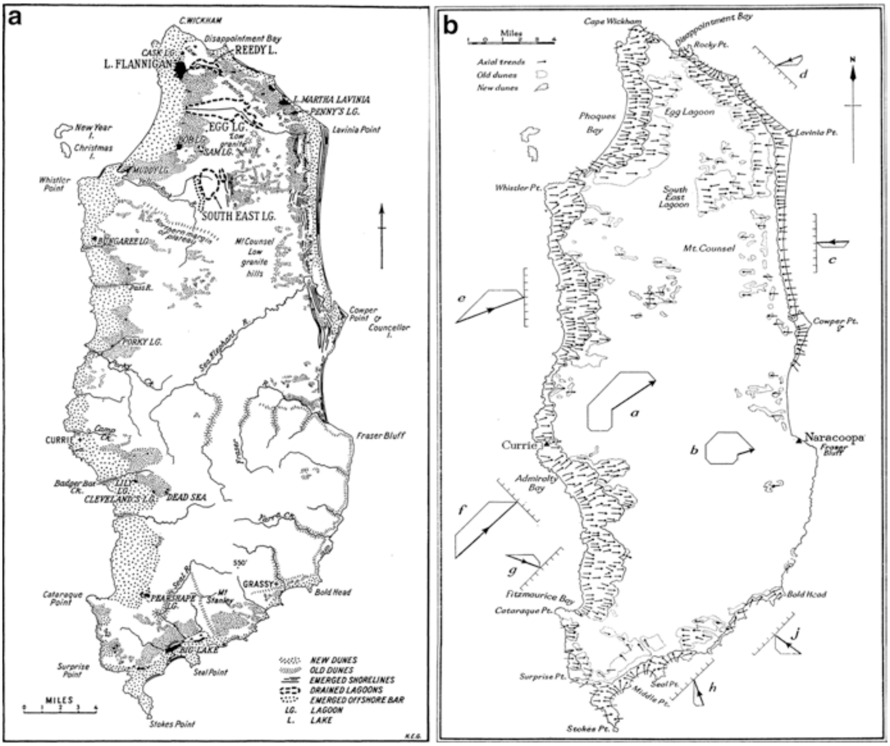

Fig. 23.12 (**a**) King Island dune and barrier geomorphology. (Source: Jennings 1957a, reproduced with permission of the Royal Society of Victoria) and (**b**) orientation and wind resultants for King Island dunes. (Source: Jennings 1957b, reproduced with permission of the Queen Victoria Museum and Art Gallery Launceston)

transgression occurred in lee of exposed higher-energy beaches, including the formation of clifftop dunes. Subsequently, the depletion of the sand supply led to shoreline recession, retreat of most of the beaches and barriers and erosion of the sand ramps that feed the clifftop dunes. What is present today are the resilient remnants of a once more extensive beach and barrier systems, some of which continue to erode in places. While most sand transport appears to have been onshore from the shelf, there is evidence of southerly transport along the long Ocean Beach, supplying sand to the large Macquarie Harbour tidal delta. The causes of recent erosion/recession of this beach reported by C Sharples (pers. comm.) remain to be resolved.

23.10 Regional Overview

The west coast of Tasmania, including western King Island, is a wild-, wind- and wave-battered coast, most of which is contained in parks and reserves, with some very limited coastal development along its northern half. The 800 km long coast is dominated by its rocky shore (69%) with 343 generally small beaches occupying

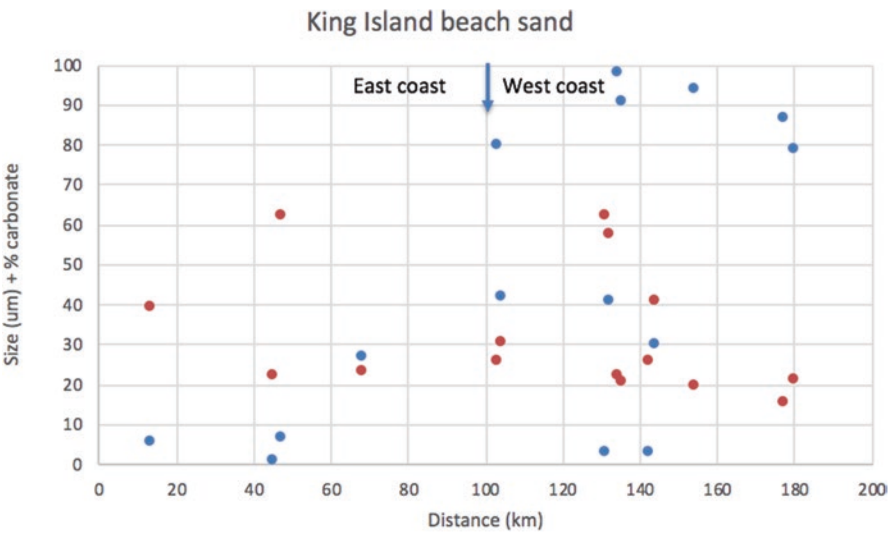

Fig. 23.13 King Island (PC:TAS02.03.08 & PC:TAS03.04.02) beach sand size (red, μm) and percent carbonate (blue)

the remainder. The majority (305) of the beaches are small sheltered-embayed R and LTT beaches which occupy just 12% of the shore. The exposed higher TBR-RBB number just 126 but being longer occupy 11% of the shore, while two longer RBB and D beaches occupy 3% and 4%, respectively (Table 23.1). The major transgressive barrier systems all lie behind the more exposed higher-energy beaches usually extending several hundred metre inland and often climbing the backing bedrock slopes including sea cliffs up to 50 m high. It is interesting to note that the orientation of the usually parabolic to long-walled parabolic dunes ranges from southeast in the south, to northeast in the centre to east in the north, driven by northwest and southwest winds, respectively. As Jennings (1957b) indicated on King Island, the orientation is a function of both the dominant onshore wind direction and the orientation of the shore (Fig. 23.12b).

This is a very high-energy coast which will mainly see the impact of sea-level rise in its drowned river and bay systems, where flood tide deltas will be reactivated, while what is left of the open coast beaches will recede even more. Tasmania Govt (2016) reported that there are 44 properties at future risk to erosion and 180 to inundation on the west coast (Table 21.5), a relatively small number but nonetheless significant on this lightly developed coast.

References

Davies JL (1973) Sediment movement on the Tasmanian coast. In: 1st Australian conference on coastal and ocean engineering, Sydney, Institution of Engineers Australia, pp 43–47

Davies JL (1978) Beach sand and wave energy in Tasmania. In: Davies JL, Williams MAJW (eds) Landform evolution in Australasia. Australian National University Press, Canberra, pp 158–167

Kalma JD, Chin AK (1988) Windspeed maps for Tasmania and their use in wind energy assessment. Aust Geogr Stud 26:264–278

Jennings JN (1957a) Coastal dune lakes as exemplified from King Island, Tasmania. Geogr J 123:59–70

Jennings JN (1957b) On the orientation of parabolic or U-dunes. Geogr J 123:474–489

Jennings JN (1959) The coastal geomorphology of King Island, Bass Strait in relation to changes in the relative level of land and sea. Record Queen Vict Mus, Launceston 11:1–39

Jennings JN (1961) Sea level changes in King Island, Bass Strait. Zeitschrift für Geomorphologie 3:80–84

Jennings JN (1967a) Clifftop dunes on King Island: Australian Geographer

Jennings JN (1967b) Clifftop dunes. Aust Geogr Stud 5:40–49

Murray-Wallace C, Goede A (1995) Aminostratigraphy and electron spin reconnaissance dating of quaternary coastal neotectonism in Tasmania and Bass Strait islands. Aust J Earth Sci 42:51–67

Short AD (2006) Beaches of the Tasmanian coast and islands. Sydney University Press, Sydney, 353 p

Tasmania Govt (2016) Coastal hazards technical report: mitigating natural hazards through land use planning and building control. Department of Premier and Cabinet, Tasmanian Government, Hobart, 125 p

Chapter 24
North Tasmania Region

Abstract The northern coast of Tasmania faces north into Bass Strait, with the region also including the eastern coast of King Island and western coast of Flinders Island. Along the north coast the prevailing westerly winds flow alongshore in the west to onshore in the east, while the entire coast is sheltered from the high westerly swell by King Island. The climate is humid temperate, and a number of small rivers flow to the coast delivering limited terrigenous sediment, with coastal sediment dominated by quartz and in places rock fragments. Coastal processes range from low waves in the west to increasing exposure to waves and wind in the east, with tide predominately meso. Beaches are tide-dominated in the west shifting to tide-modified and some wave-dominated in the east. Likewise, barriers are regressive in the west, with some extensive Pleistocene and Holocene dune transgression in the east, including 'glacial' dunes. Longshore sediment transport is limited, and most sediment has been derived from the shallow shelf. This chapter describes the coast's geology, coastal processes, beaches, barriers, sediment transport and sediment compartments.

Keywords North Tasmania · Meso-tides · Bass Strait · King Island · Flinders Island · Beaches · Barriers · Sediment transport · Sediment compartments

24.1 Introduction

The north Tasmania coast extends for 439 km in a broad concave arc from the northwest tip of the island at Woolnorth Point (40.6°S) to the northeast tip at Cape Portland (40.7°S) (Fig. 21.1). In between are two contrasting shores, a western leeward and an eastern windward coast, together with the 96 km long eastern coast of King Island and the 126 km long western coast of Flinders Island, in all 661 km of shoreline. The mainland shore is relatively continuous with generally long open north-facing embayments resulting in a low crenulation ratio of 1.6.

The north coast has the highest open coast population in Tasmania with a string of generally small towns and communities spread along the coast commencing in the west with Stanley (500), Sisters Beach (400), Boat Harbour (500), Wynyard (5000), Burnie (25,000), Penguin (4000), Ulverstone (10,000), Devonport (30,000),

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Hawley Beach (500), Low Head (600), Georgetown (5000) and Bridport (1600), with the large Launceston (100,000) located at the head of the Tamar estuary. In contrast to the east and west coasts, much of the north coast is productive farm land and has been freeholded and developed. The only national parks are at the western Rocky Cape and central Asbestos Range, together with the western conservation areas at Double Sandy Point, Waterhouse Bay and Ringarooma Bay.

24.2 Geology

The north coast truncates most of Tasmania's north-south trending geological units resulting in a wide range of rock type and age along the coast (Fig. 21.2). From the west are Precambrian to Cambrian sedimentary rocks, mixed with Jurassic dolerite in the centre, while in the east are a mix of Silurian-Devonian sedimentary rocks and Devonian granite. As discussed in Sect. 21.4, the north coast underwent neotectonic uplift during the Pleistocene with the last interglacial sea level located between 11 and 32 m above present sea level (Murray-Wallace and Goede 1995).

24.3 Climate

The north coast climate is oceanic cool temperate (Cfb), with rainfall arriving year-round with a slight winter maximum (Fig. 1.5a, b). Precipitation decreases from a high of 910 mm in the west at Smithton to 770 mm at central Devonport and 680 mm at the eastern Swan Island. Maximum daily temperatures are in the low-mid 10's in winter and low 20's in summer (Fig. 1.5c, d). At Burnie winds are predominately westerlies (Fig. 21.5).

24.4 Rivers and Creeks

Most of the coast is undulating and rises inland in the west and east to coastal ranges with crests over 1000 m high located between 25 and 50 km inland. These are drained by a series of small rivers and streams flowing northwards to the coast. The rivers and their catchments from the west are the Montagu, Duck, Black, Detention (238 km^2), Inglis (497 km^2), Cam (262 km^2), Blythe (350 km^2), Leven (655 km^2), Forth (1134 km^2), Mersey (1789 km^2), Rubicon, Tamar (11,392 km^2), Pipers (474 km^2), Brid (257 km^2), Great Forester and Ringarooma (1203 km^2). The large Tamar is feed by the South and North Esk rivers which drains the broad central valley that extends 150 km to the south.

24.5 Sediments and Processes

Beach sands are variable and moderately well sorted ranging from fine to medium (mean = 0.39 mm, σ = 0.42), with carbonate averaging 15% (range 0–48%) (Table 21.1, Fig. 21.3). Davies (1978) found that the western coast was characterised by moderately well-sorted fine sand with 25% carbonate, while the eastern coast had moderately sorted medium sand (mean = 0.28 mm) with 20% carbonate. As Table 24.1 indicates, the local rivers dominate the sediment mineralogy, with the eastern section enriched with feldspar, the centre with higher rock fragments and the west quartz-rich, which as Davies and Hudson (1987a) concluded is indicative of local sources and little longshore sand transport. King and Flinders islands are essentially devoid of rivers, with the islands drained by just a few small streams, with sediment largely derived from the shelf and longshore. King Island's east coast beaches have fine to medium quartz sand with low carbonate (Table 21.1; Fig. 23.13), while Flinders Island's west coast beach sand varies considerably in both size (fine to coarse) and carbonate (0–85%) (Table 21.1; Fig. 21.7) also indicating local sources and a lack of longshore transport.

Coastal processes along the north coast are dominated by meso-tides and a predominately westerly wind wave climate. Bass Strait's rather complex tides were modelled by Wijeratne et al. (2012) who found they are a combination of direct gravitational forcing and half-wave length resonance of the M_2 tide. The range increases from micro on the eastern and western boundaries to meso (2.3–3.2 m) along the north coast, peaking at 3.9 m at Launceston (Fig. 21.4). The increase is attributed to tide surge interaction and resonance behaviour in the strait. They are also slowed as they enter the shallow Bass Strait. Spring tide range on King Island is 1.5 m, while on Flinders it ranges from 1.6 to 2.7 m.

The wave climate varies along the coast from the sheltered and leeward western side to the more exposed eastern side. The western Bass Strait islands and rocks (Hunter, Three Hummocks, King islands and Black Pyramid and Reid Rocks) block much of the southwest swell, the remainder having to refract 90 degrees to reach the coast, arriving as much reduced swell. As a consequence, the coast is dominated by local wind waves, which are fetch-limited and low in the west, increasing in size to the east as fetch increases to as much as 350 km. The eastern King Island coast is a lee coast receiving only much lowered refracted swell and local waves, while the west-facing western Flinders Island coast is largely sheltered by a string of small islands resulting in generally lower waves along the southern half of the coast, with some more exposed beaches along the northern half.

Table 24.1 North Tasmania beach sand mineralogy (From: Davies and Hudson 1987b)

	West	Centre	East
Quartz	94	77	85
Feldspar	2	5	13
Rock fragments	4	18	2

24.6 Beaches

The north coast beaches reflect the level of exposure to waves combined with the meso-tides and fine to medium sand. Along the sheltered west coast, tides are more dominant, and TM and TD beaches prevail, while in the exposed east, TM and a few WD beaches are more the norm. The overall lower wave energy and meso-tides are reflected in a dominance of TM beaches followed by TD and WD in a minority together with 146 beaches fronted by rock flats (Table 24.2a). On King Island's long sandy northeast coast and embayed southeast coast, both sheltered lee shores, generally lower energy WD beach prevails throughout. Flinders Island's west coast is a mix of TM beaches primarily along the southern half of the coast and WD along the more exposed northern half. Overall beaches occupy 273 km (62%) of the north coast, 45 km (47%) of the King Island east coast (Table 24.2b) and 65 km (51%) of the Flinders Island west coast (Table 24.2c) in all 426 beaches occupying 383 km (58%) of the regions' coast, each of which is described in more detail by Short (2006).

Table 24.2a PC:TAS03.01 and 02 (North Tasmania) beach types and states

BS	BS	n	%	Total km	% (km)	Mean (km)	σ (km)
1	D	2	0.7	5.5	2.0	2.8	–
3	RBB	6	2.0	10.4	3.8	1.7	3.4
4	TBR	3	1.0	2.5	0.9	0.8	–
5	LTT	3	1.0	2.8	1.0	0.9	–
6	R	7	2.3	0.6	0.2	0.1	0.1
7	R+LTT	60	19.7	54.3	19.9	0.9	1.2
8	R+LTR	27	8.9	66.0	24.1	2.5	3.9
9	UD	15	4.9	36.3	13.3	2.4	3.7
10	B+RSF	4	1.3	4.6	1.7	1.2	1.8
11	B+SF	29	9.5	30.3	11.1	1.1	0.9
12	B+TSF	2	0.7	4.9	1.8	1.6	–
14	R+RF	146	48.0	55.2	20.2	0.4	0.5
		304	100	273.4	100	0.9	–

Table 24.2b PC:TAS03.03 (Flinders Island – west coast) beach types and states

BS	BS	n	%	Total km	% (km)	Mean (km)	σ (km)
3	RBB	5	4.7	0.6	0.9	0.1	0.05
4	TBR	13	12.1	17.9	27.6	1.4	1.7
5	LTT	12	11.2	10.7	16.5	0.9	1.1
6	R	38	35.5	7.4	11.4	0.2	0.3
11	B+SF	15	14.0	11.3	17.4	0.8	0.9
12	B+TSF	7	6.5	12.2	18.8	1.7	1.8
14	R+RF	17	15.9	4.8	7.4	0.3	0.2
		107	100	64.9	100.0	0.6	

Table 24.2c PC:TAS03.04 (King Island – east coast) beach types and states

BS	BS	n	%	Total km	% (km)	Mean (km)	σ (km)
4	TBR	6	13.3	21.7	33.6	3.6	6
5	LTT	13	28.9	27.5	42.6	2.1	2.1
6	R	26	57.8	15.4	23.8	0.6	0.8
		45	100	64.6	100		

Table 24.3 PC:TAS03 barrier dimensions

TAS03	TAS03.01	TAS03.02	TAS03.03FI	TAS03.04KI	Total
No.	32	37	25	14	108
Total length (km)	79.1	139.3	38.1	54.4	311
Mean min width	190	285	150	200	–
Mean max width	470	1320	650	950	–
Mean height (m)	5	14	15	15	–
Area (ha)	3090	14,792	2535	1083	21,500
Unstable (ha)	2	3990	125	70	4187
Total volume (M m^3)	156	2742	359	169	3426
Unit volume (m^3 m^{-1})	1979	19,689	9415	3085	11,016

24.7 Barriers

The north coast barriers are generally small and regressive on the sheltered western coast and eastern King Island (1979 and 3085 m^3 m^{-1}, respectively) and become larger transgressive systems on the exposed section of the eastern coast which reach 19,689 m^3 m^{-1}, while the exposed east coast of Flinders is sheltered by a number of island and has limited Holocene transgressive dunes and a moderate 9415 m^3 m^{-1} (Table 24.3). While the north coast barrier volumes are four times the size of the leeward east Tasmanian coast, they are 50% less than the exposed west Tasmanian coast (Tables 21.3 and 23.2, Appendix 34.2).

24.8 Sand Transport

The most detailed study of the northern Tasmanian coast, its sediments and their transport, was undertaken by Davies and Hudson (1987a, b) and Hudson and Davies (1987). They examined fluvial and marine sources, sediment texture and mineralogy and the potential for longshore transport. They divided the coast into three zones based on their mineralogy (Table 24.1), and together with the percentage of heavy and light minerals found that there was a strong relation between the mineralogy of the catchments and their coastal sediments concluding there was no significant transport along the coast. They attributed the lack of both Holocene and Pleistocene longshore transport to a lack of sediment on critical parts of the coast, headland obstacles to easterly transport and the generally low wave energy. They concluded that the lack of sand in the centre is owing to a lack of fluvial sources, also indicated by the higher proportion of carbonate. Davies and Hudson (1987b) concluded that the north coast sand was immediately derived from the shelf during and following the PMT, with the remainder supplied by erosion of coastal bedrock and biogenic carbonate and river supply. Davies (1973) found that most of the rivers are supplying limited sand to their mouths where carbonate drops to ~20%, the proportion of carbonate rising up to 60–80% away from the river, again indicating the lack of longshore transport. More results of their studies are presented in the following SCs.

The north coast region has two mainland PCs containing five SCs, together with the eastern King Island PC and SCs and western Flinders Island PC and SCs, in all four PCs containing eight SCs (Table 24.4), each of which is discussed below.

Table 24.4 North Tasmania region, PCs and SCs

North Tasmania	Location	Boundaries	TAS beaches	Beach no.	TAS km	km
TAS03.01.01	North coast (W)	Hunter Island-North Pt	TAS 965-984	20	1798–1868	70
TAS03.01.02	North coast (W)	North Pt-Regatta Pt	TAS 985-1138	154	1868–2012	144
TAS03.01		*Hunter Is-Regatta Pt*	*TAS 965-1138*	*174*	*1798–2012*	*214*
TAS03.02.01	North coast (centre)	Regatta Pt- Low Hd	TAS 1139-1186	48	2012–2081	69
TAS03.02.02	North coast (E)	Low Hd-East Sandy Pt	TAS 1187-1224	38	2081–2144	63
TAS03.02.03	North coast (E)	East Sandy Pt-C Portland	TAS 1225-1269	45	2144–2237	93
TAS03.02		*Regatta Pt-C Portland*	*TAS 1139-1269*	*131*	*2012–2237*	*225*
TAS03.03.01	C Barren Is	C Portland-C Sir John	C Barren Is			
TAS03.03.02	Flinders Is (W)	C Sir John-Stanley Pt	FI 29-133	105	FI 109-235	126
TAS03.03	Flinders Is (W)	C Sir John-Stanley Pt	*FI 29-133*	105		126
TAS03.04.01	King Is (E)	C Wickham-Fraser Bluff	KI 1-13	13	KI 0-48	48
TAS03.04.01	King Is (E)	Fraser Bluff-Stokes Pt	KI 14-45	32	KI 48-96	48
TAS03.04	King Is (E)	*C Wickham-Stokes Pt*	*KI 1-15*	*15*		*96*
TAS03		*Region total*		*425*		*661*

24.9 PC:TAS03.01

The north coast's western PC (TAS03.01) encompasses the western half of the coast from the northwestern tip at Woolnorth Point to Regatta Point at Devonport (Fig. 24.1). The entire 214 km of coast trends west-southwest, with the prevailing westerly winds generally flowing along to offshore (Fig. 21.5). In addition, the large western islands, in particular Hunter and Robbins, further shelter the shoreline. Tides are meso, and the shoreline ranges for TD in the sheltered regions to TM on the more exposed sections, together with a large number of generally small beaches fronted by rock flats. The PC contains two SCs (TAS03.01.01-2).

24.9.1 SC:TAS03.01.01 Woolnorth Point–North Point (Stanley)

SC:TAS03.01.01 extends for 70 km between Woolnorth Point and North Point at Stanley (Fig. 24.1a) and is the most sheltered section of the north coast. It is bordered by the prominent Hunter Island and North Point, with the large low Robbins Island dominating much of the centre. The beaches are predominately TD ranging from B+RSF to B+TSF (Fig. 24.2a), with two more exposed TM UD in Perkins Bay and several R+RF on the western side of North Point. This coast has acted as a sediment sink as indicated by the extensive intertidal sand flats, some up to 4 km wide, and in the east the regressive barriers on Robbins Island and in Perkins Bay. There are seven mainland barriers, all low regressive beaches to foredune ridge plains, with 3.3 km wide Perkins Island containing up to 50 ridges (Fig. 24.2b). The barriers have a total volume of 107 M^3 (3458 m^3 m^{-1}) and cover an area of 22 km^2. In contrast the tidal flats have an area of 170 km^2, indicating most of the sand has been deposited in the flats of Boullanger Bay and Perkins Passage. It appears that tidal currents have played a major role in transporting sand into the bay and passage, while in Perkins Bay, a combination of waves and tides has interacted to develop the two barrier islands and their prominent tidal inlets and deltas, to partially fill this open sediment trap. Thom et al. (1981) dated some of the Anthony Beach ridges but found them age contaminated, though one did date 3.3 ka.

On Robbin Island (Fig. 24.1a) is an 8 km wide regressive Pleistocene beach-foredune ridge plain containing on the order of 120 low ridges, which have been uplifted up to 15 m above sea level and cover an area of 16 km^2 (Bowden and Colhoun, 1984). They are fronted by an interbarrier depression and a 0.5 km wide Holocene barrier that curves to the northwest and consists of a series of blowouts and parabolic dunes, a marked contrast to the inner barrier.

Fig. 24.1 (**a**) SC:TAS03.02.01 and (**b**) SC03.01.02. (Source: Google Earth)

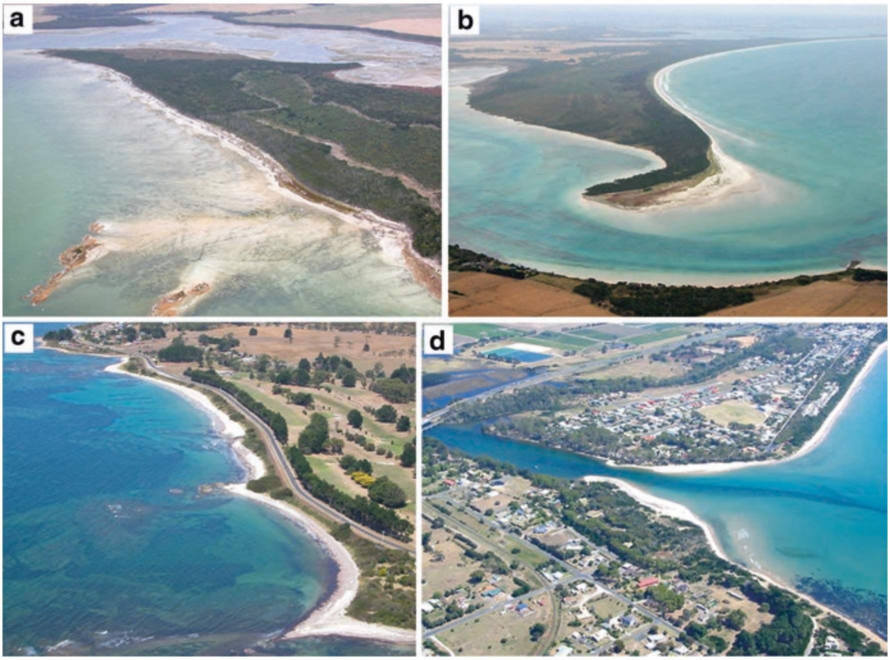

Fig. 24.2 (**a**) Sheltered sand flats and beach in Anne Bay (TAS 970); (**b**) the regressive Anthony Beach-Perkins Island and barrier in Perkins Bay (TAS 975); (**c**) Doctors Beach and extensive rock reefs (TAS 1070); and (**d**) River Forth mouth at Turners Beach (TAS 1121). (Photos: AD Short & W Hennecke)

24.9.2 SC:TAS03.01.02 North Point (Stanley)–Regatta Point (Devonport)

SC:TAS03.01.02 commences at the tip of 10 km long North Point and trends west-southwest for 144 km to Regatta Point at Devonport and the mouth of the Mersey River (Fig. 24.1b). This coast is dominated by its geology with most of the beaches embayed between rocky points, as well as six small rivers (Fig. 24.2d) and over 30 small creeks. This is also the most highly developed strip of open coast in Tasmania, with the Bass Highway paralleling much of the coast (Fig. 24.2c) from Stanley to Devonport, and most of the small towns and communities located along this section, including the larger Burnie, Ulverstone and Devonport. There are a total of 154 beaches which average just 0.5 km (σ = 0.8 km) occupying 78.5 km (54.5%) of the coast. The most dominant type is the R+RF (99 beaches, mean length = 0.35 km), indicating the overriding influence of the geology (Fig. 24.2c); these are followed in number by the TM R+LTT (23, 0.7 km), R+LTR (8, 0.4 km) and UD (11, 1.4 km), together with 15 WD beaches (T, TBR and D) and 3 TD B+SF. The rocky shore forms numerous small headlands, points and rock reefs, with extensive and near continuous inter- to subtidal reefs between Wynyard and Devonport, together with three major headlands – North Point, Rocky Cape and Table Cape.

This is a sediment-deficient coast with very limited river supply to the coast (Davies and Hudson 1987b). Rocky shore predominates with generally small sandy beaches occupying gaps in among and behind the rocks. There are 25 generally small barrier systems, the largest in the west in Sawyers Bay and adjacent Hellyer-Forwards beaches, where there are regressive barriers up to 400 m wide including the Sawyers Bay barrier island. Most of the barriers consist of one to a few low foredune ridges. They occupy 48 km (33%) of the shore, average 1.9 km in length and total just 49 M m^3 in volume (1025 m^3 m^{-1}).

24.9.3 PC Overview

This is a PC of two parts, the western sediment sink either side of and in lee of Robbin Island and the sediment-deficient coast particularly east of Rocky Cape, which Davies (1973) concluded was closed to longshore transport, with Table Cape also closed. As Davies and Hudson (1987b) concluded, the sediment deficiency is a result of a combination of lack of fluvial supply, obstacles to longshore transport and low transport potential owing to the low wave energy, with tides being the dominant mode of transport in the sheltered west. Hudson and Davies (1987) concluded that most of the sand was transported onshore from the shallow strait during the PMT, building the regressive barriers and tidal deltas in Perkins and Sawyers bays. Today both onshore transport and river supply are minimal resulting in a stable shoreline and a balanced sediment budget. While much of the coast is rocky and resilient, there are the numerous small creeks and rivers and associated estuaries, as well as generally low beach and barrier systems, the site of many residential development and infrastructure, all of which are prone to both fluvial and marine inundation, the latter increasing with sea-level rise. The beachfront Bass Highway and roads along parts of the coast between Wynyard and Ulverstone are at risk in places, as are beachfront properties at places like Sisters Beach and Boat Harbour. The Tasmanian Govt (2016) identified 978 properties at future risk to coastal erosion and 896 to inundation along this section of coast, second only to the Hobart region in exposure (Table 21.5).

24.10 PC:TAS03.02

The north coast's eastern PC (TAS03.02) extends from the mouth of the Mersey River to the northeastern tip of the island at Cape Portland, a distance of 225 km. This PC consists of a series of generally longer curving northwest-facing embayed beaches, swash-aligned by the dominant westerly waves, with the longer, more exposed eastern beaches backed by massive Pleistocene and Holocene longwalled parabolic dunes. The coast is dominated by its geology with the dolerite, sedimentary and granite rocks forming the headlands and a few small islands. The beaches are a mix of higher energy WD (D-R) (8% by length), TM (UD-R+LTT) (57%) and R+RF (20%) and a few TD (15%) in the more sheltered waters of Port Sorell, Port Dalrymple and Bridport.

24.10.1 SC:TAS03.02.01 Regatta Point (Devonport)–Low Head

SC:TAS03.02.01 is located in the centre of the north coast and extends for 69 km from the Mersey River mouth at Devonport to Low Head at the mouth of Port Dalrymple and the Tamar River (Fig. 24.3). There is development at East Devonport including Devonport airport, on the western shores of Port Sorell and along parts of the Tamar estuary; otherwise the coast is reasonably undeveloped, with Asbestos Range National Park extending for 24 km from eastern Port Sorell to West Head. It basically consists of four embayments including the 6.5 km long Northdown Beach (Fig. 24.4a), Port Sorell and 7 km long Bakers Beach (Fig. 24.4b), 4.5 km long Badger Beach and the 7 km wide entrance to Port Dalrymple between West and Low heads. There are a total of 48 beaches which average 0.9 km in length and occupy 43.7 km (63%) of the shore, the remainder a mix of metasedimentary and sedimentary rocks including Tertiary rocks. The rocks form the prominent Point Sorell, Badger Head and West Head, each of which forms major obstacles to longshore sand transport, together with the Tamar whose 1 km wide deep entrance channels are a major obstacle to longshore transport (Davies 1973). The beaches are a mix of sheltered TD B+SF in the port entrances and exposed TM on the open embayed beaches ranging from R+LTT to R+LTR to UD in the most exposed locations, together with 16 R+RF around the rocky sections.

The Tamar estuary is the largest in Tasmania winding south from its entrance for 70 km to Launceston. At Launceston the estuary is fed by the South Esk and North Esk rivers, which combined have a catchment that covers 15% of Tasmania (~10,000 km^2) (Edgar et al. 2000). It has a tide range of 3–4 m, which maintains a deep well-defined tidal channel bordered by tidal mud flats and wetlands.

Fig. 24.3 SCs TAS03.02.01 and 03.03.02. (Source: Google Earth)

Fig. 24.4 (**a**) Exposed Northdown Beach (TAS 1147) with low tide rips; (**b**) Badger Beach with low tide rips and transgressive dunes in 1978, the active dunes have since stabilised (TAS 1173); (**c**) longwalled parabolic dunes, which have been planted for stabilisation in St Albans Bay (TAS 1223); and (**d**) crenulate sand spit at Lades beach (TAS 1226) indicative of longshore sand transport. (Photos: AD Short & W Hennecke)

There are nine barriers occupying 33.6 km (39%) of the coast. They range from a few low foredunes to the 500 m wide regressive system at Bakers Beach (TAS 1167) and one 2.5 km wide transgressive system at Badger Beach (TAS 1173), whose dunes overlay older Pleistocene dunes which extend up to 4.5 km inland. The outer Bakers Beach foredune has been reworked and partially buried by a near continuous series of now stable blowout-parabolics. The barriers have a total volume of 130 M m^3 (3855 $m^3\ m^{-1}$). The most dynamic system is located along the western shore of Port Sorell where 0.5 km wide sand flats front the curving 3 km long Freers Beach (TAS 1162). Sand is moving southwards along the beach and into the deep Port Sorell tidal channel in doing so causing oscillations in the shoreline, which has generated shoreline erosion and resulted in the construction of 500 m of rubble seawall and two groynes. As this entire beach is backed by residential development, this is a potentially high-risk area. At Greens Beach (TAS 1176), a regressive barrier located just inside the entrance to Port Dalrymple was dated by Thom et al. (1981) who obtained one date of 3.6 ka, the other age contaminated.

24.10.2 SC:TAS03.02.02 Low Head–East Sandy Point

SC:TAS03.02.02 continues west of Low Head for 63 km to the prominent East Sandy Point (Fig. 24.3). This SC contains four irregular embayments (Bellbuoy Beach, Beechford, the larger Noland Bay and St Albans Bay (Fig. 24.4c)). There is little development on the coast apart from small communities at Tam O'Shanter and Weymouth-Bellingham. The coast is a mix of large protruding rocky sections and generally longer more exposed TM beaches. The beaches occupy 47.5 km (75%) of the shore and are made up of TM R+LTT (10 beaches, mean length = 1.6 km) and more exposed R+LTR (10, 1.9 km) and smaller R+RF (18, 0.7 km) along the rocky sections around the points and headlands. Most of the longer beaches curve to the northeast and in doing so become increasingly exposed to the westerly waves and wind resulting in the development of both Pleistocene and Holocene transgressive dune fields, most as longwalled parabolics (Fig. 24.4c). Pleistocene interglacial dunes, as well as lunettes, blanket much of the northeast coast (Bowden 1983), extending in places 30–40 km across the island to the east coast. Nearer the coast these are partially reworked and blanketed by Holocene longwalled parabolics, which along this compartment are located in 13 barrier systems, with larger the transgressive dune systems at East-Bellbuoy, Beechford-Stony Head and Single Tree Plain. The largest, the Beechford system, extends up to 4 km inland with some of the dunes climbing to elevations of 60 m. In total the dunes have a volume of 700 M m^3 (16,990 $m^3\ m^{-1}$).

Hudson and Davies (1987) found this central region generally sediment-deficient owing a lack of quartzose lithologies in the hinterland, and while the rivers are relatively large, they supply predominately suspended sediment load which is not retained at the coast. As a consequence, there was limited shelf supply during the PMT, some of which was lost to the large estuaries, while at present they found sand is being supplied in small quantities from the rivers and cliff erosion but being lost to the dunes, estuaries and possibly offshore. It is likely that sand is being transported northeast along the longer beaches, and there may be limited bypassing of Five-Mile Bluff, Stony Head and West and East Sandy points, which Davies (1973) defined as leaky boundaries. Sand is also being lost into the foredunes and active dunes which cover 840 ha (18% of the dunes) and is presently overpassing Five-Mile Bluff and West and East Sandy points. Hudson and Davies however concluded the sediment budget was presently balanced.

24.10.3 SC:TAS03.02.03 East Sandy Point–Cape Portland

SC:TAS03.02.03 is the easternmost section of the north coast. It extends northeast from East Sandy Point for 93 km to Cape Portland, the northern tip of TAS, with the coast dominated by the large Anderson and Ringarooma bays (Fig. 24.5). This northeast corner has a gently undulating terrain only rising above 100 m in the

Fig. 24.5 SC:TAS03.02.03 contains the larger exposed Anderson and Ringarooma bays, terminating at Cape Portland the northern tip of Tasmania. (Source: Google Earth)

Ringarooma tier, and much of it is blanketed by Pleistocene glacial dunes. The only development on the coast is the town of Bridport, and the adjacent Barnbougle Golf links set in the dunes east of the town and the small Tomahawk community; otherwise transgressive dunes occupy much of the coast and hinterland, and most of the coast is reserved in the Double Sandy Point, Waterhouse and Ringarooma conservation and protection area. Forty-five beaches occupy 71% of the coast with an average length of 1.47 km ($\sigma = 3.3$ km) and are a mix of higher energy TM and WD. The longest and most exposed beach is the 20 km long Waterhouse (TAS 1237), a R+LTR beach with up to 120 low tide rips usually spread along the shore (spacing 150 m), while 6 are WD RBB (mean length = 1.7 km), 21 are R+LTT (mean length = 0.9 km), 3 LTT, together with 5 TM B+TSF in the reef-sheltered waters around Tomahawk, and 9 are fronted by rock flats.

There are 16 barriers in the SC, most parabolic to longwalled parabolic transgressive dune systems, with the Waterhouse Bay dunes extending up to 10 km inland, and all overriding and backed by Pleistocene glacial dunes. The barriers occupy 66.3 km (71%) of the shore and have a total volume of 1910 M^3 (29,660 m^3 m^{-1}), by far the largest dunes and per metre volume of the north coast. The sand while ultimately sourced from the local rivers (Davies and Hudson 1987b) has been swept from the shallow shelf during the PMT by the westerly waves to build the beaches and by the westerly winds to build the massive dunes, some reaching heights of 140 m. There is evidence of headland overpassing and bypassing of East Sandy Point, with sand moving down the eastern side of the point and building a 2.5 km south-trending spit (Fig. 24.4d), and along the southern end of Waterhouse Beach, with both east-trending sand waves and a 5 km long series of vegetated recurved spits that have deflected the mouth of Boobyalla Inlet to the northeast.

Elsewhere, most of the mobile sand appears to be moving into the active dunes with 3150 ha (31%) presently unstable, with Bowden (1983) recording rates of inland movement up to 14 m $year^{-1}$.

Bowden (1983) and Bowden and Coulhoun (1984) mapped the interglacial long-walled parabolics and lunettes that cover an area of 350 km^2 across northeastern Tasmania. The dunes have a uniform WNW-ESE alignment, consistent with wind direction during the last glacial stage. These were initially dated at Croppies Point by Duller and Augustinus (1997) and again by Duller and Augustinus (2006). The latter dates indicated the dunes were active during the glacial period between 23.8 and 16.8 ka, a period of strong westerly winds and more arid conditions. These dates are in agreement with McIntosh et al. (2009) who dated linear dunes south of Croppies Point at between 29 and 14 ka. Similar dates were obtained for westerly generated 'glacial' dunes at Seven Mile beach near Hobart (Donaldson 2010; Oliver et al. 2017). Hudson and Davies (1987) concluded that this section received major shelf supply during the PMT, much of which was lost to the dunes, together with limited headland bypassing and overpassing. At present sand continues to move into the dunes resulting in a negative sediment budget and general shoreline recession.

24.10.4 PC Overview

PC:TAS03.02 commences with the sediment-deficient north- to northwest-facing central section with generally lower energy TM beaches. As it progresses east sediment availability increases, and the beaches become longer and curve more to the northeast to face the prevailing westerly waves and winds, in the process generating higher energy TM and some WD beaches, with the most exposed backed by increasingly larger transgressive dune systems. There has been and continues to be some headland overpassing and very likely limited bypassing; however for the most part, the sand has moved onshore and into the dune fields. This coast is susceptible to sea-level rise in the several creeks and small river mouths, and any shoreline retreat could destabilise the foredunes leading to an increase in dune transgression. There are existing erosion issues in Port Sorell and properties along the low-lying estuaries shores of Port Sorell and the Tamar estuary, all of which will become increasingly prone to inundation. The Tasmanian Govt (2016) mapped 685 properties at future risk to coastal erosion in the central Launceston region and a further 270 at risk to inundation (Table 21.5).

24.11 PC:TAS 03.03 Flinders Island West Coast

This section discusses the west coast of Flinders Island (SC:TAS03.03.02; Fig. 21.6) excluding Cape Barren Island, while the east and south coast of the island (SCs:TAS01.01.01-02) are discussed in Chap. 21. The west coast commences in the south at Big River and trends north-northwest past the protruding Settlement Point to Cape Frankland, where it turns and trends northeast to the northern tip at Stanley Point, a total distance of 126 km.

The island is dominated by Devonian granite which reaches a maximum height of 756 m at the southern Mount Strzelecki and 501 m at the central Mount Leventhorpe. The granite tends to outcrop along the south, central west (Fig. 24.6b) and northern coast, while the east coast consists of long sandy beaches, as discussed in Sect. 21.10. The granite also forms about 20 islands located off the west coast which together with headlands and shallow reefs attenuate and refract the westerly waves, with the southern Big Green Island responsible for the protruding cuspate foreland in Parrys Bay, while the 4 km Long Point Beach is tied to rock reefs at its southern end (Fig. 24.6a). Overall the islands, rocks and reefs substantially lower wave energy along this otherwise exposed windward coast, allowing seagrass to grow close to shore. More exposed beaches are located in the centre of Marshall Bay and along parts of the north coast including Killiecrankie and Palana beaches.

Beach sand ranges from fine to coarse and from 0% to 85% carbonate (Fig. 21.7), the highly variable texture indicating local sources and limited longshore transport. The two small Dock beaches are a good example with the southern beach (FI 119) composed of coarse quartz sand, while 60 m to the north the northern Dock beach (FI120) is composed of fine to medium sand. There is however evidence of longshore transport in Parrys Bay where sand has moved laterally to build the central cuspate foreland and at the northern end where sand appears to have moved southwards to build Long Beach and at the mouth of the small Pats River,

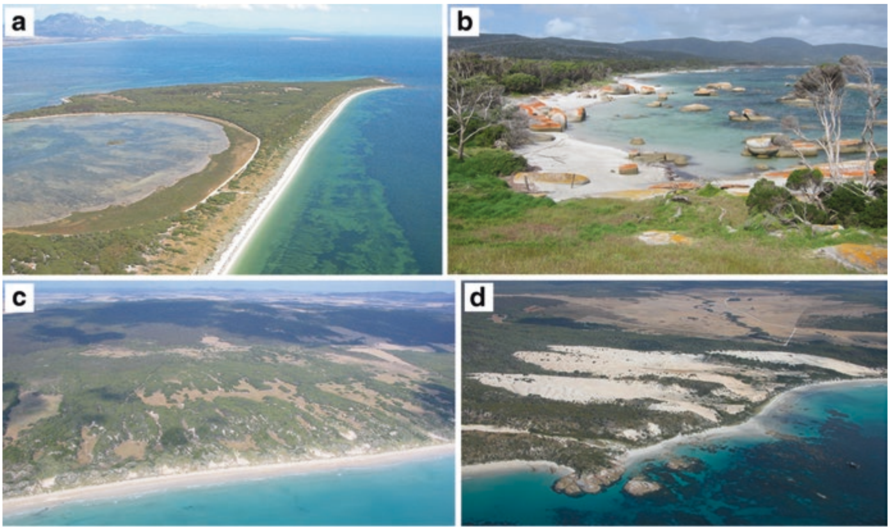

Fig. 24.6 (**a**) The sheltered Long Point Beach (FI 46) with seagrass growing close to shore; (**b**) granite boulders are scattered along the sheltered Sawyers Bay beaches (FI 54); (**c**) well vegetated longwalled parabolic dunes in Marshall Bay (FI 82); and (**d**) active parabolic dunes behind Palana Beach (FI 128), the only active dunes on the island. (Photos: AD Short)

which may be supplying sand to build the small barrier and spit that extend south of the river mouth. Otherwise most transport appears to have been from the shallow shelf onshore and into the dunes.

The west coast has 107 beaches which occupy 65 km (56%) of the shore (Table 24.2b). They are a mix of WD (R though to RBB) (56%) with the R scattered throughout and the higher energy TBR and RBB located along the northern west and north coasts; TM B+SF and B+TSF (36%) are mainly located along the island and reef-sheltered section for Whitemark up to Sawyers Bay; and a number of generally short R+RF (7%) are on the rocky northwest and north coasts.

There are 25 barrier systems along the west coast occupying 38 km (30%) of the coast. They tend to be small and short apart from the larger higher energy Marshall Bay (Fig. 24.6c), Killiecrankie and Palana beaches which are all backed by extensive transgressive longwalled parabolics, extending 2 km in from Marshall Bay and 4 km from Palana (Fig. 24.6d). The barriers total 359 M m^3 (9415 m^3m^{-1}) (Table 24.3). The west coast of Flinders Island is a windward coast exposed to strong westerlies but largely sheltered from westerly waves by the numerous islands and reefs. All the beaches and barrier, apart from Palana, appear stable, with no property presently at risk.

24.12 PC:TAS03.04 King Island: East Coast

The east coast of King Island consists of two parts, the northern predominately sandy coast (SC:TAS03.04.01) and the more rock-dominated southern half (SC:TAS03.04.02) (Fig. 23.10b). This is a 96 km long east-facing leeward coast with the prevailing westerly winds blowing offshore and the large Southern Ocean swell which batters the west coast having to refract around the northern and southern points to reach the shore much reduced in height. The east coast beach sands range from fine to medium and are low in carbonate, which ranges from 1% to 27%, considerably lower than the more carbonate-dominated west coast (Fig. 23.13). The occasional swell waves, together with local easterly wind waves and micro-tides, are the dominant processes on this generally low to moderate energy coast and combine with the sand to maintain a range of low to moderate energy WD beaches (Table 24.2c).

24.12.1 SC:TAS03.04.01 Cape Wickham-Fraser Bluff

SC:TAS03.04.01 occupies the northern half of the east coast between the northern tip at Cape Wickham and Fraser Bluff, a distance of 48 km. This is a predominately sedimentary coast with 15 beaches occupying 44 km (92%) of the shore, including the 17 km long Nine Mile Beach. The beaches are all WD ranging from R to TBR depending on exposure, with the longer beaches rip-dominated TBR. There is evidence of northerly longshore transport along the east coast with the northerly deflection of the Elephant River and now inactive recurved spits west of Lavinia Point at the former entrance to Pennys Lagoon and just west of Boulder Point. In addition, there are a series of north-trending sand waves clearly visible on Google Earth images (e.g. 25/1/2013) extending around Boulder Point and up to 1 km offshore, which would suggest sand is being transported northward and lost to the seabed north of Cape Wickham. The protruding sandy Cowper Point, located in lee of Councillor Island, also has evidence of realignment of the regressive ridges, which some parallel ridges now truncated, indicating a rotation of the point's shoreline, possibly due to changing wave climate.

Sand has accumulated along the northeast coast forming five barriers that occupy 39 km (81%) of the coast. The long Nine Mile Beach Holocene barrier consists of a regressive Pleistocene inner barrier and ~1 km wide outer Holocene barrier containing an inner transgressive units (vegetated blowouts, the 'new dunes' Fig. 23.12a) generated by the subdominant easterly winds (Fig. 23.12b) and outer foredune ridges. The barriers are separated by the low Nook Swamp. Apart from some minor blowouts on Cowper Point, all the barriers are presently stable. The barriers have a total volume of 109 M m^3 (2810 m^3 m^{-1}).

24.12.2 SC:TAS03.04.02 Fraser Bluff-Stokes Point

SC:TAS03.04.02 continues south from Fraser Bluff for another 48 km to the southern tip of the island at Stokes Point. The only development on the coast is a jetty at Naracoopa and two attached breakwaters at Grassy built to provide a small harbour for the small township and past mine located high on the hills behind. A combination of refracted southerly swell and easterly wind waves maintains low to moderate energy conditions along the coast. In contrast to the northern half, this is a rock-dominated section with 32 generally short embayed southeast-facing beaches (mean length = 0.65 km) occupying 21 km (43%) of the shore. The beaches range from R in the more embayed and sheltered beaches to LTT and TBR on the longer more exposed beaches and include a 2.5 km long boulder beach extending east of Grassy Harbour.

There are nine barriers along this section most located along the southeast-facing southern section between Bold Head and Stokes Point. They consist of climbing transgressive dunes including clifftop dunes, rising to 90 m in lee of Grassy, which include minor overpassing of the eastern headland. They have been generated by onshore south to southeast winds (Fig. 23.12b) and have a total volume of 60 M m^3 (3756 m^3 m^{-1}). Most of the east coast dunes are stable and well vegetated with just 6% presently active. The location, nature and stability of the transgressive dunes indicate that they were probably deposited during and immediately following the PMT, followed by stability, assisted by a slight fall in sea level, which also resulted in closure of some of the northeast inlets.

24.13 Regional Overview

The north Tasmanian coast (TAS03) including western Flinders and eastern King islands is a partly sheltered and regionally variable coastline, a product of both orientation and sheltering by islands. It is also for the most part a meso-tidal coast, with the combination of higher tides and low to moderate waves producing beaches that range from very sheltered TD in the west, with TM (57%) dominating much of the 'mainland' coast, together with some WD (8%) on the most exposed eastern beaches (Table 24.2a). The generally lower energy conditions also result in generally smaller barriers which range from regressive on the lee shores to transgressive on the windward shores, with a total volume for the entire region of 3426 M^3 (11,016 m^3m^{-1}) (Table 24.3).

While much of the region's coast is undeveloped or used for agriculture, there are a number of small- to medium-sized coastal towns and communities, particularly between Stanley and Launceston, where the highway parallels the coast (Fig. 24.2c), together with some properties located on beachfront, at river mouths-inlets (Fig. 24.2d) and on estuaries. These communities will be susceptible to sea-level rise and increased levels of both marine and fluvial inundation. The Tasmanian Govt (2016) identified hundreds of properties along the western northern coast, in the Launceston region and a few on King Island, that will be at risk to coastal erosion and inundation hazards (Table 21.5). While few are presently at high risk, the risk and number of vulnerable properties will increase as sea-level rises. Maps of potential coastal erosion and inundation for the entire state are also available at https://nationalmap.gov.au

A 100 km long section of the central northern Tasmanian coast between Sisters Beach and Port Sorell experienced considerable coastal damage during 2018 when a series of westerly winter storms with accompanying high waves and storm surges, the latter coinciding with spring tides, hit the coast. There was severe erosion of beaches and foredunes and damage to infrastructure, as well as inundation of low-lying areas. From the west the beaches and areas most seriously affected were at Sisters Beach (TAS 1043), Wynyard, Somerset-Cam River, Heybridge, Penguin, Ulverstone, Turners Beach, Leith, Forth River mouth and Shearwater and Freers Beach (TAS 1162) in Port Sorell. These storms are an indication of what can be expected to occur more frequently in the future (http://www.abc.net.au/news/2018-10-06/coastal-erosion-on-tasmanias-north-west-how-to-plan-for-future/10329410).

References

Bowden AR (1983) Relict terrestrial dunes: legacies of a former climate in coastal northeastern Tasmania. Zeitschrift für Geomorphologie, Supp 45:153–174

Bowden AR, Colhoun EA (1984) Quaternary emergent shorelines of Tasmania. In: Thom BG (ed) Coastal geomorphology in Australia. Academic Press, Sydney, pp 313–349

Davies JL (1973) Sediment movement on the Tasmanian coast. In: 1st Australian conference on coastal and ocean engineering, Institution of Engineers Australia, pp 43–47

Davies JL (1978) Beach sand and wave energy in Tasmania. In: Davies JL, Williams MAJ (eds) Landform evolution in Australasia. Australian National University Press, Canberra, pp 158–167

Davies JL, Hudson JP (1987a) Differential supply and longshore transport as determinants of sediment distribution on the north coast of Tasmania. Mar Geol 77:233–245

Davies JL Hudson JP (1987b) Sources of shore sediment on the north coast of Tasmania. Papers Proc R Soc Tasmania 121:137–151

Donaldson P (2010) Facies architecture and radar stratigraphy of the Seven Mile Spit Complex, Tasmania. School Earth Science, University of Tasmania, Hobart, 147 p

Duller GAT, Augustinus PC (1997) Luminescence studies of dunes from north-eastern Tasmania. Quat Sci Rev 16:357–365

Duller GAT, Augustinus PC (2006) Reassessment of the record of linear dune activity in Tasmania using optical dating. Quaternary Sci Rev 25:2608–2618

Edgar GJ, Barrett NS, Graddon DJ (2000) A classification of Tasmanian estuaries and assessment of their conservation significance: an analysis using ecological and physical attributes, population and land use. Ocean Rescue 2000- Marine Protected Area Program, Regional classification of Tasmanian coastal waters- Stage 2, Estuaries. Report to Environment Australia from Tasmanian Parks Wildlife Service

Hudson JP, Davies JL (1987) Shore sediment budgets, northern Tasmania. In: 8th Australasian conference on coastal and ocean engineering, Sydney, Institution of Engineers Australia, pp 150–154

McIntosh PD, Price DM, Eberhard R, Slee AJ (2009) Late Quaternary erosion events in lowland and mid-altitude Tasmania in relation to climate change and first human arrival. Quat Sci Rev 28(9–10):850–872

Murray-Wallace C, Goede A (1995) Aminostratigraphy and electron spin reconnaissance dating of Quaternary coastal neotectonism in Tasmania and Bass Strait islands. Aust J Earth Sci 42:51–67

Oliver TSN, Donaldson P, Sharples C, Roach M, Woodroffe CD (2017) Punctuated progradation of the Seven Mile Beach Holocene barrier system, southeastern Tasmania. Mar Geol 386:76–87

Short AD (2006) Beaches of the Tasmanian Coast and Islands. Sydney University Press, Sydney, 353 p

Tasmania Govt (2016) Coastal hazards technical report: mitigating natural hazards through land use planning and building control. Department of Premier and Cabinet, Tasmanian Government, Hobart, 125 p

Thom BG, Bowman GM, Gillespie R, Temple R, Barbetti M (1981) Radiocarbon dating of Holocene beach-ridge sequences in south-east Australia. Department Geography, UNSW Mono. 11, Canberra, 36 p

Wijeratne EMS, Pattiaratchi CB, Eliot M, Haigh ID (2012) Tidal characteristics in Bass Strait, south-east Australia. Estuar Coast Shelf Sci 114:156–165. https://doi.org/10.1016/j.ecss.2012.08.027

Chapter 25
Central and Western Victoria Region

Abstract The central-western Victorian coast contains three distinct primary compartments: an eastern series of open and enclosed bays, the southeast-facing Surf Coast, and the exposed high energy west coast. The entire open coast is exposed to persistent southwest swell and periodic strong westerly winds, with tide predominately micro, while beach sands increases in shelf-derived carbonate content from 28% in the east to 78% in the west. The eastern open bays curve to face southwest into the swell that enters through Bass Strait and are generally backed by transgressive dunes, while the two large enclosed bays, Western Port and Port Phillip, have respectively, meso- and micro-tides with very different shorelines. The Surf Coast is a lee shore with moderate energy beaches and limited barrier development, while the exposed west coast has eroding limestone cliffs in the east grading to a series of large curving bays to the west with easterly longshore transport. This chapter describes the geology, climate, coastal process and the beaches, barriers, sediment transport and sediment compartments.

Keywords Central-western Victoria · Port Phillip · Western Port · Beaches · Barriers · Sediment transport · Sediment compartments

25.1 Introduction

The central and western coast of VIC commences at South Point on Wilsons Promontory, the southern tip of the Australian continent, and trends generally west for 1057 km to Point Danger, located 14 km across the border in SA (Fig. 25.1). The central section consists of a broad 250 km wide embayment bordered by South Point and Cape Otway and includes a series of open western bays, the landlocked Western Port and Port Phillip bays (PC:VIC03.01) and the southwest-trending Surf Coast down to the cape (PC:VIC03.02), in total 574 km of open coast and 260 km inside Port Phillip. The more exposed western section essentially trends west-northwest in six curving sectors for 358 km to Point Danger (PC:VIC03.03).

This is a reasonably developed coast centred on the cities of Melbourne and Geelong both located in Port Phillip Bay. On the open coast are a series of smaller

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Fig. 25.1 The central and western Victoria PCs:VIC03.01-03. (Source: Google Earth)

towns and communities most setback from the coast behind foreshore reserves which runs as a ~100 m wide strip along much of the coast, though some sections are leased for camping and recreational and sporting facilities and some are now incorporated in national parks. The reserve system has however kept most development from the beachfront, unlike in most other states, and as a result, there are fewer beachfront 'hotspots' on the Victorian coast.

25.2 Geology

The coastal geology is a mix of ancient granites and modern volcanics (Douglas and Ferguson 1976). Beginning in the east at Wilsons Promontory are the massive Devonian granites that form the promontory. To the west is a series of southwest-trending parts of the South Gippsland Highland separated by the East and West Gippsland sunklands. To the north and west of the promontory is the Corner Inlet sunkland occupied in the west by Shallow Inlet-Waratah Bay, then the protruding sedimentary rocks of Cape Liptrap, followed by the Tarwin sunklands (Anderson Inlet-Venus Bay), and the sedimentary Bass Block which extends to San Remo. The Western Port Sunklands include the bay as well as French and Phillip islands, which have been partially covered by the 'Older' Tertiary volcanics. To the west the bay is bordered by the West Gippsland Central Ridge that comprises most of the Mornington Peninsula and which is also partly covered in volcanics. This in turn borders the large Port Phillip sunklands. The Western Districts begin to the west of Port Phillip with the Bellarine Peninsula, a mix of non-marine Tertiary sediments and Older Volcanics, which together with Tertiary marine sediments extend down the Surf Coast to Table Rock. The southern Surf Coast contains the uplifted southwest-trending Otway Range which is composed of Cretaceous non-marine rocks which dominate to Moonlight Head. To the west begins the Tertiary marine rocks of the Port Campbell National Park, best exemplified by the Twelve Apostles, which continue west to Warrnambool. The rest of the coast is made up on the "Newer" volcanics (Pliocene and Pleistocene) that reached the coast between

Warrnambool and Cape Bridgewater, to the west of which is the beginning of the Mount Gambier coastal plain composed of Quaternary marine sediments.

Along the coast the geology expresses itself in eight coastal regions which influence the coastal relief and degree of embaymentisation and thereby the nature of the coast (Fig. 25.2). In addition, the southwest trend of much of the highlands and sunklands orients the bays into the predominant southwest swell, enabling the bays to act as major sediment sinks for marine sands, as will be discussed in the following sections.

25.3 Climate

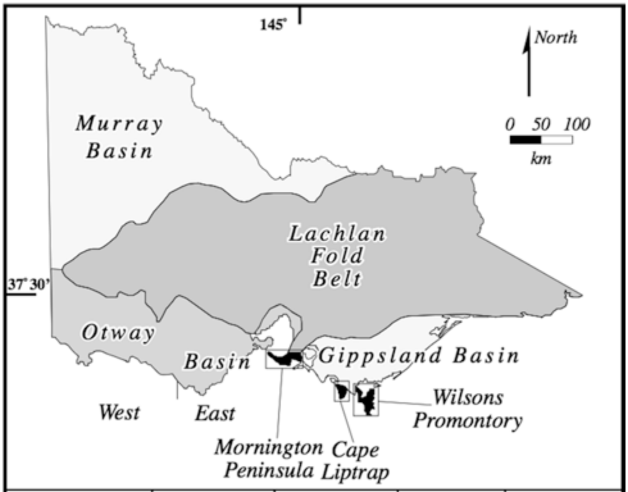
The coastal climate ranges from temperate with uniform rainfall (Cfb) in the centre to Mediterranean with drier summers west of Cape Otway (Csb) (Figs. 1.5a and1.8). The rainfall ranges from a top of 1056 mm at Wilsons Promontory to 534 mm at Melbourne to 730 mm with a winter maximum at Warrnambool (Fig. 1.5b). Temperatures are warm during summer and cool in winter (Fig. 1.5c, d). Winds at Cape Otway are predominately westerly (Fig. 21.5), together with onshore southerly afternoon sea breezes, particularly in summer.

25.4 Rivers and Creeks

Over 100 small rivers and creeks drain to the coast, the larger rivers rising in the Gippsland and Eastern Highlands, with the Yarra the largest with a catchment of 5481 km^2. Most flow into small estuaries and are depositing bayhead deltas, while none are delivering sand to the open coast. The rivers are discussed in their respective PCs.

25.5 Sediments and Processes

Beach sediment along the central and western coast is generally well-sorted fine to medium sand. However, the percent carbonate increases from a mean of 28% along the central region (VIC03.01) to 49% along the Surf Coast (VIC03.02) and 78% along the west coast (VIC03.03) (Table 25.1). The increase in carbonate reflects both a lack of fluvial supply to the coast and shelf carbonate production which is eroded and swept onshore by the increasingly higher energy waves to the west, a trend that continues right across the high energy southern Australian coast. The longshore distribution of sand size and percent carbonate is however highly variable, with size ranging from fine to coarse and carbonate from 0% to 100% with a clear trend of increasing carbonate to the west (Fig. 25.3). The variability in both size and carbonate indicates a dominance of local sources and lack of longshore transport.



Geological Region	Geology	Age (million years)	Coast Relief	Coast Embay-mentisation
Otway Basin (W)	Soft sedimentary Volcanics	Tertiary sedimentary (170 to 40) Quaternary volcanics (2 to 0)	low	large, broad
Otway Basin (E)	Hard sedimentary	Mesozoic (170 to 70)	moderate	small, steep
Mornington Peninsula	Hard Moderate Soft	Ordovician & Silurian metasediments (500 to 410) &Tertiary volcanics (35 to 25) & Quaternary Calcarenite (2 to 0)	high moderate low	narrow, steep moderate broad
Gippsland Basin (W)	Moderate to hard Soft	Mesozoic sediments (250 to 140) Quaternary sediments (2 to 0)	moderate low	moderate broad
Cape Liptrap	Hard to soft	Cambrian & Devonian (550 - 350)	high to moderate	narrow to broad
Wilsons Promontory	Hard granites	Devonian granites (400 to 350)	high	narrow, steep
Gippsland Basin (E)	Soft sedimentary	Tertiary sediments (35 to 2) Quaternary sediments (2 to 0)	low	very broad
Lachlan Fold Belt	Hard granite & metamorphic	Palaeozoic (500 to 200)	moderate	small, narrow

Fig. 25.2 The Victorian coast can be divided into eight geological regions with rocks ranging in age from 550 Ma to 2 Ma. The nature of the rocks and strata in each region, in association with the climate and erosion processes, has largely shaped the bedrock relief of the coast. The map indicates the location and extent of each region, while the table indicates the name, geology, age, coastal relief and general nature of the coast. (Source: Short 1996)

Table 25.1 Central and western Victoria PC beach sand characteristics (open = open coast; PP = Port Phillip)

VIC:PC	Open 03.01	PP:east 03.01	PP:west 03.01	Open 03.02	Open 03.03
n	30	55	33	50	107
Size (mm)	0.28	0.49	0.4	0.41	0.36
σ (mm)	0.18	0.17	0.2	0.19	0.16
Carbonate (%)	28	8	27	49	78
σ (%)	19	12	25	15	22
Sorting	0.42	0.7	0.83	0.43	0.4
σ (sorting)	0.31	0.3	0.37	0.21	0.16

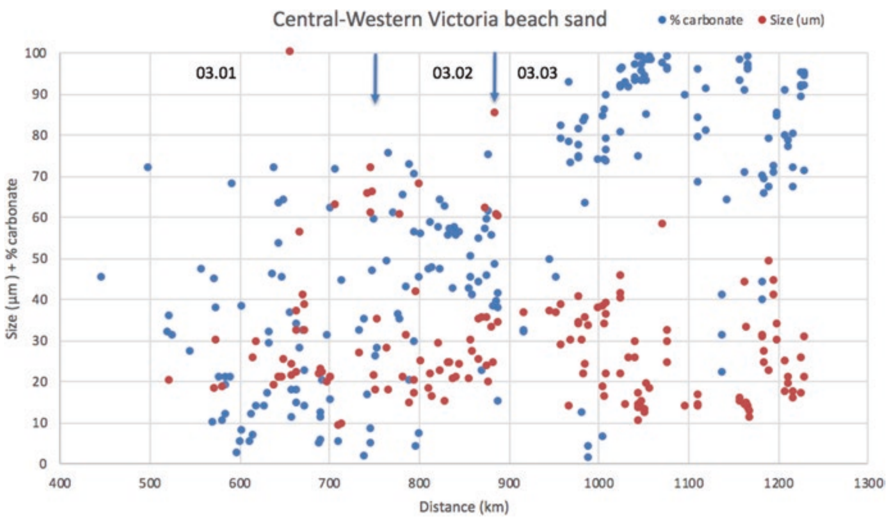


Fig. 25.3 Victorian open coast beach sand size (μm) and percent carbonate. Arrows indicated PC boundaries. Distance from NSW/VIC border

The entire open coast is exposed to Southern Ocean southwest swell with the west coast fully exposed. To reach the central coast, it has to move through the 90 km opening between Cape Otway and King Island arriving directly onshore along the eastern section between Wilsons Promontory and the Mornington Peninsula and having to refract 90° to reach the Surf Coast. Breaker wave height ranges from moderate to high along the central coast, while it remains high in the west. Inner Western Port and Port Phillip receive no swell and rely on locally generated westerly wind waves. Bird (1993) reports of mean annual wave height of 2.7 m at Wilsons Promontory, Cape Liptrap, Cape Schanck and Point Danger (Cape Nelson), while Flocard et al. (2016) found the west coast waves averaged 2–2.5 m with periods between 12 and 15 s, indicating that waves averaging this high will impact most of the exposed sections of this region (Fig. 1.12a), with lower waves in the more sheltered areas. The moderate to high waves arrive year-round with little monthly or seasonal variability (Fig. 1.12b).

Tides are amplified along the central Bass Strait coast reaching a mean spring range of 2.3 m in Western Port, 1.9 m at Waratah Bay and 3 m at Wilsons Promontory. They decrease to micro by Point Nepean (1.1 m) and in Port Phillip (<1 m) and remain micro along the Surf Coast (Apollo Bay 1.3 m) and very low along the West Coast (0.5–0.6 m) (Fig. 21.4). The tide also slows moving into Bass Strait reaching Waratah Bay and hour after the west coast. In addition, the strong westerly gales can generate storm surges of a 1 m or more, together with shelf waves which commonly reach 0.5 m and can reach 1 m as they move eastwards along the southern coast (Provis and Radok 1979). Owing to the small tide range along the west coast, the shelf waves can be a significant determinant of sea level. Gill (1972) and Bird (1993) reported that sea level along the entire Victorian coast reached 1–2 m above its present level about 6 ka, before falling to the current level.

25.6 Beaches

Beaches along the ocean coast are WD ranging from R to high energy RBB. They occupy 445 km (57%) of the coast and are predominately relative short (mean length = 0.97 km) embayed headland and/or rock-bordered beaches. The remainder of the coast is rocky and in places cliffed with many well-developed rock platforms (Bird 1993). The generally high level of wave energy is reflected in the dominance of high energy beach states, with 120 longer TBR occupying 243 km (55% of beaches by length) and 52 RBB (64 km, 14%), while the more numerous but shorter and more sheltered lower energy R and LTT have a combined length of 138 km (31%) (Table 25.2). Short (1996) provides a description of all beaches in the state.

25.7 Barriers

Barriers occupy just 262 km (33%) of the coast with the largest barriers along the west-facing central and western coasts (VIC03.01 and 03.02) and smallest along the southeast-facing Surf Coast (VIC03.02) (Table 25.3). They cover an area of 82,063 ha with 11% presently unstable. They have a total volume of 7780 M m^3 (29,694 m^3 m^{-1}), the higher volumes and rates per metre, typical of the higher energy sections of the southern Australian coast (Appendix 35.2).

Table 25.2 Central and western Victoria open coast beach type and states

BS	BS	No.	%	Total km	% (km)	Mean (km)
3	RBB	52	11.4	64.3	14.4	1.2
4	TBR	120	26.3	243.4	54.6	2.0
5	LTT	95	20.8	56.3	12.6	0.59
6	R	190	41.6	81.5	18.3	0.43
		457	100	445.5	100	0.97

Table 25.3 Central and eastern Victoria open coast barrier dimensions

VIC PC	VIC03.01	VIC03.02	VIC03.03	VIC03
No.	24	17	32	73
Total length (km)	56.5	45.6	159.5	262
Mean min width	95	105	250	150
Mean max width	275	300	1100	560
Mean height (m)	12	27	22	20
Area (ha)	56,530	1870	23,663	82,063
Unstable (ha)	2950	27	5880	8857
Total volume (M m^3)	2870	317	4593	7780
Unit volume (m^3 m^{-1})	50,783	6942	28,796	29,694

25.8 Sand Transport

The diverse nature of the sediments and the high proportion of carbonate all point to a shelf origin for the coastal sands, with the quartz sand supplied by the few small rivers at low sea level then combined with shelf carbonates to the reworked onshore during and following the PMT. It is very likely carbonate material is still being supplied to the coast, though quantities are unknown.

Longshore transport appears to be restricted within the many embayments. It is likely there is limited longshore transport in some of the longer embayed beach systems, with both north and south transport in the eastern Waratah and Venus bays and easterly transport in the western Armstrong, Portland and Discovery bays, as well as within parts of Westernport and Port Phillip; however, most of the beaches appear to the swash aligned with low rates at best for longshore transport. Transport within the PCs and SCs is discussed in the following sections.

The central-western Victoria region contains three PCs and sixteen SCs (Table 25.4) each of which is discussed below. Bird (1993) provides a detailed description of the entire Victorian coast and is an excellent and insightful reference for the coast its geology, nature and evolution.

25.9 PC:VIC03.01 Wilsons Promontory-Port Phillip Bay

PC:VIC03.01 commences at South Point, the southern tip of VIC and the Australian continent, and extends west for 311 km to Point Lonsdale the western entrance of Port Phillip (Fig. 25.1). It also includes Western Port and all of Port Phillip and its 263 km shoreline, in total 574 km of shoreline containing 174 open coast beaches and another 132 beaches in Port Phillip, which combined occupy 343 km (60%) of the coast. The open coast faces southwest directly into the prevailing southwest swell, which while attenuated in having to move through Bass Strait remains moderate to high along much of the coast. Tide range increases from 1.3 m at Point Nepean to 2 m at San Remo and Wilsons Promontory. It decreases into Port Phillip

Table 25.4 Central and western Victoria beach sand (Open = open coast; PP = Port Phillip)

Central and Western Victoria	Location	Boundaries	VIC beaches	No. beaches	VIC km	km
VIC03.01.01	Wilsons Prom (w)	South Pt-Tongue Pt	VIC 107-115	9	449–480	31
VIC03.01.02	Waratah Bay	Tongue Pt-C Liptrap	VIC 116-135	20	480–532	52
VIC03.01.03	Venus Bay	C Liptrap-C Paterson	VIC 136-156	21	532–585	53
VIC03.01.04		C Paterson-C Woolamai	VIC 157-186	30	585–624	39
VIC03.01.05	Phillip Is (S)	C Woolamai-Pt Grant	VIC 187-209	23	624–654	30
VIC03.01.06	Western Port	Pt Grant-Flinders	VIC 210-244	35	654–712	58[5]
VIC03.01.07		Flinders-C Schank	VIC 245-250	6	712–729	17
VIC03.01.08	Mornington Pen.	C Schank-Pt Nepean	VIC 251-280	30	729–760	31
VIC03.01.09	Port Phillip (east)	Pt Nepean-Gellibrand Pt	PP 1-67	67	0–114	114
VIC03.01.10	Port Phillip (west)	Gellibrand Pt-Pt Lonsdale	PP 68-132	65	114–260	146
VIC03.01.11	Port Phillip entrance	Pt Nepean-Pt Lonsdale	–	–	761–763	3
VIC03.01		*South Pt-Pt Lonsdale*	*VIC 107-280*		*449–760*	*574*
			PP 1-132	*306*	*0–260*	
VIC03.02.01	Surf Coast	Pt Lonsdale-Table Rock	VIC 281-327	47	763–823	60
VIC03.02.02		Table Rock-C Otway	VIC 328-410	83	823–902	79
VIC03.02		*Pt Lonsdale-C Otway*	*VIC 281-420*	*130*	*763–902*	*139*
VIC03.03.01	West Coast	C Otway-Peterborough	VIC 411-466	56	902–982	80
VIC03.03.02		Peterborough-Port Fairy	VIC 467-512	46	982–1054	72
VIC03.03.03		Port Fairy-C Nelson	VIC 512-547	35	1054–1150	96
VIC03.03.04		C Nelson-Danger Pt	VIC 548-560	13	1150–1232	82
			SA 1-2	2	0–14	14
VIC03.03	*West Victoria*	*C Otway-Pt Danger*	*VIC 411-560*	*152*	*902–1232*	*344*
			SA 1-2		*0–14*	
VIC03		*Regional total*		*588*		*1057*

Table 25.5 PC:VIC03.01 open coast beach types and states (excluded Port Phillip)

BS	BS	No.	%	Length	%	Mean	sd
3	R	92	52.9	62.3	33.1	0.7	0.9
4	LTT	41	23.6	25	13.3	0.6	0.7
5	TBR	32	18.4	83.3	44.3	2.6	4.9
6	RBB	9	5.2	17.6	9.4	2	1.4
		174	100.0	188.2	100.0	1.1	–

reaching 0.8 m at Melbourne but is amplified in Western Port reaching 3 m at Hastings. Even with the increasing tide range, the moderate to high waves maintain WD beaches with the TBR and RBB on the longer (2 and 2.6 km) exposed beaches and dominating by length (54%), followed by sheltered shorter R and LTT (0.6 and 0.7 km, 46%) (Table 25.5).

The dominant onshore winds are west to southwesterlies which have deposited substantial Pleistocene and Holocene carbonate-rich dunes in lee of all the exposed beach systems, with lithified Pleistocene dunes now being eroded to form cliffs, platforms and reefs. The Holocene barriers total 2870 M m^3 which represents a high 50,783 m^3 m^{-1}, the highest in the region (Table 25.3). The barrier size is a product of the abundant shelf sand, moderate to high waves, strong onshore winds and substantial accommodation space in the open southwest-facing embayments including the Wilsons Promontory coast.

A number of generally small rivers reach the coast, with Dividing Creek (83 km^2) together with several small creeks draining into Shallow Inlet; the Tarwin (1715 km^2) into Anderson Inlet; and the Bass building a small delta on the eastern shore of Western Port. In Port Phillip Bay are the channelised Patterson (684 km^2), Yarra (54,821 km^2), Werribee (1484 km^2) and Little (890 km^2) rivers, with the latter three building small deltas at their mouths, with Melbourne sited on the Yarra. However, none are presently delivering sand to the open coast.

25.9.1 SC:VIC03.01.01 Wilsons Promontory: West

Wilsons Promontory is composed of Devonian granite that rises to 700 m at the southern Mount Wilson, with much of its shoreline consisting of steep wave-washed granite slopes and boulders. This SC includes all the western bedrock section of the promontory, with 25.5 km (83%) of the shoreline consisting of granite and eight beaches making up the remainder (Fig. 25.4). The beaches are all embayed between steep granite slopes, face west with some sheltering from Norman and the Glennie Group of islands located between 3 and 10 km offshore, and range from LTT to TBR. Because of the meso-tides, they have wide intertidal zones exposed at low tide (Fig. 25.5a). They are composed of a mix of quartz and carbonate material (up to 40%) and include lithics derived from the surrounding granite. The rounded quartz grains at Squeaky Beach are responsible for its name (Beasley 1972).

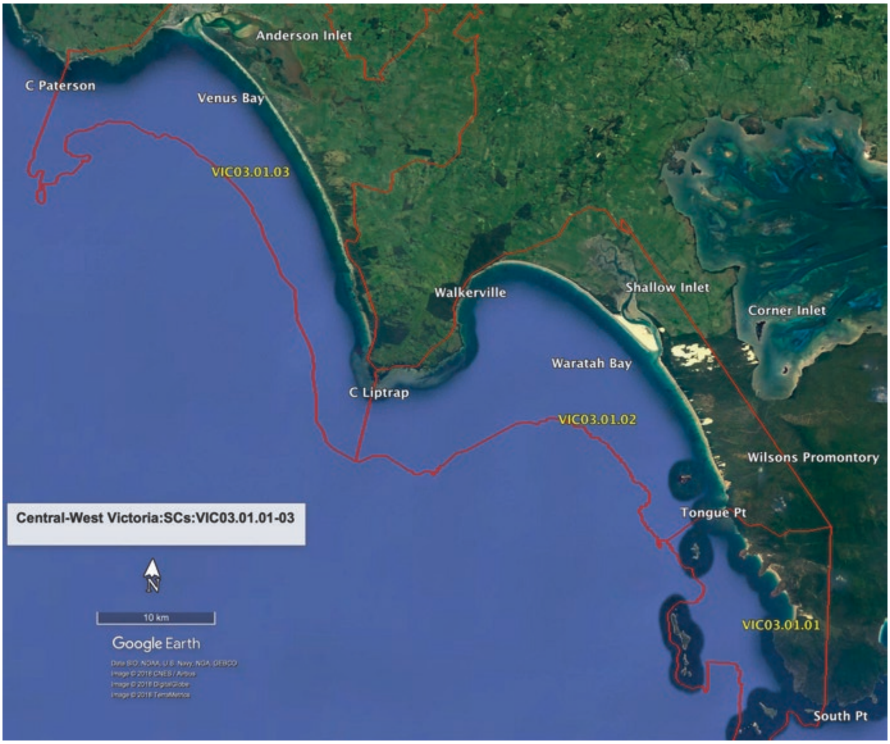


Fig. 25.4 SCs:VIC03.01.01-03: central Victoria between Wilsons Promontory and Cape Paterson. (Source: Google Earth)

Most of the beaches and some of the granite are backed by climbing parabolic dunes which overly earlier Pleistocene transgressive dunes and rise behind Oberon and Squeaky bays to 80 m. Most are now stable and vegetated, with just one large active parabolic extending 1.5 km inland in Oberon Bay. The more sheltered Tidal River bay contains a 700 m wide regressive barrier now occupied by the national park camping area, the only development on the promontory. The barriers have a total volume of 96 M m^3 (18,563 m^3 m^{-1}), and given the absence of rivers, all the sands are expected to have been derived from the shelf.

25.9.2 SC:VIC03.01.02 Waratah Bay

Waratah Bay is a curving 30 km wide generally southwest-facing carbonate-rich (30–70%) sandy embayment located between the promontory's granitic Tongue Point and heavily folded sedimentary rocks of Cape Liptrap (Fig. 25.4). It contains the small communities of Sandy Point (250) located behind the high foredune and Waratah Bay (150) on the western slopes. The bays 20 beaches occupy 37 km (71%)

of the shore, most contained in the main higher energy (TBR) Darby River (15 km) and Sandy Point (11 km) beaches, with 300 m wide Shallow Inlet separating the two. Both Pleistocene and Holocene parabolic dunes back all the coast between Tongue Point and Shallow Inlet (Fig. 25.5c) and at Yanakie isthmus have linked the promontory to the mainland. The Pleistocene dunes contain both lower quartz-rich sand, overlain by dune calcarenite, which at the shore has been scarped to form cliffs up to 40 m high (Fig. 25.5b). The carbonate-rich Holocene dunes have recoded a date of 5.8 ka (Bird, 1993) and in part bury the Pleistocene dunes and extend up to 8 m eastwards reaching Corner Inlet where they have extending up to 2 km into the inlet at The Drum. The present instability in parts of this dune field is attributed to burning and grazing before it became a national park. The eastern barrier has a volume of 1300 M m^3 and a high 81,250 m^3 m^{-1}.

To the west of Shallow Inlet Waratah Bay beach is backed by a few regressive Holocene foredunes grading into east-trending recurved spits towards the inlet, which is in turn backed by a Pleistocene calcarenite ridge. The Holocene barrier has a volume of 45 M m^3 (3214 m^3 m^{-1}). Sand is moving eastwards along the beach and into the inlet, causing the inlet mouth to migrate up to 5 km to the east before it relocates back to the west. This result is a very dynamic inlet as well as loss of marine sand to the inlet, which is now filled with shallow sand flats. The inlet has an

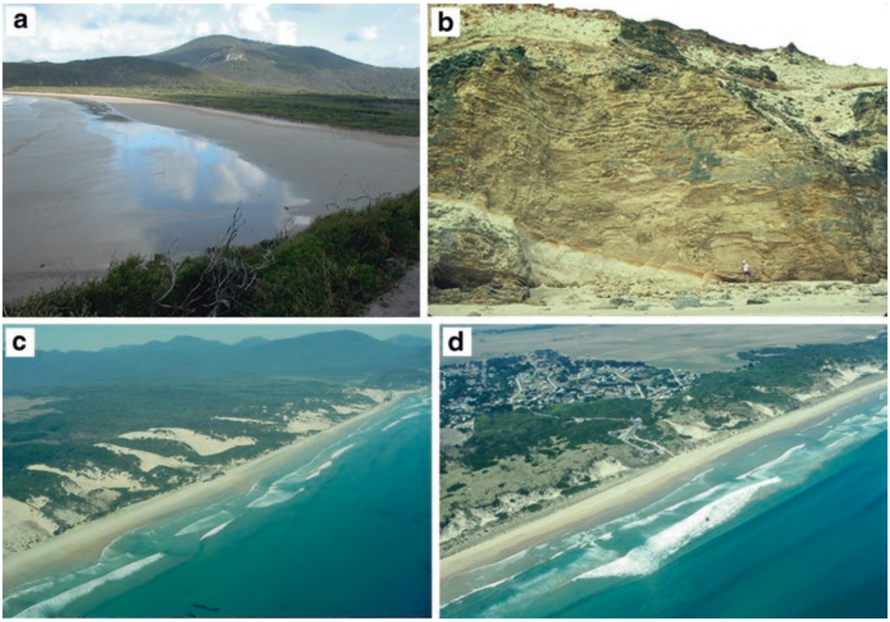


Fig. 25.5 (**a**) the wide beach at Tidal River at low tide (VIC 109); (**b**) 20 m high Pleistocene dune calcarenite at Darby River (VIC 118) (note person for scale); (**c**) parabolic dunes and a rip-dominated surf zone along Cotters beach (VIC 118); and (**d**) high foredune with blowouts in front of Venus Bay community, with rips in the surf zone (VIC 141). (Photos: AD Short)

area of 18 km^2, though one third of its original salt march has been dyked reclaimed for grazing (Bird 1993). Gill (1973a) recorded a date of 6.7 ka for a higher Holocene sea level in the inlet.

Wave energy decreases westwards along Waratah Bay, as the beach transforms to a wide LTT, reducing to <0.5 m at Walkerville, where the limestone cliffs were mined from 1878 to 1926 for the Melbourne market. The next 12 km out to Cape Liptrap are predominately cliffed sedimentary rocks with rock platforms and 12 smaller embayed beaches including some with rock flats and a mix of sand and cobble beaches along Maitland Bay and cobble-boulder beaches at the cape. Some of the Maitland Bay cobble beaches are elevated and vegetated indicating they may have been deposited at a higher Holocene sea level. There is limited longshore transport within the bay which has essentially swash-aligned beaches and is closed at both boundaries.

25.9.3 SC:VIC03.01.03 Cape Liptrap and Venus Bay

Venus Bay is another 36 km wide curving southwest-facing predominately sandy carbonate-rich (30–50%) embayment, whose shoreline extends for 53 km between Cape Liptrap and Cape Paterson, with the large Anderson Inlet occupying the northern corner. The main Venus Bay-Morgan beach faces west-southwest into the prevailing swell and extends for 31 km between Cape Liptrap and the inlet (Fig. 25.4). Twenty-one beaches occupy 38.4 km (72.5%) of the shore, the remainder a mix of calcarenite-covered bedrock in the east and sedimentary rocks including coal measures in the west. The twin Venus Bay communities (600) are located in the centre of the bay sheltered behind the 40 m high foredune (Fig. 25.5c), while the larger Inverloch (5500) is spread along the northern entrance to Anderson Inlet, while Cape Paterson (750) backs the low western cape.

Most of the bay is exposed and receives moderate to high energy southwest swell throughout the year which maintains a double-bar TBR-RBB along the exposed beaches, with the smaller embayed and sheltered beaches either R or LTT, including steep cobble beaches on Cape Liptrap. The Morgan-Venus Bay beach is backed by a continuous series of vegetated Holocene parabolic dunes extending up to 3.5 km inland and aligned at 75° by the strong westerly winds. These overly more extensive Pleistocene transgressive dune calcarenite the latter eroded to form cliffs, platforms and reefs along the southern Morgan beach section. The calcarenite is in turn underlain by older quartz-rich dunes (Bird 1993). Gardner et al. (2006) found the calcarenite was deposited between 112 and 68 ka during periods of lower sea level at ~115 ka, 89–85 ka and ~70 ka and contains 9 aeolian units separated by palaeosols. These were periods of cold, arid windy conditions, with the dunes still having to cross 12 km of exposed shelf to reach their present location. The Holocene dunes have a total volume of 691 M m^3 (24,829 m^3 m^{-1}).

Anderson Inlet has a very dynamic open mouth and a large flood tide delta extending 7 km into the shallow 16 km^2 estuary which has a 1.7 m spring tide range.

The southern Point Smythe entrance has well vegetated northwest-trending recurved spits extending for 8 km east of the mouth, indicating past northerly transport into the inlet. On the northern side, wave- and tide-driven sand waves migrate along the Inverloch shoreline alternately eroding and accreting the shore and causing seawalls to be built during the erosion phases, which are subsequently buried. For the most part, the sand has moved onshore from the shelf and been deposited in the Pleistocene and Holocene dune fields and the flood tide delta, gradually reducing the size of the mouth, perhaps aided by the fall in sea level. Within the inlet *Spartina anglica* was introduced in 1962 to stabilise the mud flats and has succeeded in replacing the grassy reed (Bird 1993).

25.9.4 SC:VIC03.01.04 Cape Paterson-Cape Woolamai

West from Cape Paterson is a 25 km wide embayment with an exposed southwest-facing shore that extends to Kilcunda beyond which it trends more westerly for another 14 km and becomes increasingly sheltered by Cape Woolamai (Fig. 25.6). The coast is largely undeveloped west of Cape Paterson, with the regional centre of Wonthaggi (16,000) located 4 km inland, while San Remo (1000) and Newhaven-Cape Woolamai (2200) are located either side of the Eastern Entrance for Western Port. The Bunurong Marine Park and Coast Reserve extends along the coast from Coal Point to Inverloch, and the small Powlett River reaches the coast in the centre

Fig. 25.6 SC 03.01.04-08 includes Phillip Island, Western Port and the Mornington Peninsula. (Source: Google Earth)

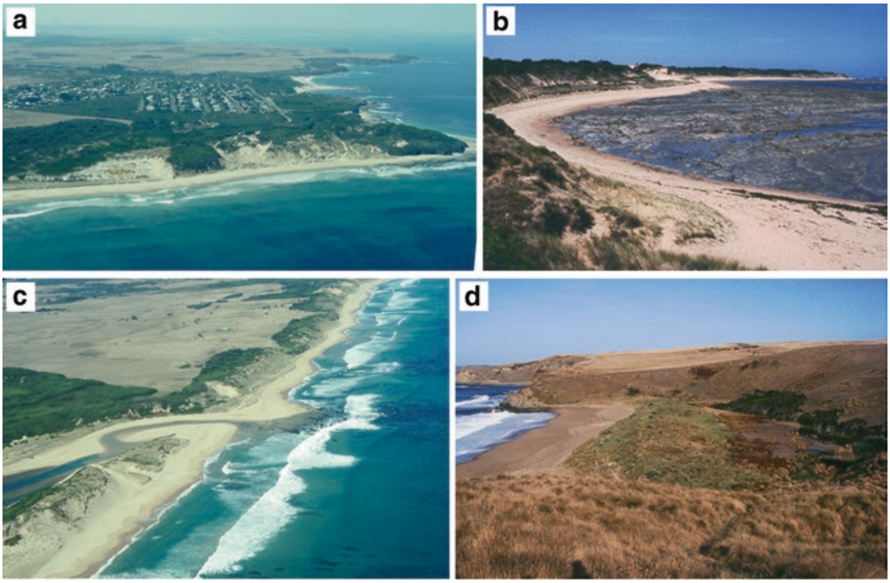


Fig. 25.7 (**a**) Cape Paterson township and active dune field (VIC 157); (**b**) a high tide R beach and intertidal rock flats at Coal Point (VIC 159); (**c**) the small Powlett River mouth enters a rip-dominated surf zone (VIC 163-4); and (**d**) the embayed Back beach and its stable foredune (VIC 176) that fills the embayment. (Photos: AD Short)

(Fig 25.7c), next to the Wonthaggi or Victorian desalinisation plant which commenced operation in 2012.

This SC has 39 km of shore and contains 30 beaches which occupy 26.6 km (68%) of the coast, most bordered by bedrock and/or calcarenite and a number fronted by intertidal rock flats. Beginning at Cape Paterson (Fig. 25.7a), the coast trends west for 6 km with the steep high tide R beaches fronted by rock flats up to 300 m wide (Fig. 25.7b). The coast then turns at Coal Point and trends northwest for 14 km to Kilcunda with near continuous exposed beaches that range from LTT-TBR-RBB (Fig. 25.7c) depending of the level of sheltering by inshore rocks and reefs. West of Kilcunda, bluffs and headlands dominate the remaining coast together with 15 shorter lower energy R and some LTT beaches, owing to the beaches becoming increasingly sheltered by Cape Woolamai. Most of the beaches are bordered or interrupted by rock reefs and platforms in the south grading into sandstone headlands in the north. The exposed southern section is backed by continuous east-trending Holocene parabolic dunes overlying older Pleistocene dune calcarenite which also forms bluffs, platforms and reefs along the shore. The transgressive dunes have a volume of 97 M m^3 (5966 m^3 m^{-1}), while the small embayed foredune barriers in the west (Fig. 25.7d) total another 3 M m^3.

The beaches are carbonate rich in the south (20–70%) decreasing to 5–15% in the northern entrance area. Shelf sediment has been transported onshore during the

PMT to be deposited as transgressive dunes in lee of the southern exposed beaches and as narrow barriers in the west. Cleeland Bight contains the extensive Eastern Entrance ebb and flood tide deltas which have an area of ~10 km^2. Flooding currents flow along the western side of Cleeland Bight generating northerly sand transport which is eroding the southern shore, where the overpassing Woolamai transgressive dunes reach the shore, and accreting the northern shore where a 300 m wide series of low foredunes ridges have developed since 1842 (Bird 1980). On the eastern side of the bight ebbing, tidal currents generate sand waves that move southward along the eastern San Remo shore causing alternating erosion and accretion between San Remo and Griffith Point.

25.9.5 SC:VIC03.01.05 Phillip Island–South Coast

Phillip Island is a gently undulating plateau 40–50 m high and largely composed of Older Volcanics which also dominate the coast and overlie older sedimentary rocks which outcrop at San Remo and the Cape Woolamai granite. The island actually consists of three 'islands' linked along the south coast by Woolamai and Summerland barrier systems. The south coast extends for 30 km between Cape Woolamai and Point Grant and consists of two south-facing 'embayments' separated by the central Redcliff Head, both containing a series of smaller embayed beaches (Fig. 25.6), with variable orientation within the smaller embayments. The entire southern coast has been eroded to form cliffs, bluffs and rock platforms, some of which are now stranded and vegetated indicating a 1–2 m higher Holocene sea level. The south coast is lightly developed with the main communities at Newhaven-Woolamai in the east and at Surf Beach-Sunset Strip-Sunderland Bay (600) backing the northern end of the Woolamai embayment. The Phillip Island Nature Park occupies the western end of the island and includes the famous Summerland Bay penguin colony.

The south coast contains 23 beaches averaging 0.6 km in length, which occupy 13.5 km (45%) of the shore, the remainder mainly basalt cliffs, platforms, rocks and reefs. The beaches range from well-exposed, southwest-facing higher energy TBR-RBB, particularly along the southern half of the Woolamai embayment (Fig. 25.8a), to partly (Fig. 25.8b) and very sheltered deeply embayed beaches along the western embayment like Kitty Miller Bay. They are composed of fine to medium sand with carbonate ranging from 15% to 70%. The Woolamai and Summerland are the two major barrier systems on the island, with the Woolamai overpassing the 500 m wide isthmus, which links Cape Woolamai to the mainland, the dunes reaching Cleeland Bight. Most of the parabolic dunes are now well vegetated and stable and overlie Pleistocene dune calcarenite. The dunes have a volume of 12.5 M m^3 (1926 m^3 m^{-1}). The smaller Summerland barrier links with the west coast's Flynns beach barrier via a backbarrier wetland to join Grants Point to the mainland. All of the beaches are embayed and swash-aligned with no evidence of longshore transport.

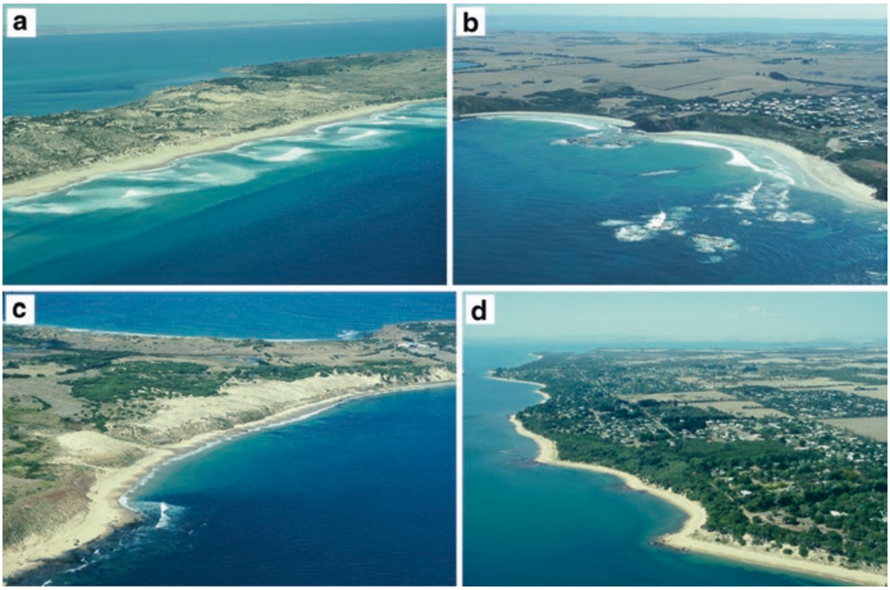


Fig. 25.8 Four images of Phillip Island illustrating the gradation in wave energy and beach state on the south, west and north coasts. (**a**) High energy rip-dominated (TBR-RBB) Woolamai Beach (VIC 90); (**b**) partly sheltered Smith and YCW beaches (LTT-TBR) (VIC 199-200); (**c**) reflective Flynn beach (VIC 212); and (**d**) the low energy north coast east of Saltwater Creek (VIC 219–221). (Photos: AD Short)

25.9.6 SC:VIC03.01.06 Western Port: Sandy Point-Flinders

Western Port occupies a 30 km wide southwest-trending tectonic depression (sunkland) bordered by faults to the east and west and includes the Older Volcanics which formed French and Phillip islands in the south (Fig. 25.6) (see Jenkin (1976b) and Marsden et al. (1979) for an overview of its stratigraphy and evolution). The bay was flooded by a higher Holocene sea level (+1–2 m) whose sandy shoreline is located at the rear of the present salt marshes. Following the flooding, the bay acted as a large sink for initially marine sand (Marsden and Mallett 1975, Marsden 1977) and subsequently intertidal mud flats covered by high tide salt marsh and intertidal mangroves (the most extensive in Victoria) in the inner more sheltered northern areas (North and East Arms). Harris et al. (1979) divided the bay into four systems: the high energy tidal channel of the Western Entrance, the ebb-flood channels, the subtidal mud basin, and the extensive intertidal flats. Owing to the low intertidal gradient and tides up to 3 m, the inner tidal flats are up to 10 km wide at spring low tide. Mahon (1977) found that the bay has an area of 690 km^2, containing 260 km^2 of seagrasses, with mangroves occupying 105 km of shoreline and beaches 65 km, while the tidal channels are up to 14 m deep. In the southeast the small Bass River delta contains a 500 m wide upper deltaic plain of inner beach ridges and a 1 km wide lower deltaic salt marsh plain and 1 km wide intertidal sand and mud flats. In addition to being a sink for mud and extensive tidal flats, the bay does have a few sections of more dynamic shoreline. Sandy beaches occur along the most exposed western shore, south French Island and the entire northern Phillip Island shores, together with a few eroding cliffed sections. The remainder of this section describes parts of the outer bay shore, beginning at Phillip Island and working clockwise around the shore.

The western-northern coast of Phillip Island commences at the island's western tip, Grant Point, and trends northeast then east as a predominately sandy shore for 20 km to the tip of Observation Spit, with Red Bight in its lee and Deene Bay just beyond. The sheltered shores are mangrove-lined with some of the southernmost mangroves in Australia (38.4° S) and most poleward in the world. Seventeen low energy R beaches occupy 17 km (85%) of the northern shore (Fig. 25.8c, d), the remainder mainly low basalt bluffs, rocks and platforms, with the island's main town of Cowes (4000) sited on bluffs overlooking the Western Passage. Waves entering the 7 km wide Western Passage entrance between Point Grant and Flinders run along the northern shore maintain a drift-aligned coast, with easterly sand transport. While rates are expected to be low, the ultimate sink is the 4 km long Observation Point sand spit (Fig. 25.9a) and its 400 m wide sand flats. It is also likely some sand is moving past the spit and into the tidal channel. This coast has just six small barriers occupying 8.5 km of shore, dominated by the larger Observation Point spit. The bar-

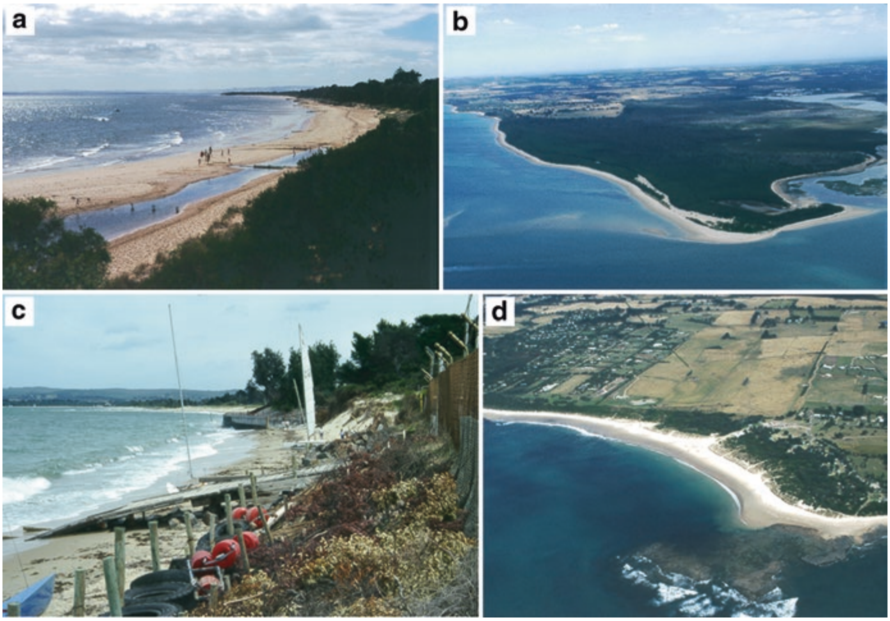


Fig. 25.9 (**a**) View along Observation Point (VIC 226) beach from Cowes with a migrating sand wave attached to the beach; (**b**) the dynamic Sandy Point terminates in a recurved spit (VIC 227); (**c**) beach erosion and makeshift protection works at Somers (VIC 229); and (**d**) Point Leo beach and foredune (VIC 236). (Photos: AD Short)

riers have a total volume of 8 M m^3 (930 m^3 m^{-1}). Based on the size of Observation Point and its sand flats (1.7 km^2) it may have a volume of ~3.4 M m^3, which if deposited over the past 6000 years would represent a longshore transport rate of ~500 m^3 $year^{-1}$, which seems reasonable for this low energy drift-aligned shore.

On the eastern side of the bay at Stockyard Point, sand is being eroded from the low Red Bluff and deposited immediately to the south as a 1.2 km long series of south-trending recurved spits (Bird 1993). In the adjoining Pioneer Bay, the marsh was eroded ~6 ka, then as the spit migrated south, it became protected leading to the deposition of marine sand, the marine clays dating 1.5 ka and finally salt marsh peat and clay. In the northwest at Yaringa, cheniers have been deposited on the salt marsh during periods of salt marsh erosion and cliffing (Bird 1993).

Sandy Point to Flinders The western mainland shore of the bay commences at the low Sandy Point and curves to the west and then southwest for 28 km to Flinders at the western entrance to the bay. In between are 18 low energy R and R + RF beaches occupying most (25 km, 89%) of the shore. There is a string of small coastal communities along the shore including Somers (1500), Balnarring-Merricks (3300), Point Leo (160), Shoreham (600) and Flinders (900). Like the northern shore of Phillip Island, this is also a drift-aligned shore beyond Point Leo (Fig. 25.9d), with the southwest swell running along the northeast to east-trending shoreline to an ultimate sink at Sandy Point. Bird (1993) reported that sand moves eastwards along the shore as sand waves which causes periods of erosion and accretion, as well as deflecting Merricks Creek up to 2 km to the east. At Somers construction of a yacht club on a temporally accreted section was followed by erosion and led to the construction of wooden groynes (Fig. 25.9c) and then rubble seawalls. Bird (1993) monitored the Somers-Sandy Point section of coast between 1975 and 1985 and found the western section eroded up to 21 m, while the eastern section accreted up to 55 m, but the whole section experienced an overall loss of 11,800 m^3. The eroded sand migrated east along Cormorant-Sandy Point as a large sand waves causing it to migrate 800 m to east between 1947 and 1984. This sand wave may be part of ongoing easterly transport along the point and into the tidal channel where it will be reworked by the tidal currents into the extensive Middle Bank tidal shoals that extend to the southwest, the sand possibly recycled onto the beaches to the southwest. The sand is transported both by eastward tidal currents up to 0.8 m s^{-1} (Mardsen 1977) and refracted westerly swell that at high tide can reach this far into the bay, combined with local southwesterly wind waves.

At the end of this transport system, Sandy Point (Fig. 25.9b) has undergone 1 km of southward regression and 4 km of eastward progradation between when it was first mapped by Bass in 1798 and the 1930s (Bird 1993). It now appears to have stabilised owing to it having reached the edge of a deep 2.5 km wide tidal channel between the point and French Island. Such dramatic recent changes could have been a response to an easterly shift in the location of this channel, which may shift westwards at some time in the future. There are three barriers along this section dominated by the terminal Sandy Point, which have a total volume of 14 M m^3 (1383 m^3 m^{-1}).

25.9.7 SC:VIC03.01.07 Flinders-Cape Schanck

To the west of Flinders the Older Volcanics occupy the 17 km coast to Cape Schanck (Fig. 25.6). The 60–80 m high undulating terrain has been cliffed with well-developed rock platforms at their base, as well as caves, arches and stacks and columnar basalt, with just a few small pockets of sand, cobbles and boulders located in some of the gaps in the cliffs, as well as the sandy ocean beach at Flinders. This is a predominately rocky shore with six small embayed beaches occupying just 2 km (12%) of the coast and no barrier systems. The only development is at Flinders where the golf course backs the foredune with the town set well back on the higher terrain.

25.9.8 SC:VIC03.01.08 Mornington Peninsula: Cape Schanck-Point Nepean

The Mornington Peninsula commences at 80 m high Cape Schanck where the coast turns and trends northwest, with a very slight curve, for 31 km to Point Nepean, the eastern entrance to Port Phillip Bay (Fig. 25.6). This is an exposed higher energy section of coast, underlain and bedded to the Older Volcanics, but largely covered by early Pleistocene quartz-rich sand, followed by Pleistocene dune calcarenite and Holocene carbonate-rich parabolic dunes. Bird (1993) reports that most of the Mornington Peninsula is composed of multiple layers of dune calcarenite, which at Sorrento are at least 140 m thick, each layer no doubt representing a Quaternary marine transgression which transported sand from the seafloor to the coast. The carbonate-rich sand subsequently lithified with the dunes now comprising the Mornington-Nepean and Lonsdale peninsulas, with the calcarenite eroded to form cliffs and reefs along their seaward edge. The most recent PMT was accompanied by the deposition of the Holocene beaches and parabolic dunes which have since had their sources exhausted, with the ramps eroded and the dunes now stabilise and vegetated, with the waves left to sculpture the calcarenite cliffs and platforms. In places the cliffs expose the multiple layers of dune calcarenite and their soil horizons.

Beginning at Cape Shank, the dunes have blanketed the peninsula extending up to 14 km inland and overpassing Cape Schanck to reach Burrabong Creek and along much of the western half of the peninsula to reach the shores of Port Phillip Bay as far as Rosebud. This barrier has a volume of 560 M m^3 (20,000 m^3 m^{-1}). Along the coast are a series of 30 small carbonate-rich (5–60%) sandy beaches which occupy

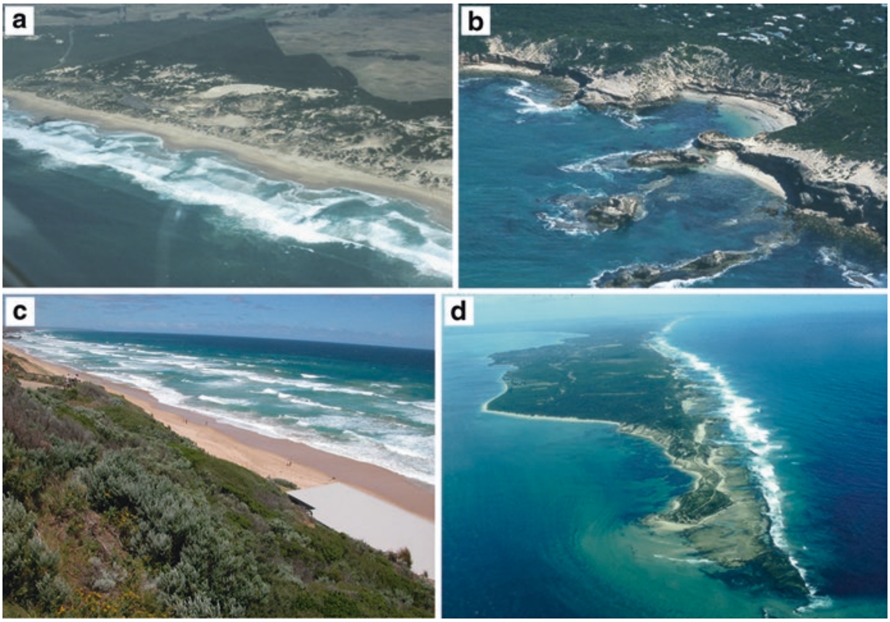


Fig. 25.10 Mornington peninsula beaches. (**a**) High energy rip-dominated Gunnamatta (TBR-RBB) (VIC 253); (**b**) reef-sheltered reflective Diamond Bay (VIC 266); (**c**) high energy (RBB) Portsea Back beach (VIC 269); and (d) view east along the eroded calcarenite of Point Nepean (VIC 278-280). (Photos: AD Short)

19 km (61%) of the shore. This is an exposed high energy coast with waves averaging ~2 m. The waves have both eroded the calcarenite forming the cliffs and platforms (Fig. 25.10b), as well as maintaining a range of beaches from reef-sheltered R with waves <0.5 m to fully exposed RBB, with waves averaging ~2 m and several strong topographic rips running out against the rocks and reefs (Fig. 25.10a, c). It was in a strong topographic rip at Cheviot beach (VIC 277) where Prime Minister Holt was drowned, the area now part of the Harold Holt Marine Reserve, with the eastern Point Nepean (Fig. 25.10d) also a national park. Behind the beaches clifftop dunes blanket the calcarenite with a date of 5.3 ka obtained from the upper of eight dune layers (horizons) at Diamond Bay (Bird 1993). While the main beaches, including the popular Gunnamatta and Portsea Back beaches (Fig. 29.10a, c), and their surf clubs are accessible by car, all development is located on the lower energy northern Port Phillip side of the peninsula, discussed in the next section.

Fig. 25.11 Port Phillip Bay contains SCs VIC03.01.09-10. (Source: Google Earth)

25.9.9 SCs:VIC03.01.09-11 Port Phillip Bay

Port Phillip is a 1930 km^2 bay occupying the 30–60 km wide Port Phillip sunkland, which is bordered in the east by the Selwyn Fault and west by the Bellarine and Rowsley faults (see Jenkin 1976a for an overview of the bay and its geology). It has 260 km of shoreline, the 114 km eastern half a more continuous curving shore, while the 146 km long western half includes Corio Bay (Fig. 25.11). The bay is open to the sea through the 3 km wide entrance at the heads between Point Nepean and Point Lonsdale, with strong tidal flows reaching 4 m s^{-1} and scouring channels to 90 m depth (Bird 1993). The tide is delayed by 3 hours in reaching Melbourne as well as decreasing from 1.1 m at the entrance to 0.8 m at Geelong and 0.6 m at Melbourne. Ocean swell enters the entrance but is soon attenuated, with waves within the bay generated by the predominately north to northwest winds in winter and south to southwest in summer, with seas reaching 3 m with a 4 s period along the central eastern shore during westerly gales. Goodfellow and Stephenson (2008) found there was a close correlation between wind speed and wave height, with winds >10 m s^{-1} generating waves >0.5 m.

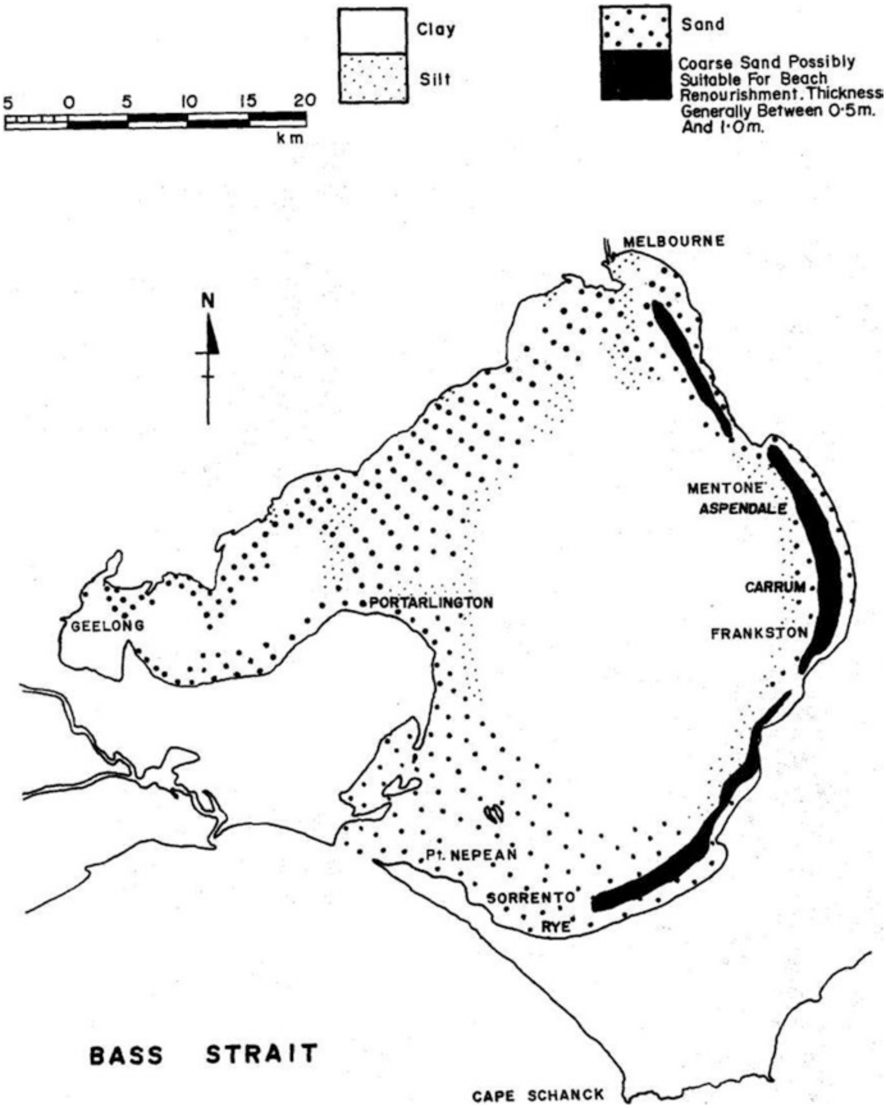


Fig. 25.12 Pott Phillip Bay sediments. (Source: Jennings and Barraclough 1978)

The bay has been flooded by successive Quaternary marine transgressions which have both contributed to the evolution of the Mornington Peninsula, discussed above, and also deposited the large 250 km^2 flood tide delta (Nepean Bar) which contains Pleistocene calcarenite (Bird 1993). Assuming the delta has 10 m of Holocene sediments, it would have a volume of 2500 M m^3 and order of magnitude greater than the large Mornington Peninsula barrier. There is also considerable evidence (emerged beaches and platforms, vegetated bluffs) around the bay of a higher (1–2 m) Holocene sea level likely between 6 and 4 ka (Van den Berg 1973; Bird 1993). The bay floor contains beach sand along the higher energy eastern bay beaches out to 12 m depth and along the northwestern shore out to 20 m, grading into silty mud and mud in the deeper (>20 m) central bay and Corio Bay (Beasley 1966, Fig. 25.12).

Beach sediments include quartz sand from bay floor and local weathering of cliffs particularly in the northeast, together with black sand from weathered basalts on west coast, gravel beaches from ferrigenous sandstones, calcareous sand from eroded calcarenite in south and marine organisms throughout. The bay shoreline has been heavily modified by a range of shoreline protection structure including groynes, seawalls, boulder ramparts, boat harbours (attached breakwaters), jetties, beach nourishment and dredged and rerouted rivers and streams mouths, together with the Werribee sewerage farm embankments. The impact of some of these are discussed in the following sections.

25.9.10 SC:VIC03.01.09 Port Phillip–East

The eastern shore of Port Phillip Bay commences at Point Nepean and trends to the northeast, east and finally northwest for 114 km to Point Gellibrand on the western side of the Yarra River mouth (Fig. 25.11). This is a highly developed coast containing the Mornington Peninsula towns (Portsea, Sorrento, Blairgowrie, Rye, Rosebud and Dromara) and communities (total population 140,000) and in the north is backed by much of the massive Melbourne city (4 M) whose eastern suburbs extend down the eastern side of the bay. This is a heavily utilised and heavily modified coast, reflecting the size and density of the surrounding population.

There are 67 beaches occupying 82 km (72%) of the eastern shore the remainder a mix of soft bedrock bluffs and generally low resilient cliffs. The beaches range from exposed storm-generated WD triple-barred systems (TBR inner bars) between Frankston and Mentone (Fig. 25.13b) to a range of lower energy and sheltered R and LTT in the north to B + RSF and SF in the sheltered south between Blairgowrie (Fig. 25.13a) and Frankston (Table 25.6), together with several beaches fronted by rock flats (Fig. 25.13c). The dynamics of the Seaford multi-bar system was investigated by Goodfellow and Stephenson (2008), while Lowe and Kennedy (2016) monitored the seven beaches between Half Moon Bay and Middle Park (PP 52–64) and found the beaches were only significantly reworked during storm events and that sand size was a major determinant of beach state. Beach sand is generally well sorted but ranges considerably in size (fine-coarse), with a mean bordering on medium-coarse (0.49 mm) and generally lower in carbonate (mean = 12%) compared to the western shore (Table 25.1). The considerable longshore variation in both size and carbonate (Fig. 25.14) indicating the sand is sourced locally with limited longshore transport. Likewise, Bowler (1966) found the bay sand had significant variation in grain size, sorting and mineralogy over short distances, with carbonate ranging from 7% to 35%. Black and Rosenberg (1992) modelled wave refraction and sediment transport on the southern Safety Beach (PP 17D) and north-

Fig. 25.13 Eastern Port Phillip beaches. (**a**) Tide-dominated ridged sand flats along Blairgowrie Beach (PP 16); (**b**) wave-dominated triple bar systems at Seaford pier (PP 43); (**c**) reflective beach and rock flats at Beaumaris (PP 46); and (**d**) cuspate foreland formed in lee of the Brighton Yacht Club attached breakwater (PP 60). (Photos: AD Short)

Table 25.6 Port Phillip SCs:VIC03.01.09-10 beach types and states

BS	BS	No.	%	Length (km)	%	Mean (km)	σ (km)
4	D-TBR[a]	3	2.3	20.7	11.8	6.9	–
5	LTT	23	17.4	22.2	12.7	1.0	0.9
6	R	22	16.7	12.6	7.2	0.6	0.4
10	B + RSR	34	25.8	70.3	40.1	2.1	3.3
11	B + SF	20	15.2	15.1	8.6	0.8	1.1
12	B + TSF	26	19.7	30.8	17.6	1.2	1.1
14	R + RF	4	3.0	3.5	2.0	0.9	0.7
		132	100	175.2	100	1.3	–

[a]Outer D, Inner TBR

ern Sandringham-Elwood beaches (PP 53–61) and found that while net transport was predicted on the order of 10,000's m^3 $year^{-1}$ to both the north and south, gross transport was essentially zero as the beaches are in equilibrium with the local wave conditions. It appears that the alternating winter northerly wind and waves and summer southerly wind and waves result in a balanced net transport along the eastern shore. The largest Holocene barrier is located in the 20 km long Carrum-Seaford

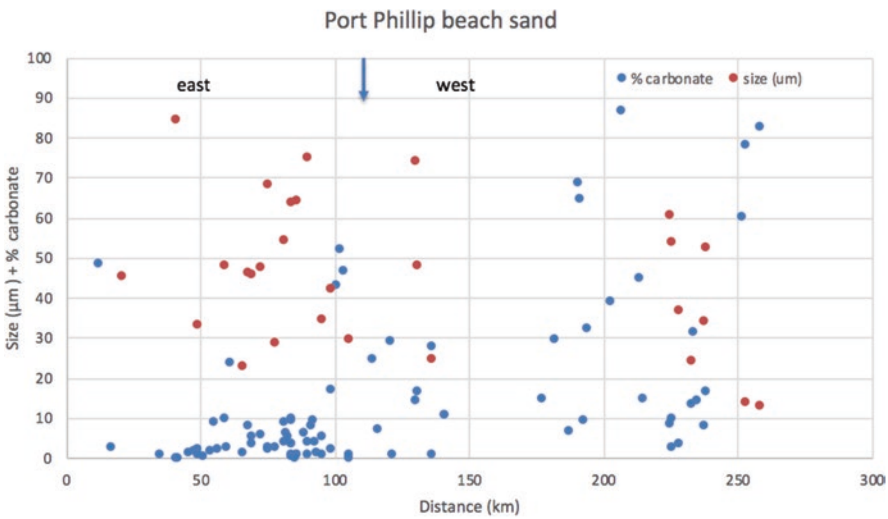


Fig. 25.14 Port Phillip beach sand size (μm) and percent carbonate. Distance from Point Nepean

embayment (PP 43), an area of balanced sediment transport and major sink for sand supplied from the bay floor. The inner ridge was dated 3.7 ka (Hurst 1986). It then prograded 1.3 km into the bay as a series of low foredune ridges and has a volume on the order of 100 M m^3 (~5000 m^3 m^{-1}).

The bimodal summer-winter wave climate generates alternating northerly and southerly longshore sand transport, which within embayed beaches causes beach rotation (north in summer, south in winter). In a number of places, this has been constrained or prevented by the construction of groynes, boat harbours, attached breakwaters and training walls leading in places to shoreline recession. In addition, the many erodible Tertiary bluffs which backed the northeastern beaches (Brighton, Mentone, Black Rock) and acted as a sand sources have largely been protected by seawalls and boulder ramparts (Jennings and Barraclough 1978) and vegetated cutting of their supply of sand to the beach systems, which has further exacerbated the erosion (Bird 1980). The response to the erosion has been further shoreline protection which continues to amplify the problem. The final solution has been to nourish the beaches. This commenced on the eastern shore at Hampton in 1975 and Mentone in 1977 using a mix of sand dredged from the bay (Guerin 1983). It has continued ever since at 20 locations in the south, northeast and at Geelong in the southwest of the bay (Bird 1993). In 2018 Sorrento West, Carrum, Sandringham, Hampton, St Helens and Moorpanyl and Eastern Beach (Geelong) were all nourished (https://www.coastsandmarine.vic.gov.au/coastal-programs/beach-renourishment). The northeastern shore from Carrum around to Altona has been the most heavily modified with near continuous seawalls, bluff stabilisation as well as the construction of a range of shore perpendicular structures (Bird 1993; Fig. 25.13d). In the south at Portsea, a range of measures (including groyne, seawall, beach nourishment) were being considered in 2018 to combat the erosion (www.coastsandmarine.vic.gov.au).

During the Pleistocene 'glacial' period hot dry summers and cold stormy winters prevailed, with aridity peaking between 18 and 16 ka, leading to intensified aeolian activity between 25 and 13 ka (Bowler 1978). At this time strong northwest winds blew quartz sand from the exposed bay floor to the southeast from at least Green Point and Beaumaris Bay (Jenkin 1976a) and between Mordialloc and Frankston to form longitudinal and barchan dunes and lunettes behind swamps (Whincup 1944). The longitudinal dunes extend for up to 50 km as far as Hastings and French Island (Bird 1993), thereby blanketing sections of the eastern hinterland with the dunes.

The Yarra River delta has been heavily modified by the development of Melbourne city and port, including realignments of the lower channel in the 1880s. Material obtained 20 m below sea level during this phase was dated at 8.8 ka (Bird 1993). Up to 70,000 tonnes of silt is dredged from the lower channel each year, silt that would have otherwise prograded the delta. The delta stratigraphy and its modifications are described by Nielsen (1976). The submerged channels of both the Yarra and Werribee rivers have been mapped across the bay floor by Holdgate et al. (1980) who found they are cut into firm mid-Pleistocene clays, infilled with 6 m of mud and sand, widening and thickening to 12 m in the south of the bay.

25.9.11 SC:VIC03.01.10 Port Phillip–West

The western shore of the bay commences at Point Gellibrand and extends for 146 km to the western bay entrance at Point Lonsdale (Fig. 25.11). This is a considerably lower energy lee shore that is also more irregular and in the northwest has very low gradient shoreline. It is less developed than the eastern shore but still is backed by the western suburbs of Melbourne in the north, the coastal communities of Altona and Werribee in the northwest and the large Geelong (193,000) in Corio Bay. Around the higher Bellarine Peninsula are a series of small communities including Portarlington (3700), St Leonards (2000) and Point Lonsdale-Queenscliff (1500).

This is a leeward shore with the dominant westerly winds largely blowing offshore, and only weaker easterly winds contribute to coastal processes. Beach sands are mainly locally derived consisting of sand, pebbles and shells and vary considerably around the shore ranging from fine to coarse and carbonate from 10% to 90% (Table 25.1, Fig. 25.14). The 65 beaches have a total shoreline length of 93 km occupying 64% of the shore, with the remainder generally low eroding bluffs. The beaches range from the very low energy TD B + TSF (27) and B + SF (6) in Corio Bay and along the Werribee coast to B + RSF (20) where the flats are more exposed to low waves as along the northwestern Bellarine Peninsula coast, west of Point Richards, and WD LTT (13) in the more exposed northern and southern locations including east of Point Richards.

Fig. 25.15 (**a**) North-trending recurved spits with low waves breaking over the ridged sand flats at Skelton Creek (PP 73); and (**b**) view south to Werribee River mouth with wave breaking over the ridged sand flats (PP 79-81). (Photos: AD Short)

Sediment transport along the western shore is predominately very low and northerly, as well as into Corio Bay. At the mouth of Skeleton Creek, near Point Cook, the broad shallow bay has been filled with north-trending shelly ridges, spits and intertidal swales up to 800 m wide fronted by 500 m wide ridged sand flats (Fig. 25.15a). Between Werribee River (Fig. 25.15b) and Point Wilson the shoreline is very low energy with crenulate TD shelly ridges, spits and islands and tidal flats together with low basalt bluffs and reefs of the Newer Volcanics, backed by embankments holding the Werribee sewerage farm. The orientation of the ridges indicates generally northerly transport. The new Wyndham boat harbour at Werribee (constructed 2013) will interrupt the northward sand transport, which may require armouring of the beaches to the north to prevent shoreline recession. In Corio Bay there is evidence of limited westerly sand transport along the northern side of bay with a 500 m long shelly spit attached to the eastern entrance to the small mangrove-fringed Limeburners Bay and a second 100 m long north-trending spit attached to the western side of the bay. Gill (1972) dated a 2 m high shelly ridge in the bay at 5.6 ka.

Along the northeastern shore of Bellarine Peninsula, northeast waves transport sand from the west of Indented Head to Point Richards where it has accumulated in a 1 km wide low regressive triangular shaped barriers. The sand continues around the point and to the west contributing to the 1 km wide ridged sand flats that continue west for more than 15 km. At Portarlington, Colleter et al. (2015) report that sand is being transported to and trapped in the harbour at rates between 3000 and 5000 m^3 $year^{-1}$ leading to beach and bluff shoreline recession west of the harbour. An additional T-shaped eastern breakwater was built in 2016 combined with dredging to reduce sedimentation in the harbour. To help overcome this, they recommended sand backpassing from the sand flats and bluff management.

Between Indented Head and Point Lonsdale, northeast waves move sand south from Indented Head for 5 km to Edwards Point and along the 3 km long Edwards Point spit which terminates in Swan Bay. To the south sand is moving northwards from Point Lonsdale along Queenscliff beach bypassing around Queenscliff to build Swan Island and feed Swan Bay and thereby converging with the Indented Head sand. The Point Lonsdale system has a negative sand budget leading to erosion of the beach which has resulted in a series of successive seawalls being built along the southern half of the beach between 1939 and 1977, which by the 1970s had trapped 1.25 M m^3 of sand. However, sand began bypassing the groynes from 1961 and moving into the Queenscliff boat harbour which then required 0.7 M m^3 $year^{-1}$ of maintenance dredging (Bird 1980, 1993). Riedel and Fidge (1977) found that Swan Island experienced pulses of sand from Queenscliff which lead to 200 m oscillations in the shoreline. However, the Boat Harbour construction also removed 2 M m^3 of sand from the system leading to downdrift erosion. They also found that the groynes on Queenscliff beach were inefficient in retarding longshore sand transport.

Garcia-Webb and Provis (2011) investigated coastal issues along the coast between Portarlington and St Leonards following major storm damage in 2009. They reported a range of issues including insufficient setback, inundation, beach and dune erosion, storm water drains, failed protection structures and downdrift erosion. They also proposed a range of possible solutions.

25.9.12 PC Overview

The central Victoria PC (VIC03.01) has a long (574 km) and highly variable coast ranging from high energy southwest-facing beaches backed by massive Pleistocene and Holocene dune transgression to numerous sheltered embayed open coast beaches and the very low energy TD shore of Western Port and Western Port Phillip. The entire coast has a legacy of highstand Pleistocene coastal deposits and dune activity, much of which has subsequently been blanketed by Holocene dunes, while inland Pleistocene longitudinal dunes were active during the last glacial. The carbonate-rich Pleistocene coastal dunes have also left a legacy of dune calcarenite as inner barriers and where exposed along the shore as cliffs, bluffs, rocks and reefs.

Future climate-induced changes in sea level, winds and wave climate will have a range of impacts on this coast. The most dramatic will be in the estuaries (Shallow and Anderson inlets) and the large Western Port and Port Phillip, particularly along their low gradient shores, which will experience greater inundation together with retreat of the salt marshes and mangroves, as well as possible changes in tide range. Much of Port Phillip's higher relief eastern and Bellarine coast and its beaches is already protected by seawalls and nourishment both of which will need to be maintained and expanded into the future, particularly as beach recession is predicted to increase (Bird 2006). On the generally sediment deficient, open coast erosion will continue and in places accelerates as longshore transport gradient increases with the deeper water and higher breaker waves and reactivation of the large flood tide deltas in the inlets and bays, resulting in further loss of sand. The extensive but predominately stable dune systems will need to be managed to maintain their stability so sand is not lost to these systems as beaches erode and foredunes are destabilised.

25.10 PC:VIC03.02 Surf Coast: Point Lonsdale-Cape Otway

PC:VIC03.02 commences at Point Lonsdale the western entrance to Port Phillip and trends roughly southwest for 139 km to Cape Otway (Fig. 25.16). Based on its geology, it can be divided into two parts and two SCs. In the north between Point Lonsdale and Table Rock is a mix of non-marine Tertiary sediments together with Newer Volcanics extending down the coast to Torquay, then Tertiary marine sediments down to Table Rock. The hinterland is generally low (<50 m) and undulating. The largest river on this section is the Barwon (4496 km^2); however, it flows through a series of lakes it is still infilling and is not delivering sand to the coast. South of Table Rock, the sedimentary rocks of Otway Range occupy the coast, with generally steep slopes rising to 300–600 m inland. The higher rainfall along the range however and steep slopes generate a series of small steep creeks and rivers which are supplying low quantities of terrigenous sediment to the coast.

Fig. 25.16 PC:VIC03.02 and its two SCs: VIC03.02.01-02 The Surf Coast - Point Lonsdale to Cape Otway. (Source: Google Earth)

Table 25.7 PC:VIC03.02 beach types and states

BS	BS	No.	%	Length (km)	%	Mean (km)	σ (km)
4	TBR	50	38.6	41.5	53.1	0.8	1.3
5	LTT	22	16.7	12.8	16.4	0.6	0.9
6	R	50	38.6	9.4	12.0	0.2	0.2
		130	100.0	78.1	100	0.6	–

The coast is micro-tidal (1.1–1.3 m), and the prevailing southwest swell has to refract 90° to reach the southeast-facing shore, resulting in a moderate to occasionally high wave conditions and an entirely WD shore. Flocard et al. (2016) used WaveWatch III and Swan modelling to estimate H_s between Point Lonsdale and Discovery Bay and found along the southeast-facing Cape Otway to Barwon River coast that it averages 1–1.5 m and 1.5–2 m on the south-facing coast between Barwon River and Point Lonsdale. Similarly, Falconer (1972) found the waves averaging 2 m at Port Phillip Heads. There are 130 beaches along the coast occupying 78 km (56%) of the shore (Table 25.7). They range from shorter R-LTT in sheltered locations to predominately TRB and some longer RBB in more exposed location, with the higher energy beaches making up 72% of the beaches by length. While wave energy remains moderate, the orientation of the coast parallel to the dominant winds and its steeper southern half limits the development of barriers systems, with their volume and per metre volume an order of magnitude less than the adjoining

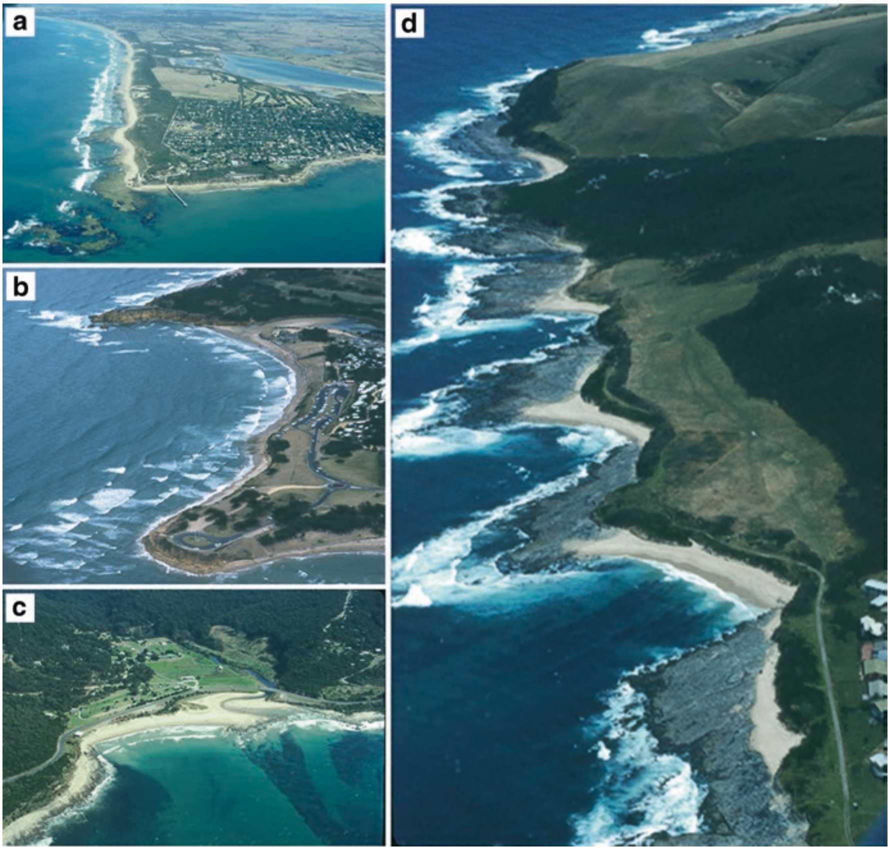


Fig. 25.17 (**a**) View west from Point Lonsdale (VIC 281-282); (**b**) Point Danger and Torquay beach (VIC 297); (**c**) Kennett River and beach (VIC 359) with bedload extending into the nearshore; and (**d**) view south along the rocky Swell Point beaches (VIC 384–387). (Photos: AD Short)

PCs (Table 25.3). The beaches and barrier are discussed in more detail in the following sections.

25.10.1 SC:VIC03.02.01 Point Lonsdale-Table Rock

SC:VIC03.02.01 extends for 60 km between Point Lonsdale and Table Rock (Fig. 25.16). The coast initially trends due west to Black Rocks then turns and trends southwest past a series of low headlands and beaches to Table Rock at Aireys Inlet. A series of moderate-sized towns are located along the coast commencing in the east with Point Lonsdale, then Ocean Grove (14,000), Barwon Heads (4000), Torquay (10,000), Jan Juc (3700), Anglesea (2500) and Aireys Inlet (800). All are setback behind the foreshore reserve with no property at risk from erosion. There are 47 generally small beaches along this coast occupying 48.2 km (80%) of the shore, the remainder a mix of low basalt points in the north and steeper Tertiary bluffs and cliffs south from Torquay (Fig. 25.17b). Beach sands range from fine to coarse and carbonate from 0% to 80% (Table 25.1, Fig. 25.3) indicating a range of local sources, including contributions for the eroding cliffs. As an example, Bells Beach (VIC 302) has steep reflective coarse beach (mean size = 0.69 mm) with low carbonate (5%) and rocky reefs fringing the base of the beach, whereas neighbouring Southside (VIC 303) located just 0.5 km to the south has fine sand (0.25 mm) and is carbonate-rich (45%) with a sandy 200 m wide TBR-RBB surf zone. Beach state is dependent on orientation, sand size and level of exposure and ranges from R-TTT in sheltered locations to TBR-RBB on the most exposed beaches.

There are seven barriers along the SC, the largest on the northern south-facing beaches between Point Lonsdale and Barwon Heads (Fig. 25.17a) which are backed by vegetated transgressive dunes extending up to 1.3 km inland. Stable foredunes dominate the central-southern barriers where the dominant westerly winds blow offshore. Combined the barriers have a total volume of 186 M m^3 (5684 m^3 m^{-1}). The Barwon River flood tide delta which winds for 9 km inland has a 9.5 km^2 tidal delta which has also acted as a substantial Holocene sediment sink, particular when sea level was higher.

25.10.2 SC:VIC03.02.02 Table Rock-Cape Otway

SC:VIC03.02.02 continues south from Table Rocks for 79 km to Cape Otway (Fig. 25.16), the prominent 90 m high boundary between the central and western coasts. This is a rugged coast famous as the start of the Great Ocean Road which has been etched into the cliffs as its winds its way south. There are four small communities here are all located on some of the limited flatter areas at the base of the ranges or valleys, namely, Lorne (1200), Wye R (80), Kennett R (50) and Apollo Bay (1600). All are setback behind their foreshore reserves; though in the case of Lorne and Apollo Bay, there are recreational facilities and clubs built in the reserve, the latter prograding since construction of the boat harbour in the 1950s. This is very much a coast dominated by its geology. The 84 beaches average 350 m in length and occupy 27% of the shore, the remainder sedimentary rocks of the backing range which forms steep cliffs, rock platforms and reefs. Gill (1977) described last interglacial rock platforms and boulder beds along the Otway coast which have been reactivated by the Holocene transgression, while Stephenson and Thornton (2005) provide an overview of the rocky Otway coast. The cliffs and steep slopes rise 20–40 m to the road then up to 200 m to their crests and higher inland. The rugged terrain is cut by scores of small creeks and a few small rivers (Erskine, Cumberland, Wye, Kennett (Fig. 25.17c), Grey, Barham, Parker) each flowing through steep-sided V-shaped valleys and delivering small quantities of terrigenous material to the coast.

Over half the beaches are sheltered in small embayments and in lee of reefs (Fig. 25.17d) and are low energy R-LTT, some fronted by rock flats, with the remainder more exposed and predominately TBR with a few of the most exposed RBB, including the 6 km long Fairhaven beach (VIC 328). There are ten generally small regressive barriers along the coast, some with large foredunes like Fairhaven, which when combined have a low volume of 18 M m^3 (1454 m^3 m^{-1}). The only transgressive barrier is at Point Franklin which is partly blanketed in transgressive dunes that originated to the west of Cape Otway and are part of the adjoining upwind SC.

25.10.3 PC Overview

The well-known Surf Coast between Point Lonsdale and Cape Otway is a coast of two halves. The north half is the topographically lower, predominately sandy and generally higher energy, while to the south is the rugged rock-dominated section whose orientation, reefs and headlands afford considerable protection to the shoreline. The prevailing southwest swell runs up this coast providing potential for northeast to east sand transport towards Port Phillip Heads. There is evidence of headland bypassing at Point Roadknight and Torquay, and many of the northern beaches are linked by low sand fronted headlands and points. The ultimate sink for this carbonate-rich sand is the Barwon flood tide delta, the Point Lonsdale transgressive barrier, both now largely occupied and stable, together with ongoing bypassing of Point Lonsdale into Port Phillip, and the converging Swan Island sediment system. Rising sea level will reactivate the flood tide deltas and provide accommodation space at the creek mouths, generate shoreline recession, including the friable Tertiary bluffs, and may increase longshore transport as the eroded sand becomes available.

25.11 PC:VIC03.02 Cape Otway to Point Danger (SA)

The 244 km long western Victorian coast starts at the prominent 80 m high Cape Otway and extends to the border at the Glenelg River and continues for another 14 km to low cobble Point Danger in SA. The coast is lightly developed in the east where the Port Campbell National Park occupies much of the coast together with the small communities of Port Campbell (600) and Peterborough (200). The major regional centre is the large Warrnambool (35,000) and nearby Port Fairy (3500) and in the west the port city of Portland (10,000) and the small Cape Bridgewater (250) and Nelson (250) near the border. While most of the towns and communities are located inland and in lee of foreshore reserves and generally at low risk from erosion, however east of Portland at Duttons Way is one of the most at risk and defended sections of the Australian coast.

The coastal geology can be divided into three segments: the Mesozoic sedimentary rocks of the Otway Range which extend to the Gellibrand River; the Tertiary

Port Campbell Limestones that extend to near Warrnambool and are largely contained in the national park; beyond which are the plains of the New Volcanics, which only reach the coast in a few locations forming headlands, rocks and reefs, and where largely Quaternary marine sediments dominate the coast and contribute to the extensive Pleistocene and Holocene barrier systems.

Boreen and James (1993) investigated the nature and evolution of the Otway shelf carbonate platform between Cape Otway and Robe, as briefly discussed in 16.5.4. That found that during the PMT (10–6.5 ka) shallow embayments on the shelf were infilled and outer shelf sediment accumulation began by 7 ka. As sea level stabilised near its present level by 6.5 ka, the shelf was partitioned into three zones by the energetic Southern Ocean swell (Fig. 16.9b): (1) a shoreface with protected embayments and/or beach/dune complexes with high sediment accumulation rates (about 100 cm ka^{-1}), (2) an open shelf with carbonate production but patchy (3–5 cm ka^{-1}) to non-existent accumulation within the zone of wave abrasion and minimal (about 23 cm ka^{-1}) between maximum abrasion depth and swell wave base; and (3) a deep shelf edge and upper slope where sediment is accumulating at rates of 2–50 cm ka^{-1}. They concluded that during the early PMT (17–10 ka) coarse, shelf debris and lowstand dune sands were erosively reworked and transported onto the upper slope and redistributed to deep-slope aprons, with the Otway slope sedimentation described by Passlow (1997). Boreen et al. (1993) found the seafloor of the shallow shelf (<70 m depth) is characterised by exhumed limestone substrates which host dense encrusting assemblages of molluscs, sponges, bryozoans and red algae (Fig. 16.9a). The entire area lies within wave base, and material is eroded and bedload transported daily. It is this zone which supplied the bulk of the PMT carbonate material to the coast and continues to supply carbonate at much reduced rates.

The west coast climate is increasingly Mediterranean with cool winters, warm summers and a winter rainfall maximum (Figs. 1.4, 1.5b). The coast is WD and microtidal (spring range 0.5–0.6 m). This is an exposed southwest-facing shore that receives the full forces of the Southern Ocean waves and strong westerly winds. The shelf is just 60 km wide with little wave attenuation allowing the long southwest swell waves averaging 2–2.5 m (Flocard et al. 2016), with periods 12–15 s, to arrive year-round with a late winter maximum, while calms are rare. The south to southwest orientation of the coast combined with the high energy wave climate and fine to medium sand and micro-tides maintains extensive high energy TBR-RBB beaches along 151 km of the coast, with equally numerous, though shorter R and LTT occupying 28% of the shore (Table 25.8). The combination of persistent high waves and orientation into the

Table 25.8 PC:VIC03.03 beach types and states

BS	BS	No.	%	Length (km)	%	Mean (km)	σ (km)
3	RBB	35	23.2	32.3	18.0	0.9	1.4
4	TBR	37	24.5	118.6	66.2	3.2	6
5	LTT	32	21.2	18.5	10.3	0.6	1.1
6	R	47	31.1	9.8	5.5	0.2	0.2
		151	100	179.2	100	1.2	–

Fig. 25.18 SC:VIC03.03.01 Cape Otway to Peterborough. (Source: Google Earth)

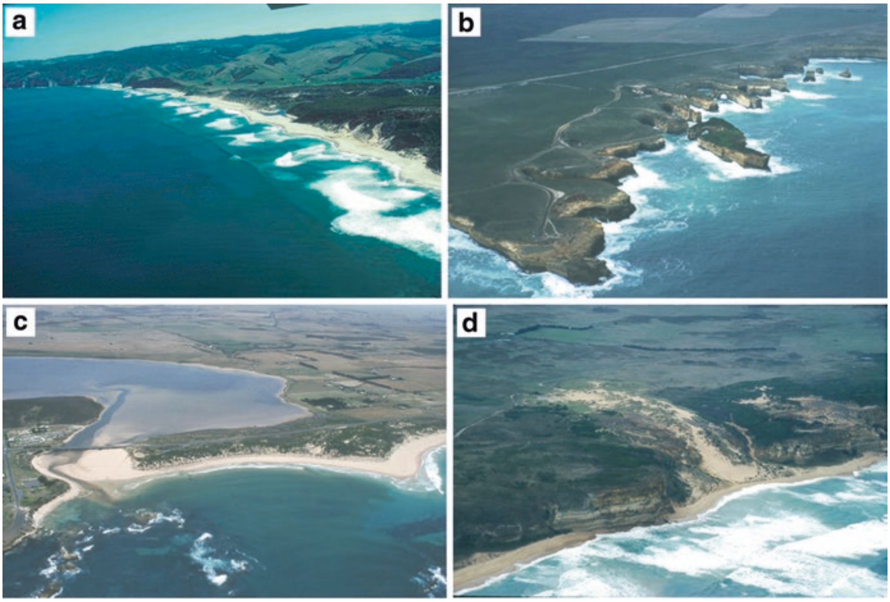


Fig. 25.19 (**a**) The high energy rip-dominated Johanna beach (VIC 420); (**b**) the cliffed and indented Port Campbell Limestone coast at Broken Head; (**c**) Curdies Inlet, barrier and flood tide delta (VIC 458); and (**d**) climbing dune at Flaxman beach (VIC 486). (Photos: AD Short)

strong westerly wind has led to the development of 32 barriers which occupy 160 km (47%) of the coast with a total volume (4593 M m^3) which is the largest in the region, with a per metre volume of 28,796 m^3 m^{-1} (Table 25.3). The shoreline evolution of the west coast has also been impacted by the Holocene highstand (+1–2 m) and subsequent fall to the present level (Gill and Lang 1982; Bird 1993).

The small Aire (279 km^2), Johanna and Gellibrand rivers flow out of the Otway Range to the west coast, while draining the basalt plain to the west are the Curdies (1006 km^2), Hopkins (8984 km^2), Moyne (687 km^2) Shaw, Eumeralla, Fitzroy (1467 km^2), Surrey (370 km^2) and the larger Glenelg (11,841 km^2). All of the rivers flow into estuaries, and none are delivering sand to the coast. This PC contains three SCs which are discussed below.

25.11.1 SC:VIC03.03.01 Cape Otway-Peterborough

SC:VIC03.03.01 extends west from Cape Otway for 80 km to the Peterborough at the mouth of Curdies Inlet (Figs. 25.18 and 25.19c). The coast consists of two parts, the eastern Otway Range section to the Gellibrand River and the cliffed Tertiary limestone west to Peterborough (Fig. 25.19b), with the 30 km of coast between Gellibrand River and Curdies Inlet located in the Port Campbell National Park. The entire coast is orientated southwest to south and fully exposed to the Southern Ocean. It contains 56 beaches which occupy just 25 km (31%) of the shore, the remainder steep rugged slopes in the Otway section and often vertical limestone cliffs and stacks up to 70 m high in the limestone section. The exposed beaches are all high energy TBR and particularly RBB (34 beaches) (Fig. 25.19a) together with some sheltered beaches particularly in the indented and reef protected parts of the limestone section where there are R-LTT together with some TBR in more exposed locations. Most of the beaches are short (mean length = 0.44 km) and embayed, the longest is 3.6 km Johanna beach (VIC 420, Fig. 25.19a), with little potential for longshore sand transport. They generally are composed of well-sorted medium carbonate-rich (50%) sand (Table 25.1) with considerable longshore variation (Fig. 25.3). The sand has been derived from the shelf and locally from limestone cliff erosion, though the proportion of sand delivered from the cliffs is small.

Gill (1973b) estimates rates of retreat of the Otway non-marine rocks of between 0.9 and 1.75 cm $year^{-1}$ which would supply some feldspathic sand and gravel from the predominately silty cliffs. The Port Campbell limestone was estimated to retreat between 1 and 2 cm $year^{-1}$ which supplies mainly silty material and only 1–2% sand, plus limited coarser material winnowed from the cliff debris (Bird 1993). More recently, Bezone et al. (2016) used aerial photography and satellite imagery to measure limestone cliff retreat and found the mean long-term rates of erosion from 1947 to 1994 was 22 cm $year^{-1}$ and the short-term rate of erosion from 2004 to 2014 was 36 cm $year^{-1}$ both an order of magnitude greater than Gill's calculations. The eroding cliffs have left a number of well-known features that have become major tourist attractions including the Twelve Apostles, the late London Bridge and the tragic Loch Ard Gorge.

This is an exposed high energy coast however accommodation space is limited by the steep terrain. While there are eight barrier systems along the coast, the bulk of the sand is contained in the Cape Otway-Aire River clifftop transgressive dunes (280 M m^3, which represents a very high 140,000 m^3 m^{-1}) which sit on cliffs up to 80 m high and have overpassed the 6 km wide base of the cape to reach Point Franklin and the eastern shore. The remaining barriers are all located in valleys and low points in the coast (Glenaire, Johanna, Gellibrand, Sherbrooke, Port Campbell, Childers Cove) and Two Mile Reef and total 205 M m^3 (22,260 m^3 m^{-1}). These are all transgressive system which extend up to 3.5 km inland and are now predominately stable with only 4% unstable. While the western limestone section is cliffed with few beaches, the straight 10 km long cliffed section between the Gellibrand River and the Twelve Apostles (VIC 445–442) has a near continuous surf zone running along the base of the cliffs and linking the patches of beach sand and has potential for longshore sand transport when wave arrive at an angle to the shore.

Most of the limestone coast is cliffed with very limited access to the shore. However, at Two Mile Reef, the sloping Pleistocene escarpment has not been eroded as it is sheltered in lee of an emerged rock platforms, capped by a Holocene foredune, with foot access to the shore. The modern platform and limestone reefs also extend a few hundred metre offshore, producing a famous big wave surfing break.

25.11.2 SC:VIC03.03.02 Peterborough–Griffith Island (Port Fairy)

SC:VIC3.03.02 commences at Peterborough and trends generally northwest for 72 km to Warrnambool and then curves to face south in Armstrong Bay with the boundary at Port Fairy's low Griffith Island (Fig. 25.20). It contains the coastal towns of Warrnambool and Port Fairy and can be divided into two sections, the relatively straight 35 km long Peterborough to Warrnambool-Lady Bay containing 40–60 m high cliffs of Tertiary marine limestone between Peterborough and Logans Beach, followed by the Quaternary sands of Lady Bay with dune calcarenite forming the western boundary at Thunder Point. This is followed by the gently curving southeast- to south-facing 12 km long Armstrong Bay which is separated from Port Fairy by 7 km of basalt rocks and reefs and the basalt also forming the western boundary at Griffith Island. This basalt was deposited by lava flows from the Tower Hill volcano (~10 ka) located a few kilometre to the north and Australia's most recent volcanic activity. Gill (1967) provides a detailed report on the evolution of the coast between Warrnambool and Port Fairy and estimated the rate of calcarenite retreat at 4 cm $year^{-1}$, while Bird (1993) suggests a rate of between 1 and 10 cm $year^{-1}$. At Robe, 250 km to the west, Fotheringham (2009) obtained rates

Fig. 25.20 SC:VIC03.03.02 Peterborough to Port Fairy. (Source: Google Earth)

from 48 transects around Cape Dombey between 1 and 25 m year^{-1}, with most between 5 and 10 cm year^{-1}, in general agreement with Gill and Bird.

Unlike the previous SC, this is a sedimentary coast with 46 beaches occupying 40 km (87%) of the shore, including several long beaches within the bays, the longest 8 km long Armstrong Bay (VIC 504). The beaches range from R to RBB, with numerous small headland and reef-sheltered R and LTT beaches particularly along the limestone section, as well as the more exposed TBR and RBB on the longer southwest-facing bay beaches.

There are 11 barrier systems occupying 38.5 km (53%) of the coast and generally extending from a few hundred metres to over 1 km inland, as both transgressive dune systems (e.g. Crofts, Flaxman (Fig. 27.19d), Armstrong Bay, Hummocks) and high foredune systems together with some regressive barriers in sheltered locations (Warrnambool-Lady Bay and Port Fairy). They have a total volume of 630 M m^3 (16,352 m^3 m^{-1}). The Holocene barriers are in turn backed by an interbarrier depression (Belfast Lough and Kelly Swamp) and a lithified Pleistocene barrier, which behind Armstrong Bay has been scarped to form 20 m high bluffs, with both Port Fairy and Warrnambool townships mainly located on the higher calcarenite. The Warrnambool calcarenite rises to 50 m inland and extends to at least 20 m below sea level (McAndrew and Marsden 1973). Gill (1978) calculated that 30 M m^3 of Holocene dune sand had been deposited on the western side of Cape Reamur, while erosion of the calcarenite bluffs to the west at a rate of 0.5 m^3 year^{-1} has released 29.3 M m^3 over the past 6 ka enough to supply the dunes.

There appears to be easterly longshore transport along parts of this coast to Cape Reamur and on to Griffith Island and into Port Fairy and around Thunder Point and into Lady Bay. At Warrnambool a 400 m long attached breakwater was built by 1890, which resulted in 250 m of shoreline progradation into the bay (Rae 1977), smothering an earlier jetty, with 1.2 M m^3 of sand deposited between 1884 and 1925 (Bird 1980). This land now houses a foreshore reserve and caravan park. At Port Fairy the 50 m wide gap between Griffith Island and mainland was closed in 1870 and training walls constructed for the port. Port Fairy Beach however has experienced ongoing recession since the 1850s of between 0.1 and 0.3 m $year^{-1}$ (Flocard et al. 2012). This appears to be related to closing the gap and the training walls interrupting the supply of sand with the loss estimated at 5000 m^3 $year^{-1}$ by BMT WBM (2007), while easterly longshore sand transport along Port Fairy (East) beach is estimated at 20,000 m^3 $year^{-1}$ (CES 2013) leaving a shortfall along the beach. Port Fairy has 271 buildings presently vulnerable to inundation and 117 to erosion, which is expected with sea-level rise to increase to 444 and 203, respectively by 2080 (Flocard et al. 2012). Sand bypassing of the training walls commenced in the 1990s but has not stop the erosion. As sea-level rise is expected to exacerbate the erosion, there have been proposals for a seawall and beach nourishment on the order of 100,000 m^3 (CES 2013).

25.11.3 SC:VIC03.03.03 Griffith Island (Port Fairy)–Cape Nelson

SC:VIC03.03.03 contains the long-curving Portland Bay, extending for 96 km from the low Griffith Island to the prominent calcarenite-capped basalt of 80 m high Cape Nelson, with the city of Portland located at the sheltered western end of the bay (Fig. 25.21). The coast consists of three sections: a 20 km long basalt (Newer Volcanics) and calcarenite bluff-reef section with short beaches between Port Fairy and Yambuk River; the 43 km long near continuous sandy beaches of Lady Bay (Eumeralla, Fitzroy and Surf); and finally the rocky bluffs and cliffs of Point Danger and Cape Nelson which contains some cobble beaches in Grant Bay (VIC 544).

Fig. 25.21 SC:VIC03.03.03 Port Fairy to Cape Nelson. (Source: Google Earth)

This SC contains 35 beaches which occupy 59 km (61%) of the shore, the remainder either basalt reefs and calcarenite cliffs and reefs in the east, and calcarenite-capped basalt cliffs in the west. Beach sands range from fine to coarse, fining in to Discovery Bay, and carbonate remains high between 60% and 99% (Table 25.1, Fig. 25.3). Flocard et al. (2016) found that while the open coast has waves averaging 2–2.5 m, in Portland Bay they dropped to between 0.5 and 1.5 m. Most of the shorter beaches are sheltered by the headlands, rocks and reefs and are lower energy R to LTT, while the longer exposed bay beaches are LTT with medium sand grading to TBR-RBB with fine sand.

Nine moderate-sized barriers occupy 55 km (57%) of the coast including the 43 km long Portland Bay system, with a total volume of 720 M m^3 (13,075 $m^3\ m^{-1}$). The long bay barrier system grades from a 0.5 km wide regressive system in the west to with increasing exposure and more southerly orientation 0.5 km wide transgressive system towards the east, with the most extensive transgressive dunes at McKechnie Craig (VIC 534) near Port Fairy, where parabolic dunes extend 1.5 km inland, with Gill (1976) reporting a date of 5.1 ka for an inner stabilised dune behind Tower Hill beach (VIC 505). Dunes to the west of Port Fairy were destabilised by European settlement in the nineteenth century, resulting in the introduction of European marram grass to help stabilise the sand. The grass has now successfully taken over most of the coastal foredunes.

There is evidence of easterly longshore transport in this system with the mouths of the Eumeralla, Fitzroy and Surrey rivers deflected up to 7 km to the east. Baker (1956) using tracer minerals concluded that sand is moving around Cape Nelson and bypassing Portland Harbour to reach the eastern shore of Portland Bay between Fitzroy River and Cape Reamur. Since then, Portland Harbour with its attached breakwater was constructed between 1957 and 1966. This was followed by downdrift recession of Dutton Way beach commencing in 1959 at rates averaging 3 m $year^{-1}$. This recession however has been attributed to changes in wave refraction around the harbour rather than sediment starvation (Gill 1967, 1979). In response, rubble seawalls were constructed beginning in the 1960s at the western end of the beach, which in turn generated downdrift erosion, causing the seawalls to be extended. Ongoing erosion and extension of the seawalls has continued, with now 7.5 km of irregular and in places disjointed seawalls along the formerly wide low sandy beach. The draft coastal management plan for Portland (Glenelg Shire 2017) only has plans to improve access across the seawall.

25.11.4 SC:VIC03.03.04 Discovery Bay: Cape Nelson-Point Danger

SC:VIC03.03.04 is the westernmost Victorian SC extending from Cape Nelson for 82 km to the SA border and then 14 km to SA's Point Danger (Fig. 25.22). This SC is dominated by the remnants of Pleistocene Volcanics which form capes Nelson and Bridgewater in the east and the curving southwest-facing Discovery Bay

Fig. 25.22 SC:VIC03.03.04 Cape Nelson (VIC) to Danger Point (SA). (Source: Google Earth)

shoreline in the centre-west. The 60–80 m high capes consist of Newer Volcanics covered by Pleistocene dune calcarenite and Holocene clifftop dunes (Fig. 25.23a, b). The Quaternary geology of the region was investigated by Boutakoff (1963) and is also included in Sprigg's (1952) classic study of the regressive Coorong barrier system.

The 15 beaches along this section occupy 71 km (74%) of the shore, with 58 km of near continuous beaches in Discovery Bay (Fig. 25.23c, d), the longest beach system in western VIC (VIC 557–560). The beaches are all moderately to well exposed to the southwest swell, with the more exposed central Bridgewater and Discovery bays having 400–600 m wide double-bar surf zones, with a TBR-RBB inner bar containing rips spaced on average every 0.5 km with up to 100 large beach rips operating along Discovery Bay beach. Wave energy decreases into the sheltered western end of Discovery Bay and into SA where inshore reefs attenuate the waves. Overall however this is the highest energy section of the western VIC, a fact also reflected in the extensive barrier systems including the clifftop dunes. The Bridgewater Bay and Discovery Bay barriers both consist of massive transgressive dunes (Fig. 25.23c), with the Bridgewater Bay dunes climbing over the basalt and dune calcarenite (Fig. 25.23a) and extending up to 5 km inland with rates of migration recorded at 13 m year^{-1} for a 10 m high dune and 3 m year^{-1} for the 30–40 m high dunes (Bird 1993), while in Discovery Bay, they extend up to 4 km inland. They have a total volume of 2760 M m^3 supplied at a high rate of 50,360 m^3 m^{-1}, the

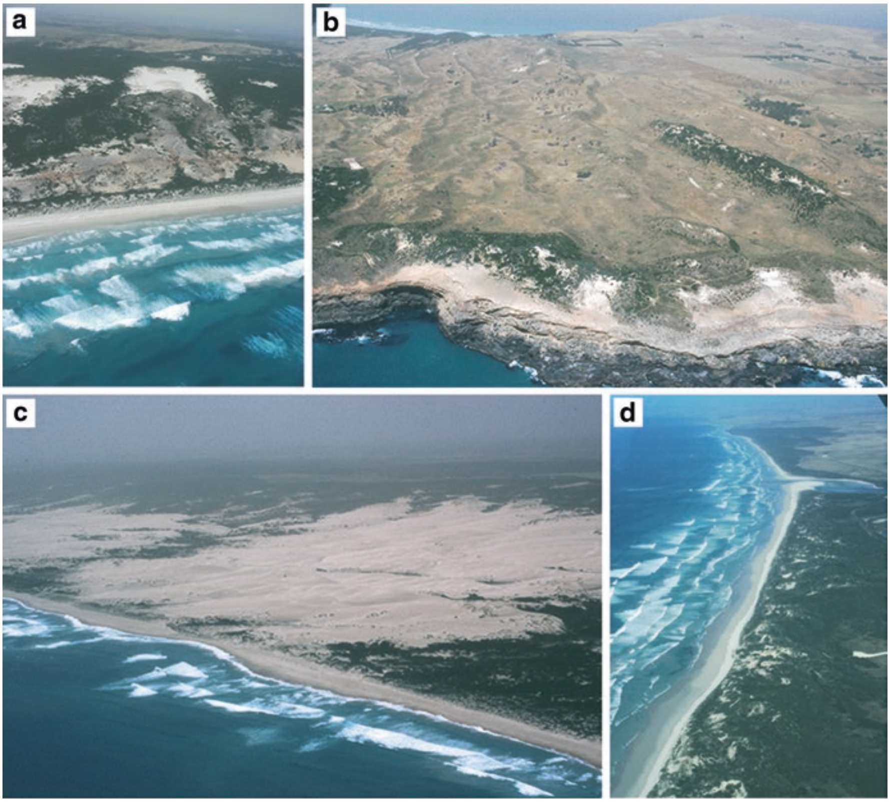


Fig. 25.23 (**a**) Parabolic dune climbing over Pleistocene calcarenite in Bridgewater Bay (VIC 551); (**b**) stable long-walled parabolic dunes on top of 40 m high Cape Bridgewater; (**c**) massive transgressive dunes in Discovery Bay (VIC 557); and (**d**) view west past the Glenelg River mouth (VIC 559-560). (Photos: AD Short)

highest SC rate in VIC (Appendix 34.2). Like many dune systems along this coast, they were destabilised following European settlement (Baker 1956) with active dunes reaching 60 m in height and rates of migration recorded between 0.2 and 16 m year^{-1} (Kenley (1976), with most now stabilised or stabilising.

This is a high energy swash-aligned coast with little evidence or potential for longshore transport, and most sand deposited in the dune systems and the Glenelg River flood tide delta, apart from limited past overpassing of Cape Bridgewater from Descartes to Bridgewater Bay. The beaches range in carbonate from 60% to 98% and include some local shell deposits in Bridgewater Bay (Shelly Beach VIC 552–553, 98% carbonate) and green olivine from the volcanics tinge the eastern Descartes Bay swash zone. The Glenelg River estuary is an ICOL closing during the drier summer months.

25.11.5 PC Overview

The western Victorian coast is an exposed high energy coast consisting of high energy beaches backed by some massive transgressive barrier systems, together with rocky shores consisting of rapidly eroding Port Campbell limestone and Pleistocene dune calcarenite and the far more resilient basalt. Like most high energy coasts, the initial carbonate-rich shelf sand reserves have been transported onshore-alongshore to fill the barriers and estuaries with little or diminished supply since. As the sand is predominately carbonate, there is the potential for continuing shelf carbonate supply; however, the rates are unknown. Likewise, the eroding cliffs are supplying limited sand to the adjacent beach systems at small but unknown rates. Most of the coast however appears to be stable to receding, some man-induced, as at Port Fairy and Dutton Way. Rising sea level will reactivate the few estuaries and their flood tide deltas and accelerate erosion of the calcarenite and limestone cliffs (Bezone et al. 2016). Shoreline and particularly foredune erosion could lead to renewed dune activity; however, this can be managed through dune planting and management.

25.12 Regional Overview

The central and western Victorian coast contains a wide range of coastal systems from the very sheltered TD Western Port, to the leeward and windward fetch-limited shores of Port Phillip, to the generally exposed open coast, with variability related to gradation within the curving embayed beach systems and to the variable coastal geology. The coastal sands are predominately carbonate increasing in proportion to the west where they average 78%. The sand has been transported onshore from the shelf during and following the PMT into the now largely stable barrier systems. Most of the coast is also swash-aligned with minimal longshore transport, apart from parts of the western coast where easterly transport is apparent, with relatively low rates reported of 20,000 m^3 $year^{-1}$ at Port Fairy.

The coastal fringe is largely undeveloped protected by the foreshore reserve, and all major towns are located on higher ground, with the only vulnerable area being parts of Port Phillip, Port Fairy and the receding Duttons Way. Rising sea level will have major impacts in the estuarine areas like Shallow, Anderson and Curdies Inlet and particularly in Western Port with its extensive low gradient shoreline and all low-lying communities including parts of Port Fairy, all of which will experience increased inundation and flooding. On the open coast, sea-level rise will induce shoreline recession which could reactivate many of the presently stable foredune and dune systems, a situation which could be managed though dune maintenance. In the estuaries it will reactivate the flood tide deltas causing loss of coastal sands to the tidal deltas also inducing erosion of the adjacent shorelines.

References

Baker G (1956) Sand drift at Portland, Victoria. Proc Roy Soc Victoria 68:151–198
Beasley AW (1966) Port Phillip survey 1957–63. Bottom sediments. Mem Nat Mus Vict 27:69–105
Beasley AW (1972) Sands from Squeaky Beach area, Wilsons Promontory, Victoria. Mem Nat Mus Victoria 33:47–54
Bezone R, Kennedy DM, Ierodiaconou D (2016) The drowned apostles: the longevity of sea stacks over eustatic cycles. J Coast Res SI 75:592–596
Bird ECF (1980) Historical changes on sandy shorelines in Victoria. Proc R Soc Vic 91:17–33
Bird ECF (1993) The coast of Victoria. Melbourne University Press, Melbourne, 324 p
Bird ECF (2006) The effect of higher sea level on the coasts of Port Phillip Bay. Vic Nat 123:49–54
Black KP, Rosenberg MA (1992) Natural stability of beaches around a large bay. J Coast Res 8:385–397
BMT WBM (2007) Port Fairy east beach – coastal erosion engineering and feasibility study. Report prepared for Moyne Shire Council, BMT WBM
Boreen TD, James NP (1993) Holocene sediment dynamics on a cool-water carbonate shelf: Otway, southeastern Australia. J Sediment Petrol 63:574–588
Boreen TD, James NP, Wilson C, Heggie D (1993) Surficial cool-water carbonate sediments on the Otway continental margin, southeastern Australia. Mar Geol 112:35–56
Boutakoff N (1963) The geology and geomorphology of the Portland area, Geological Survey of Victoria. Memoir, no. 22. Department of Mines, Melbourne
Bowler JM (1966) Port Phillip survey 1957–1963 – geology and geomorphology. Mem Nat Mus Vic 27:19–67
Bowler JM (1978) Glacial age aeolian events at high and low latitides: a Southern hemipsphere perspective. In: van Zinderen Bakker EM (ed) Antartic Glacial History and World Paslaeoenvironments. AA Balkema, Rotterdam, 149–172
CES (2013) East Beach Seawall Works preparation: seawall assessment and design concepts. Report prepared for Moyne Shire Council by Coastal Engineering Solutions, Fish Creek, 70 pp
Colleter G, James D, Northeast F (2015) Portarlington Beach renourishment and seawall renewal projects. In: 22nd Australasian coastal ocean engineering conference, Institution of Engineers Australia, pp 439–444
Douglas JG, Ferguson JA (eds) (1976) Geology of Victoria. Geological Society of Australia special publication 5. Geological Society of Australia, Melbourne, 528 p
Falconer RL (1972) Ocean waves at Port Phillip Heads, Bureau Meteorology, Depart Interior, Canberra
Flocard F, Carley JT, Rayner DS, Rahman PF, Coghlan IR (2012) Future coasts – Port Fairy coastal hazard assessment. Water Research Laboratory Technical Report 2012/21, 152 p
Flocard F, Ierodiaconou D, Coghlan IR (2016) Multi- criteria evaluation of wave energy projects on the south-east Australian coast. Renew Energy 99:80–94
Fotheringham D (2009) Cliff top erosion adjacent to Cape Dombey, Robe, South Australia. Coastal Management Branch Technical Report. 2009/08, 17 p
Garcia-Webb J, Provis D (2011) Coastal processes and management study for the Bellarine Peninsula. In: 20th Australasian conference on coastal and ocean engineering, Institution of Engineers Australia, pp 238–243
Gardner TW, Webb J, Davis AG, Cassel EJ, Pezzia C, Merritts DJ, Smith B (2006) Late Pleistocene landscape response to climate change: eolian and alluvial fan deposition, Cape Liptrap, southeastern Australia. Quat Sci Rev 25(13–14):1552–1569
Gill ED (1967) Evolution of the Warrnambool-Port Fairy coast and the Tower Hill eruption, western Victoria. In: Jennings JN, Mabbutt JA (eds) Landform studies in Australian and New Guinea. Australian National University Press, Canberra, pp 341–364
Gill ED (1972) Emerged marine shell beds near Geelong, Victoria, Australia, with marine shells bored into freshwater limestone. Vic Nat 89:315–319
Gill ED (1973a) Second list of radiocarbon dates on samples from Victoria. Proc R Soc Vic 86:133–136

Gill ED (1973b) Rates and modes of retrogradation on rocky coasts in Victoria, Australia, and their relationship to sea level changes. Boreas 2:143–171

Gill ED (1976) Warrnambool-Port Fairy district. In: Douglas JG, Ferguson JA (eds) Geology of Victoria, Geological Society of Australia Special Publication 5. Geological Society of Australia, Melbourne, pp 299–304

Gill ED (1977) Evolution of the Otway coast, Australia, from the last interglacial to present. Proc R Soc Vic 89:7–18

Gill ED (1978) Quantification of coastal processes as a basis for coastal management and engineering. In: 5th coastal ocean engineering conference, Adelaide, Institution of Engineers Australia, pp 213–216

Gill ED (1979) Coastal erosion, northwest Portland Bay, Victoria, CSIRO Division of Applied Geomechanics, Tech report 94. CSIRO, Division of Applied Geomechanics, Melbourne

Gill ED, Lang JG (1982) The peak of the Flandrian transgression in Victoria, S E Australia – faunas and sea level changes. Proc R Soc Vic 94:23–34

Glenelg Shire (2017) Portland coastal management plan. Victorian State Government, Glenelg Shire, 27 p

Goodfellow BW, Stephenson WJ (2008) Role of infragravity energy in bar formation in a strong-wind bay: observations from Seaford beach, Port Phillip Bay, Australia. Geogr Res 46:208–233

Guerin B (1983) Beach restoration, Mentone, Port Phillip, Victoria. In: Knight MJ, Minty EJ, Smith RB (eds) Collected case studies in engineering geology, hydrology and environmental geology. Engineering Geology Specialist Group, Geological Society of Australia, Sydney

Harris JE, Hinwood JB, Marsden MAH, Sternberg RW (1979) Water movements, sediment transport and deposition, Western Port, Victoria. Mar Geol 30:131–161

Holdgate GR, Thompson BR, Guerin B (1980) Late Pleistocene channels in Port Phillip Bay. Proc R Soc Vic 92:119–130

Hurst AM (1986) The late quaternary morphostratigraphy and evolution of the Seaford barrier system, Port Phillip Bay, Australia. Department of Geography, Honours thesis, University of Sydney, Sydney

Jenkin JJ (1976a) Port Phillip Sunkland. In: Douglas JG, Ferguson JA (eds) Geology of Victoria, Geological Society of Australia Special Publication 5, Geological Society of Australia, Melbourne, pp 305–309

Jenkin JJ (1976b) Western Port and southern Gippsland. In: Douglas JG, Ferguson JA (eds) Geology of Victoria, Geological Society of Australia special publication 5. Geological Society of Australia, Melbourne, pp 315–325

Jennings DS, Barraclough JR (1978) Port Phillip – the practicalities of coast protection. In: 4th Australian conference on coastal and ocean engineering, Adelaide, Institution of Engineers Australia, pp 13–18

Kenley PR (1976) Southwestern Victoria. In: Douglas JG, Ferguson JA (eds) Geology of Victoria, Geological Society of Australia special publication 5. Geological Society of Australia, Melbourne, pp 290–298

Lowe MK, Kennedy DM (2016) Stability of artificial beaches in Port Phillip Bay, Victoria, Australia. J Coast Res SI 75:253–257

Mahon BPG (1977) The Westernport regional environmental study. In: 3rd Australian conference on coastal and ocean engineering, Institution of Engineers Australia, pp 220–225

Marsden MAH (1977) Transport and deposition of sediment, and implications for harbour development, Westernport, Victoria, 3rd Australian Coastal Ocean Engineering Conference, Melbourne, Institution of Engineers Australia, pp 226–232

Marsden MAH, Mallett CW (1975) Quaternary evolution, morphology and sediment distribution, Westernport Bay, Victoria. Proc R SocVic 87:107–138

Marsden MAH, Mallett CW, Donaldson AK (1979) Geological and physical setting, sediments and environments, Westernport Bay, Victoria. Mar Geol 30:11–46

McAndrew J, Marsden MAH (1973) Regional guide to Victorian geology. School Geology, University of Melbourne, Melbourne, 224 p

Nielson JL (1976) Yarra Delta. In: Douglas JG, Ferguson JA (eds) Geology of Victoria, Geological Society of Australia special publication 5. Geological Society of Australia, Melbourne, pp 309–315

Passlow V (1997) Slope sedimentation and shelf to basin sediment transfer: a cool-water carbonate example from the Otway margin, southeastern Australia. In: James NP, Clarke JAD (eds) Cool-water carbonates. Society for Sedimenary Geology, Tulsa, pp 107–125

Provis DG, Radok R (1979) Sea-level oscillations along the Australian coast: Australia J Marine Freshwater Res, 30:295–301

Rae, GA (1977) Problem areas on the Victorian coastline, and some effects of developmental works. In: 3rd Australian conference on coastal and ocean engineering, Institution of Engineers Australia, pp 245–251

Riedel HP, Fidge BL (1977) Beach changes at Swan Island, Victoria 1886–1976. In: 3rd Australian conference on coastal and ocean engineering, pp 163–169

Short AD (1996) Beaches of the Victorian coast and Port Phillip Bay. Sydney University Press, Sydney, 298 p

Sprigg R (1952) The geology of the south-east province, South Australia, with special reference to Quaternary coastline migrations and modern beach development. Bull Geol Surv S Aust 29. 120 p plus photos

Stephenson WJ, Thornton LE (2005) Australian rock coasts: review and prospects. Aust Geogr 36:96–115

Van Den Berg AHM (1973) Geology of the Melbourne District. In: McAndrew J, Marsden MAH (eds) Regional guide to Victorian geology. School of Geology University, Melbourne, pp 14–30

Whincup S (1944) Superficial sand deposits between Brighton and Frankston, Victoria. Proc R Soc Vic 56:53–76

Websites

https://www.coastsandmarine.vic.gov.au/coastal-programs/beach-renourishment

https://www.coastsandmarine.vic.gov.au/coastal-programs/port-phillip

Chapter 26
Southern South Australia Region

Abstract The southern South Australian coast is an exposed high energy carbonate-rich system containing some of the highest energy beaches and the largest transgressive dunes systems in Australian, together with some large regressive barriers, all backed by extensive Pleistocene barrier systems which have been uplifted and tilted by regional neotectonics. The coast is exposed to persistent moderate to high southwest swell and periodic strong south though westerly winds, with micro-tides throughout. Sediments are predominately shelf-derived carbonate enriched with quartz towards the Murray Mouth. The coast consists of a southern limestone section, the 200 km long Coorong barrier system and the more rugged southern Fleurieu and southern Kangaroo Island coasts. The latter is blanketed in Pleistocene dune calcarenite capped by Holocene clifftop dunes. This chapter describes the coastal geology and processes, the beaches, barriers, sediment transport and sediment compartments.

Keywords South Australia · Kangaroo Island · Coorong · Murray Mouth · Calcarenite · Beaches · Barriers · Sediment transport · Sediment compartments

26.1 Introduction

The South Australian coast extends for 3273 km and comprises 30% of the temperate province and 49% of the Great Southern division. While its open coast faces into the full force of the Southern Ocean waves and winds, there is considerable variability along the coast in orientation and exposure owing to the two major gulfs (St Vincent and Spencer), the 150 km long Kangaroo Island and a series of moderately to well-sheltered bays in the south and west. At a State level, the coast is divided into eight management provinces (Table 26.1) which reflect both the changing physical nature of the coast, together with the city of Adelaide. In this book it is divided into the four NCCARF regions: the exposed southern coast between the VIC-SA border and Cape Jervis, including the south and west coasts of Kangaroo Island (this chapter); the generally sheltered coasts of Gulf St Vincent, Yorke

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Table 26.1 South Australia's eight coastal management provinces and their relation to the NCCARF regions and some key references

SA State province	SA NCCARF region	References
1. South East	Southern SA (SA01)	Short and Hesp (1980, 1984)
2. Fleurieu Peninsula	Southern/SA Gulfs	CPB (1984)
3. Adelaide metropolitan	SA Gulfs (SA02)	CPB (2005)
4. St Vincent Gulf	SA Gulfs (SA02)	–
5. Kangaroo Island	Southern/SA Gulfs	Short and Fotheringham (1986a, b)
6. Yorke Peninsula	SA Gulfs (SA02)	Wynn (1980)
7. Spencer Gulf	SA Gulfs (SA02)	Gostin et al. (1984) and Belperio et al. (1985)
8. Eyre Peninsula	Eyre Peninsula (SA03)	Short et al. (1986a, b)
(inc. Nullarbor)	Nullarbor (SA04)	Short et al. (1986a, b)

Peninsula and Spencer Gulf including the north coast of Kangaroo Island (Chap. 27); the long, exposed Eyre Peninsula coast west from Cape Catastrophe to Head of Bight (Chap. 28); and the Nullarbor coast (Chap. 29) which extends into WA.

This chapter examines the southern SA coast which includes 488 km of mainland coast and 269 km on Kangaroo Island, a total distance of 757 km. It contains 285 beach systems including the 200 km long Coorong beach-barrier system. The coast is located between 35.5° and 38°S and faces south to southwest exposing most of the shore to the full forces of the southwest swell and westerly winds, while tides are micro throughout, resulting in a very much WD shoreline.

26.2 Geology

The 135,000 km^2 Murray Basin (Fig. 1.3) dominates much of the south coast geology extending from the border to Middleton. The basin which was initially inundated 43 Ma has been primarily infilled with marine sediments. The plain slopes seaward at 0.5° and has been uplifted at a rate of 70 mm ka^{-1}, resulting in the preservation of a ~400 km wide sequence of Pliocene-Pleistocene barriers and interbarrier depressions which contain a 7 Ma record of barrier and sea level history (Fig. 26.1; Murray-Wallace 2018). The neotectonics is associated with the Gambier volcanics that has resulted in the gradual uplift between Nelson and Kingston SE together with northward tilting of the basin. The basin borders the Lachlan Fold Belt in the east, while in the west it abuts the more rugged and folded rocks of the Adelaide Fold Belt which form the eastern-southern Fleurieu Peninsula and much of Kangaroo Island (Fig. 1.2). West of Middleton to Cape Jervis and along the southern coast of Kangaroo Island, the more rugged Cambrian metasediments (graywacke and siltstones) of the Kanmantoo Trough dominate the coast. For more information on the coastal geology, see Murray-Wallace (2018) for a very detailed examination of the Murray Basin's coastal geology; Bourman et al. (2016) the geology of the entire southern coast; Davies et al. (1979) the Kangaroo Island geology; and Drexel and Preiss (1995) the entire SA geology.

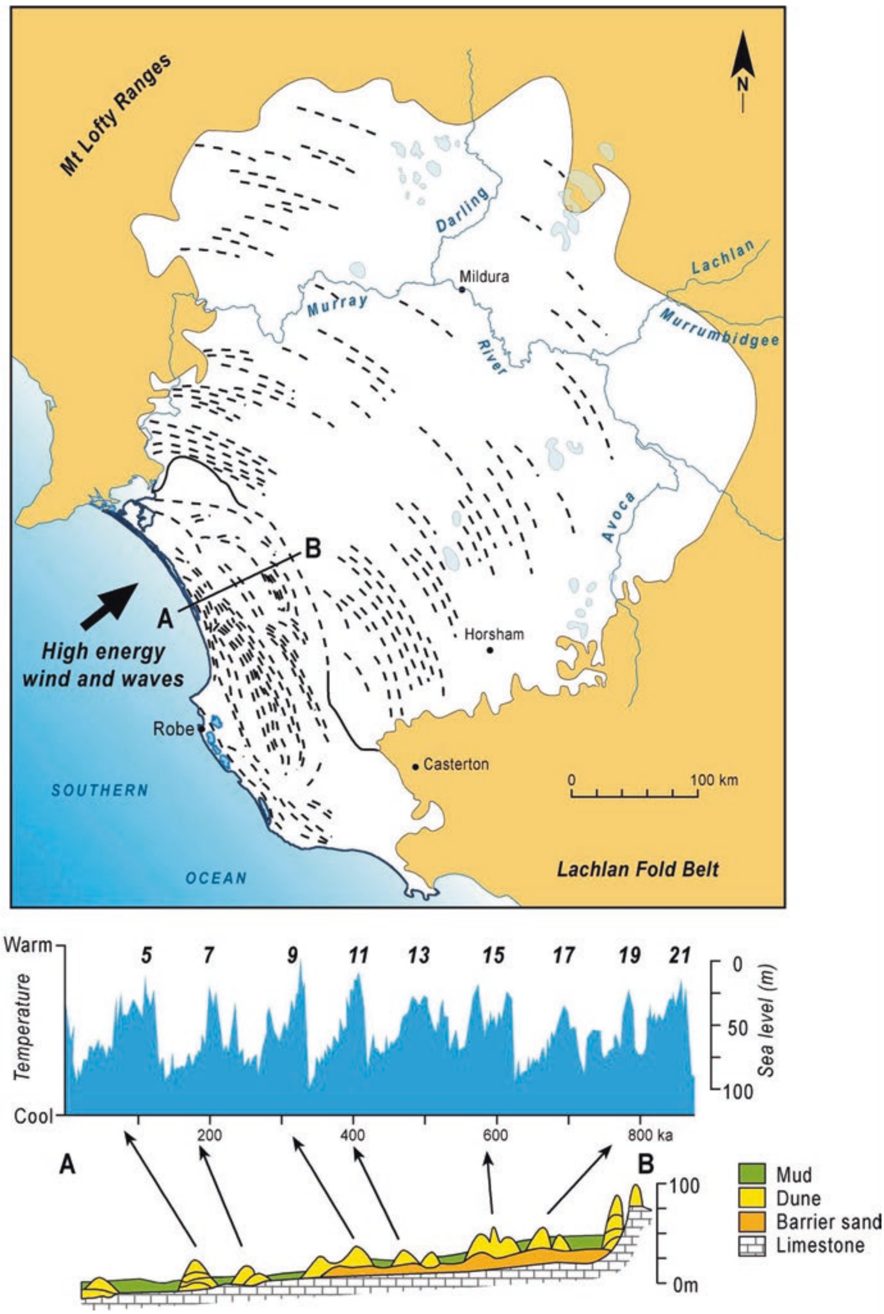

Fig. 26.1 The Murravian Gulf contains a 400 km wide series of regressive Pliocene-Pleistocene barrier systems that extend to the present coast and offshore. The carbonate-rich barriers have been slowly uplifted and lithified assisting their preservation. The A–B cross-section shows the outer barriers in profile and correlates them with Quaternary warm periods (sea-level highstands). (Source: Short and Woodroffe 2009)

26.3 Climate

The south coast has a Mediterranean climate with a rainfall decreasing from a maximum of 700 mm in the south and on Kangaroo Island to 500 mm at Goolwa and with an increasing winter maximum to the north. Mean monthly temperature ranges from 15–18 °C in winter to 20–25 °C in summer. Summers are typically warm to hot and dry, while winters are cool to mild and wet. Winds are predominately westerly, shifting to the northwest in winter and southwest in summer. Summer sea breeze arrives from the southeast.

26.4 Rivers and Creeks

The southern mainland coast is a sedimentary coast dominated by carbonate-rich sediments, calcarenite and in the south limestone. It has no external drainage other than the constructed draining ditches. The only mainland river is the mouth of the Murray-Darling, Australia's largest river, which drains over 1 M km^2 of southeastern Australia. However, the generally semi-arid catchment combined with dams and water extraction has decreased its discharge to the extent that the narrow river mouth occasionally closes and requires dredging to remain open. The river is presently depositing its bedload in the lower lakes Alexandria and Albert, with no sand reaching the coast. It has however delivered terrigenous sediment to the shelf at lower sea levels. The only other drainage is a series of small creeks draining the south coast of the Fleurieu Peninsula, and on Kangaroo Island there are a handful of small rivers (Wilson, Eleanor, Harriet, Sun'sail Boom) reaching the coast, all of which may be delivering small quantities of bedload.

26.5 Sediment

Beach sediments along the southern coast are predominately well- to moderately well-sorted, fine to medium carbonate-rich sand (Table 26.2 and Fig. 26.2). The predominance of carbonate is indicative of its shelf origin (Fig. 16.8), with the remainder predominately quartz derived from the shelf via the Murray River and in the west delivered by the small streams draining the Fleurieu Peninsula and Kangaroo Island. As discussed in Sects. 16.5.4 and 25.11, the carbonate sands originate on the shelf as calcareous marine invertebrates: molluscs, bryozoans, coralline algae, echinoids and foraminifers (James et al. 1997; Fig. 16.9). These are eroded and broken down by the wave action as they are transported shoreward (Boreen and James 1993), arriving at the coast as fine though coarse, white through brown sand particles (Fig. 16.10). James et al. (2018) found that the carbonate sediments forming the outer Murray Basin barrier systems, dating back to ~900 ka, are derived

Table 26.2 Southern South Australian region beach sand characteristics

	Southern SA	Kangaroo Is
n	111	28
Size (mm)	0.25	0.26
σ (mm)	0.14	0.09
Carbonate %	69	71
σ (%)	27	20
Sorting	0.53	0.46
σ (sorting)	0.21	0.17

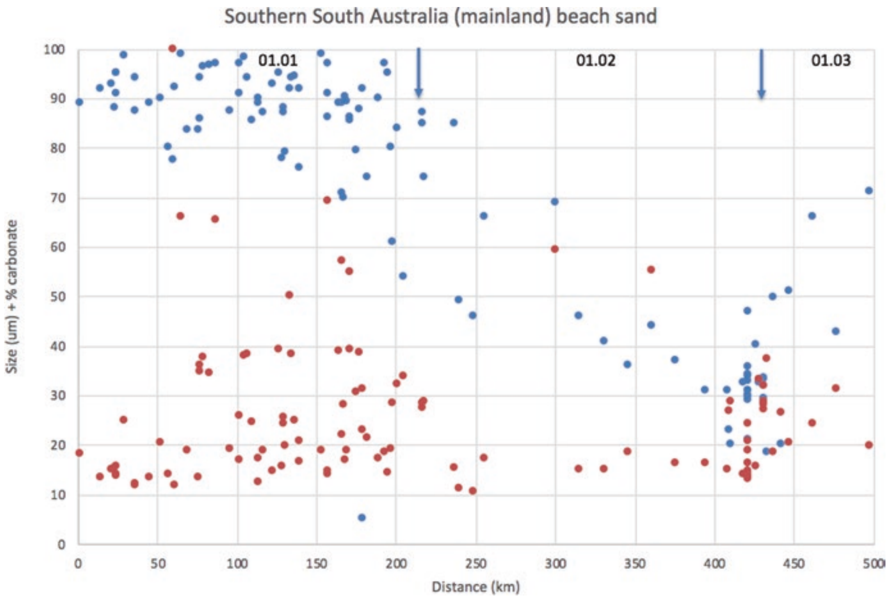

Fig. 26.2 Southern SA mainland (VIC-SA border to Cape Jervis) beach sand characteristics. Red = size (μm), blue = % carbonate. Arrows mark PC boundaries (PC:SA01.01-0-3)

from a suite of cool-water, heterozoan carbonate sediments produced on the adjacent offshore shelf. They found the beach-dune sediments are derived mainly from the shallow adjacent seafloor to 30 m depth. The sediment is mollusc-rich but with most bryozoan particles having been destroyed in the surf zone. Joury et al. (2018) examined in detail the composition of beach-dune sediments at seven locations along this coast (Canunda, Southend, Beachport, Little Dip, Robe, The Granites and 42 Mile Crossing) (PC:SA01.01-2) and found they are composed of siliciclastic particles (mainly quartz), relict allochems, Cenozoic and limestone pieces, but dominated by Holocene invertebrate and calcareous algal biofragments. The most numerous grains in order are molluscs (17–50%), benthic foraminifera (~33%), coralline algae (~26%), echinoids (~17%) and bryozoans (~18%). They concluded that coastal beach-dune sediment and carbonate aeolianite deposits formed in cool-water open-platform settings are primarily derived from adjacent intertidal and nearshore (<10 m depth) and not further offshore. This shallow environment contains carbonate factories including macroalgal forests, rocky reefs, seagrass meadows and low-relief seafloor rockgrounds, that produce infauna that can inhabit this high energy environment. Most of the material supplied to the coast was eroded, reworked and transported during and immediately following the PMT (10-5 ka) and included reworked drowned coastal barrier systems as well as shelf supply (Boreen et al. 1993; Oliver et al. in press). The extensive carbonate-rich dunes are then slowly lithified into dune calcarenite, which occurs along much of the southern and Western Australian coast (Brooke 2001; Short 2013).

26.6 Waves

Coastal processes are dominated by the Southern Ocean swell, micro-tides and shelf waves. The coast is exposed to a persistent high-energy southwesterly swell generated by the midlatitude cyclones that pass continuously south of the continent (Fig. 16.3). This swell is supplemented by west through south storms and southeast sea breeze seas. Short and Hesp (1984) summarise observational wave data from Cape Northumberland, located 150 km southeast of Cape Jaffa. These data reported a persistent southwest swell averaging 2–4 m and arriving 62% of the year. High waves (>4 m) arrived 6%, and low to moderate waves (<2 m) 31%. Calms were only observed on 1% of the days, with waves exceeding 2 m expected to arrive 68% of the year. This agrees with the Swan modelling along the adjacent western Victorian coast by Flocard et al. (2016). Superimposed on the swell are the locally generated seas. During summer the southerly sea breezes generate waves <1 m 68% and 1–2.5 m 20%, while during winter storms can generate seas >2.5 m 12% of the time. Short and Hesp summarised the wave climate as being ‘persistent year-round moderate to high southwest swell, peaking during April to September, while periods of low swell are infrequent and calms rare’.

The establishment of the Cape du Couedic waverider buoy off the southwestern tip of Kangaroo Island by the Bureau of Meteorology in November 2000 provides a continuous more accurate record of deepwater wave conditions for the South East region. Table 26.3 summarises the main parameters from the Cape du Couedic

Table 26.3 Cape du Couedic wave parameters (2000–2007) (derived from data provided by Bureau of Meteorology)

Parameter	Mean	σ
H_s	2.5 m	0.9 m
H_{max}	4.1 m	1.4 m
T_s	10.5 s	1.8 s
T_p	12.4 s	1.8 s

waves, while Fig. 16.4 presents a monthly summary. These results provide more detail to the observational data and show that waves average 2.5 m with an average H_{max} of 4.1 m and period of 12.4 sec, all representative of a persistent year-round high swell, with a peak in wave height between July and October.

26.7 Tides, Surges and Sea Level

Tides are micro throughout the entire region, with mean spring tide ranging from 1.1 m at Port MacDonnell to 1.3 m at Cape Jervis. In addition, two types of shelf waves make a significant contribution to sea level along the southern Australian coast (Provis and Radok 1979). Progressive waves are driven by Southern Ocean pressure systems and travel year-round from west to east across the southern coast with periods between 5 and 20 days with amplitudes typically ~0.5 m but can reach 1.5 m, exceeding the tide range. A second seasonal wave stands against the southern Australian coast with periods of months which can raise or lower sea level by as much as 0.5 m. The combination of the two waves and the low tide range complicates the actual tide range and sea level along the coast and can result in sea level being abnormally high or low, at times for days at a time.

Storm surges occur along the SA coast in association with intense low-pressure systems. On the open coast, they seldom exceed 1 m; however, surges of 1.4 m and 2 m have been recorded in the gulfs at Adelaide and Port Pirie, respectively (CPB 1992), and are predicted to range between 1.5 and 2 m for the southern coast (Fig. 1.14). The surges are most damaging if they coincide with high tide and the crest of a shelf wave.

Sea level along the northern Coorong area was first assessed by Belperio et al. (1983) who found the PMT reached its peak between 6.6 and 6.4 ka at an elevation +1 m in Lake Alexandria and the Coorong. Belperio et al. (2002) in a review of South Australian sea levels found the data indicate a very rapid sea-level rise in the early Holocene, at about 16 mm year^{-1}, reaching present levels at 6.4 ka. This was followed by regionally variable regression and emergence of the land of between 1–3 m, the emergence consistent with a hydro-isostatic origin as predicted by geophysical models. The last interglacial sea level was considerably higher along the southern coast owing to the neotectonic uplift, reaching elevations ranging from 8 to10 m above present sea level (Murray-Wallace and Belperio 1991).

26.8 Beaches

The southern region contains 287 beaches which occupy 517 km (68%) of the coast. They range from R to D, with the sheltered R dominating by number (140), but with a mean length of 0.5 km occupying only 13.5% of the beaches by length (Table 26.4). In contrast the three D beaches occupy 44%, followed by TBR (21%), RBB 14%

Table 26.4 PC:SA01 beach types and states

BS	BS	No.	%	Total length (km)	% (km)	Mean length (km)
1	D	3	1.0	226.5	43.8	75.5
3	RBB	31	10.8	70.3	13.6	2.3
4	TBR	66	23.0	109.0	21.1	1.6
5	LTT	47	16.4	41.4	8.0	0.9
6	R	140	48.8	70.0	13.5	0.5
		287	100	517.2	100	1.8

Table 26.5 PC:SA01 Southern SA barrier dimensions

SA01	SA01.01	SA01.02	SA01.03	SA01.04	SA01
No.	15	2	2	7	26
Total length (km)	181.1	211	4.3	83	479.4
Mean min width	380	2400	75	1950	–
Mean max width	1560	6800	1750	6850	–
Mean height (m)	9	13	30	20	–
Area (ha)	21,106	39,000	350	48,800	109,256
Unstable (ha)	12,714	11,800	110	1900	26,524
Total volume (M m^3)	4426	6850	105	9760	21,141
Unit volume (m^3 m^{-1})	24,442	32,464	24,418	117,590	44,100

and LTT 8%. The range of beach types and their length is a reflection of the influence of the calcarenite along the coast which generates considerable wave refraction and attenuation, as well as forming numerous small embayed headland and reef-bound beaches, particularly along the Robe Range and Kangaroo Island coasts. The long D beaches are all associated with the Coorong coast. Short (2001) provides a description of all the southern coast and Kangaroo Island beach systems.

26.9 Barriers

This is a high-energy sediment-rich coast with 26 Holocene barriers occupying 480 km (63%) of the coast (Table 26.5). They tend to be large (total volume = 21,141 M m^3) which represents a high per metre volume of 44,100 m^3 m^{-1}. Their large area (1092 km^2) and total and per metre volume are all a product of the exposure of the coast to the carbonate shelf factory, lowstand shelf deposits of bedload by the Murray River, the high waves to deliver the sand to the shore, and periodic strong westerly winds to transport it into the often massive transgressive dune systems that can extend several kilometres inland (Short 1988b). There are also two substantial regressive barriers in Rivoli and Guichen Bays. See Short and Hesp (1984) for a more detailed description of the coast, its beaches and barrier systems; for the range of barriers, see Short (1988a); and for a detailed overview of the entire Pleistocene and Holocene barrier systems, see Murray-Wallace (2018).

26.10 Sand Transport

The carbonate-rich beach and dune sand have been sourced from the nearshore-inner shelf and transported predominately onshore by the persistent moderate to high southwest swell along the length of the coast to build the beaches and massive barrier systems. Because of the south to southwest orientation of much of the coast, it faces directly into the southwest waves resulting in a dominance of swash-aligned beaches with little potential for longshore sand transport. Longshore sand transport does however occur, particularly along the low energy Lacepede Bay and into Rivoli and Guichen Bays, with reversals in transport also recorded around the Murray Mouth coast. These will be discussed below in the relevant SCs.

The southern SA region contains four PCs and eight SCs which are listed below (Table 26.6 and Fig. 26.3) and discussed in the following sections.

Table 26.6 Southern SA region: SA01 PCs and SCs

Southeast SA[a]		Boundaries	SA beach no.[b]	No. beaches	km[c,d]	Total km
SA01.01.01	Limestone coast	Danger Pt-C Banks	SA 3-43	41	14-65	51
SA01.01.02	Robe Range	C Banks-C Jaffa	SA 44-147	104	65-216	151
SA01.01				*145*	*14-216*	*202*
SA01.02	The Coorong	C Jaffa-Middleton Rocks	SA 148-149	2	216-428	212
SA01.03.01	Fleurieu Pen (SE)	Middleton Rocks-Newland Hd	SA150-169	20	428-458	30
SA01.03.02	Fleurieu Pen (S) Dudley Peninsula	Newland Hd-C Jervis Kangaroo Hd-C Willoughby	SA 170-186 KI 45-57	17 13	458-502 KI 76-113	44 37
SA01.01-3	*SE of SA*	*Danger Pt-C Jervis NE Kangaroo Is*	*SA 3-186 KI 45-57*	*50*		*111*
SA01.04.01	Kangaroo Is (SW)	C Willoughby-C Gantheaume	KI 58-83	26	KI 113-200	87
SA01.04.02	Kangaroo Is (S)	C Gantheaume-C du Couedic	KI 84-135	52	KI 200-293	93
SA01.04.03	Kangaroo Is (W)	C du Couedic-C Borda	KI-136-145	10	KI 293-345	52
SA 01.04	S & W *Kangaroo Is*	*C Willoughby-C Borda*	*KI 58-145*	*88*	*KI 113-345*	
SA01		**Regional total**		**285**		**757**

[a]NCCARF compartment number
[b]ABSAMP beach ID
[c]Clockwise distance from state border
[d]KI: Clockwise distance from Marsden Point

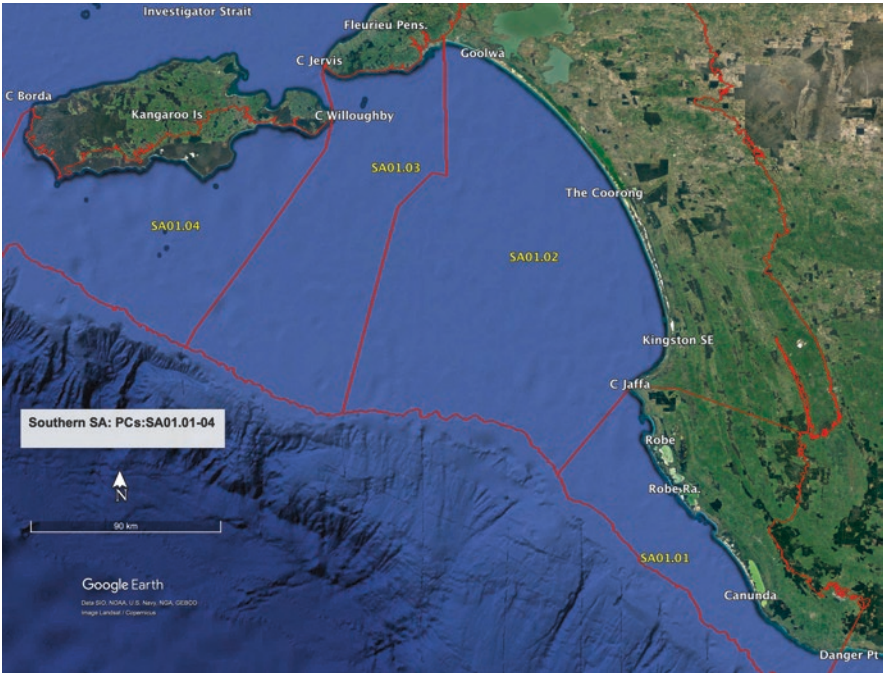

Fig. 26.3 The southern South Australian region (SA01) and its four PCs:SA01.01-01.04. (Source: Google Earth)

26.11 PC:SA01.01 The Limestone Coast: Point Danger–Cape Jaffa

The southernmost south coast PC extends for 202 km from Point Danger (located 14 km inside the SA border) to the low but prominent Cape Jaffa (Figs. 26.3 and 26.4a) which also marks the western boundary of the Otway Basin. This PC is commonly known as the Limestone Coast owing the dominance of both Gambier limestone in the south and lime or carbonate-rich dune calcarenite along much of the coast, particularly the Robe Range (Short and Hesp 1984). This is a sparsely populated section of the coast, which includes Canunda National Park (45 km of coast) and several conservation areas. The only towns are at Port Macdonnell (1100), Southend (550), Beachport (900) and Robe (1300) together with small communities at Nene Valley (200), Blackfellows Caves (80), Pelican Point (80), Bungaloo Bay, Carpenter Rocks (180) and Nora Creina (40). The coast is divided into two SCs.

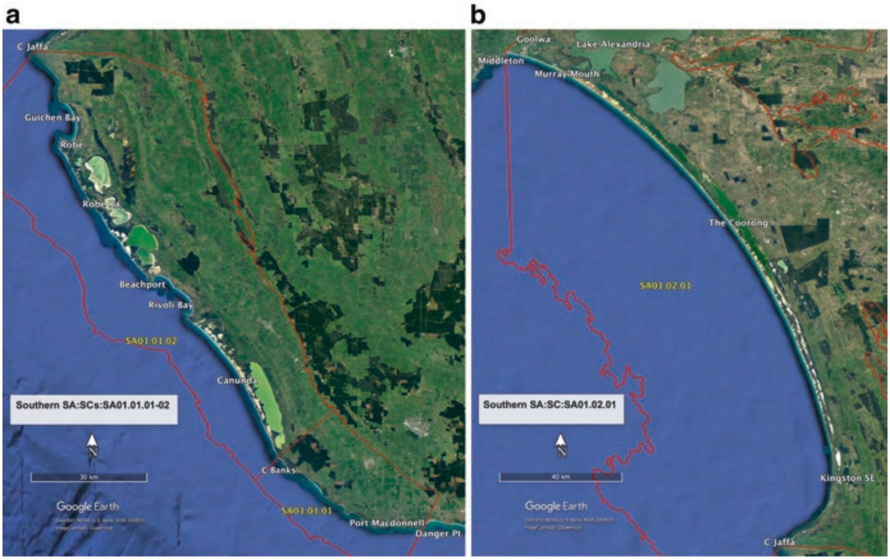

Fig. 26.4 (**a**) SCs SA01.01.01-02 the Limestone coast and (**b**) SA01.02.01 the Coorong. (Source: Google Earth)

26.11.1 SC:SA01.01.01 Point Danger–Cape Banks

SC:SA01.02.01 commences at the low limestone cobble foreland at Point Danger and curves to the west then northwest for 51 km to the low sandy Cape Banks (Fig. 26.4a). This SC is dominated by the Oligo-Miocene Gambier Limestone and Pleistocene dune calcarenite which outcrops along much of the coast (Fig. 26.5b), terminating in the west at Cape Banks. The Bonney shelf is relatively narrow, widening from 20 km in the south to 40 km off Cape Jaffa resulting in little deepwater wave attenuation. However, close to the coast the limestone forms generally low cliffs and bluffs (<10 m high), fronted by rock platforms and flats, as well as inshore reefs and 53 small islands which extend 1–2 km offshore and all of which substantially refract and attenuate the waves as they move inshore. The result is an often substantial reduction in wave energy, considerable wave refraction and a supply of limestone cobbles to a number of beaches in the east of the SC where they form 20 km of continuous cobble beach ridges, composed of rounded dolomite or flint, often with a sandy LTT. The 41 beaches along this SC reflect the lower breaker wave energy with 31 R, eight LTT and just two TBR, one at Cape Banks (Table 26.7). The beaches are near continuous in places, separated by low cuspate forelands and occupy 82% of coast as far as Port MacDonnell (Fig. 26.5a). The sandy beaches are composed of predominately well-sorted, fine to medium carbonate-rich (80–99%) sand (Fig. 26.2). Because of the generally low breaker wave energy and prevalence

Table 26.7 PC:SA01.01 beach types and states

BS	BS	No.	%	Total length (km)	%	Mean length (km)	σ (km)
3	RBB	11	7.5	46	23.8	4.2	4.7
4	TBR	35	23.8	71.3	36.9	2	3.2
5	LTT	23	15.6	26.7	13.8	1.2	1.3
6	R	78	53.1	49.1	25.4	0.6	1.6
		147	100	193.1	100	1.3	–

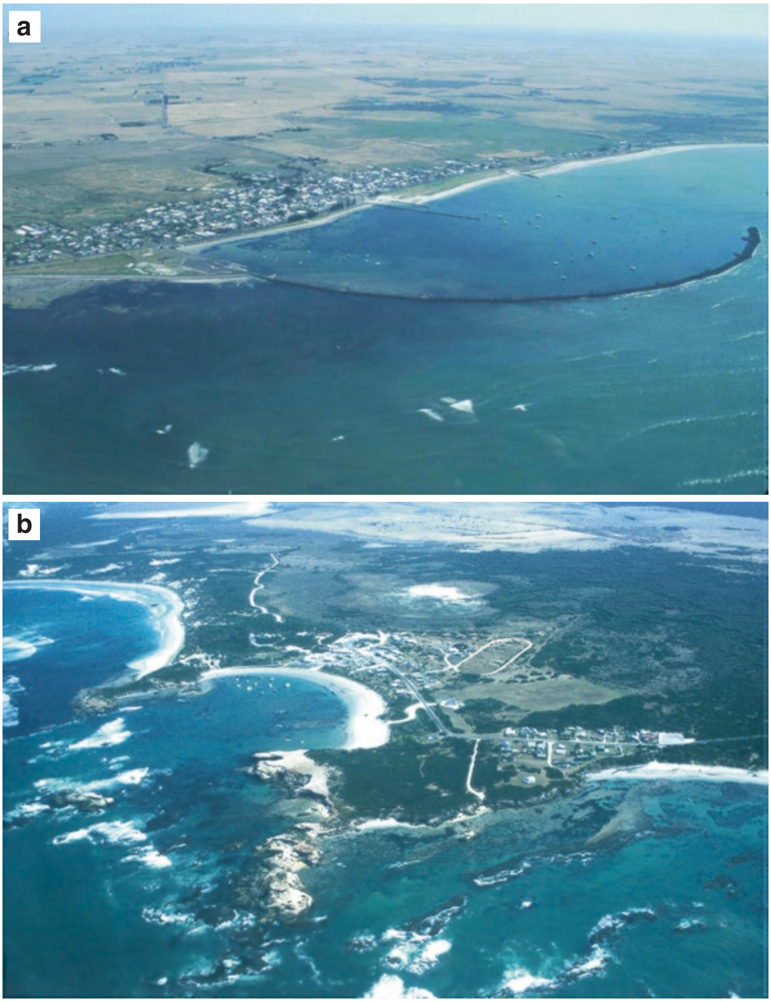

Fig. 26.5 (**a**) Port MacDonnell and its attached breakwater (SA 8-10) with shallow reefs offshore and (**b**) Carpenter Rocks and sections of the partly submerged Robe Range (SA 39-41). (Photos: AD Short)

of cobble beaches east of Port MacDonnell, the main barriers along this SC are located to the west predominately between Cape Northumberland and Cape Banks, where they are a mix of minor to moderate dune transgression and regressive beach and foredune ridges, including some cobble ridges. The barriers have relatively low volume and per metre volume of 163 M m^3 and 6150 m^3 m^{-1}, respectively, all reflecting the lower breaker wave energy. While the cobble coast between Picanninnie Ponds, near the border and Port Macdonnell is low in energy, many of the cobble ridges are scarped and receding, which may be a result of sea level rise.

26.11.2 SC:SA01.01.02 Cape Banks–Cape Jaffa

SC:SA01.01.02 continues northwest from Cape Banks for 151 km to Cape Jaffa, encompassing the long high energy Canunda beaches, the moderately sheltered Rivoli Bay, the exposed jagged calcarenite Robe Range and the northern sandy Guichen and Wright Bays, with all of the coast between Cape Banks and Cape Buffon contained in Canunda National Park and parts of the Robe Range in the Beachport, Little Dip and Guichen Bay conservation areas (Fig. 26.4a). The Robe Range essentially extends along this entire SC and between Beachport and Guichen Bay lies between 0.5-2km offshore paralleling the coast and substantially modifying and lowering the inshore wave climate. It is a Pleistocene barrier deposited between 116 and 95 ka (Murray-Wallace 2018). At the present highstand, it has been partly submerged and eroded to form numerous calcarenite rocks, reefs, islets and islands and supply sediment to the coast to form the beaches, barriers and dune systems, including clifftop dunes (Fig. 26.6d). The stratigraphy of the inner Beachport barrier (125 ka) is exposed in the Woakwine or McCourt's cutting and records both the beach and overlying transgressive dune units as well as the initial regressive phase (Murray-Wallace et al. 1999). The 45 long Canunda section is dominated by high energy beaches backed by massive active and stable dune transgression and is one of the higher energy sections of the SA coast. The range is titled and becomes increasingly submerged to the west where it has been breached to form Rivoli and Guichen Bays, both located in the interbarrier depression located behind the range, the barriers partly sheltered by its eroded remnants.

There are 104 generally short embayed beaches along this SC with a mean length of 1.3 km, which occupy 137 km (91%) of the coast (Table 26.7). They are composed of predominately well-sorted, fine to medium carbonate-rich (80–99%) sand (Fig. 26.2). Because of the sheltering afforded by the headland, rocks and reefs, the majority (48) are R together with 15 LTT. There are also 33 more exposed TBR and 9 high energy RBB, all located along the high-energy Canunda section (Fig. 26.6a). However, by length the majority of the beaches are longer TBR-RBB (100 km).

The SC contains essentially five barrier systems – the two large transgressive Canunda (44 km, 1900 M m^3, 43,180 m m^{-1}) and Robe Range (45 km, 1800 M m^3, 40,000 m^3 m^{-1}) and the three large regressive systems (Rivoli (Fig. 26.6b), Guichen

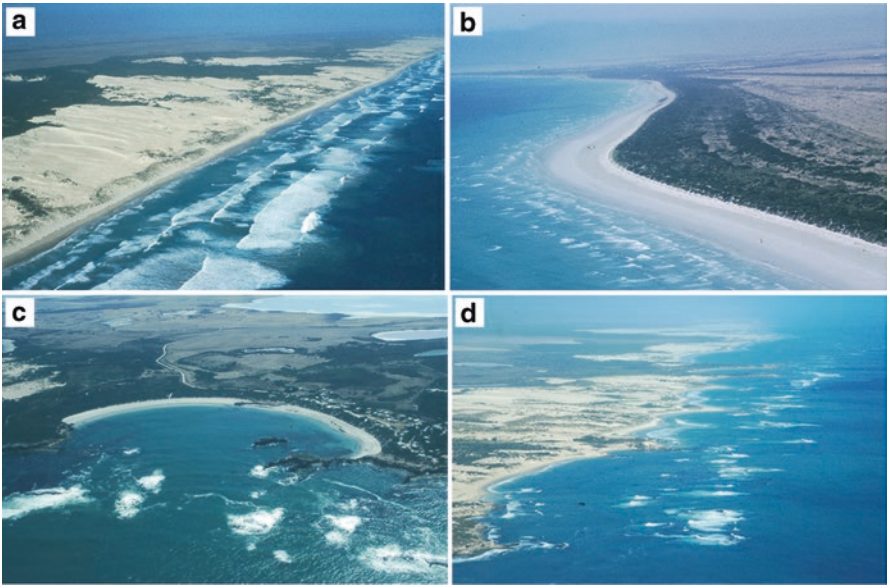

Fig. 26.6 (**a**) High energy Canunda beach and its massive transgressive dunes (SA 52); (**b**) the foredune and outer ridges of the Rivoli Bay barrier (SA 70); (**c**) Nora Creina Bay is located in a breach in the Robe Range (SA 94); and (**d**) view south along the partly submerged Robe Range (SA 99-100). (Photos: AD Short)

and Wrights Bays, with combined total of 535 M m^3, 13,375 m^3 m^{-1}), together with smaller regressive barriers such as Nora Creina (Fig. 26.6c). In total the SC has barriers totalling 4235 M m^3 (32,830 m^3 m^{-1}), an order of magnitude greater than its lower energy neighbouring SC to the east. This large volume of sand can be attributed to a number of factors, including: an abundant the shelf source inlcuding erosion of the partly submerged Woakwine and Robe ranges; the PMT combined with high wave energy to transport sediment to the coast; strong onshore winds to transport sand into the dunes; and in the case of the bays sediment sinks located in breaches in the Pleistocene calcarenite barriers providing wave and sand access to accommodation space in the interbarrier depression. Murray-Wallace (2018) reported that the interbarrier depression between Beachport and Robe was a fully marine seaway 6–10 km wide between 7 and 2 ka, following which sedimentation divided it into a series of salt lakes (George, St Clair, Eliza and Robe). Oliver et al. (in press) following more recent dating of the Rivoli Bay barrier found that infilling of Rivoil and Guichen bays restricted the marine corridor between the Woakwine and Robe ranges to a narrow channel by 4 ka in the north and 2 ka in the south. Ohmori et al. (1987) dated a transgressive dune sequence in the Canunda National Park that extends 4 km inland. They found that there have been four episodes of dune activity between 8.0-5.5 ka, 5.5-2.7 ka, 2.7-0.5 ka and during the past 0.5 ka. They also recorded shell beds dating 6-4 ka located 4-5 m above sea level.

In addition to the massive onshore supply of sand, there is evidence of limited longshore transport. At Port MacDonnell a 1.5 km long curving attached breakwater (Fig. 26.5a) was constructed in 1977 and has since trapped ~0.45 M m^3 of sand, half on the open western side of the breakwater and half along the inner port shoreline, particularly between and to the east of the two groynes. This represents an accumulation rate of ~10,000 m^3 year^{-1}. The sand has no doubt been derived from the east and west of the port as well as some probably swept into the port from the nearshore, with the port acting as a low energy sink. The port shoreline prograded up to 80 m between 1977 and 1983 (~13 m year^{-1}) (Short and Hesp 1984) and by 2018 has prograded to 120 m (~1 m year^{-1}), indicating the infilling has slowed considerably.

At Beachport dieback of seagrass has led to increased longshore transport and shoreline recession resulting in the construction of a series of nine small groynes and a small attached breakwater protecting the boat ramp (Detmar et al. 2005). All of these structures have trapped sand on their southern updrift side indicating sand is moving northwards into the bay. At the northern end of the groynes, ~0.5 M m^3 of sand has also been lost into the Lake George drain (Short and Hesp 1984). Just to the west of Beachport at Post Office Rocks, a sand tombolo connecting the rocks to the shore was eroded in 1975, allowing sand to leak eastwards along the coast leading to 30 m recession of the adjoining beach, with ongoing recession likely to breach a backing salt lake (Fotheringham 2009b). To combat this, a rock groyne has been built to replace the eroded tombolo.

Beachport forms the northern boundary of 11 km wide southwest-facing Rivoli Bay. The bay occupies an interbarrier depression in lee of a breach in the Robe Range, with the largely submerged remnants (reefs and rocks) of the range partly sheltering the bay shore. Sand has moved into the bay and developed a curving 16 km long, up to 3 km wide series of ~60 foredune ridges, with a total volume of 280 M m^3 (16,470 m^3 m^{-1}). Oliver et al (in press) dated the Holocene evolution of the ridges and found there was rapid progradation in the south and the north up to ~5 ka, with raised beach strata suggesting sea level was 1.7–2.3 m higher ~3.5 ka. This was followed by a steady fall to present sea level by 1 ka, which would have promoted further shoreline progradation. In addition, the regional uplift (0.07 mm yr^{-1} Murray-Wallace et al. (2010)) would amount to 0.8 m over the Holocene and 0.25 m since 3.5 ka. This would reduce the sea level highstand in Rivoli Bay to between 1.45 and 2.05 m. The large volume of sediment delivered to both Rivoli and Guichen bays by 5 ka implies the sand was sourced from erosion of the partly submerged Robe and Woakwine Ranges as well as the inner Bonney shelf. Oliver et al. calculated that sediment was delivered to the bay at rates between 1 and 2.8 m^3 m^{-1} year, which is in agreement with the estimated regional rate of 4.1 m^3 m^{-1} year (Appendix 34.2). However, they also found that sediment supply through the late Holocene has decreased and the shoreline in the north and south of the bay are presently eroding. A 400-ha area of the normally stable well vegetated ridges in the southern portion of the bay were destabilised by stock overgrazing in the 1920s and were very active until the 1970s extending up to 1.5 km inland (Short and Hesp 1984). This area is now vegetated and stable. At Robe, an attached breakwater protecting the harbour entrance and one groyne have both trapped sand on their western side indicating that sand is continuing to move into Guichen Bay. Robe's Cape Dombey is a calcarenite headland that has been eroding since it was first surveyed in 1896. Fotheringham (2009a) reviewed the erosion and found it is eroding at rates ranging from 2 mm yr^{-1} in sheltered locations to 30 mm yr^{-1} in exposed locations, with a modal retreat rate of between 5 and 10 mm yr^{-1}, in agreement with Short and Hesp (1980) estimate of 4 mm yr^{-1}.

Guichen Bay is located immediately to the north of Robe and the 8.5 km wide bay faces due west into the waves and winds. However, like Rivoli Bay it occupies the interbarrier depression, and emerged and submerged remnants (reefs and islets) of the Robe Range partly shelter the bay shore leading to the development of a 5 km wide series of 90 foredune ridges. The barrier has a volume (above 0 m) of 193.4 M m^3 (Bristow and Pucillo 2006) essentially identical to the ABSAMP estimnate of 190 M m^3. The ridges are spaced ~50 m apart and rise >2 m above the swales. The regressive barrier was first described by Sprigg (1952) and investigated by Thom et al. (1981) who drilled and dated the 3–5 km wide foredune ridge plain using radiocarbon dating and found the ridges were deposited between 8 ka to present. Murray-Wallace et al. (2002) then used OSL to date the ridges and found that they rapidly prograded ~1.6 km by 5 ka, followed by a constant rate of progradation for the past 4 ka of 0.39 m $year^{-1}$. This represents an average rate of ridge development of one every 80 year from 3.9 ka to the present. The ridges were further investigated using GPR by Bristow and Pucillo (2006). They found multiple truncation surfaces interpreted as storm events; while the shoreface steepened from ~2.9º to ~7.5º, which they attribute to increasing wave energy as the beach prograded into deeper water. They estimated that sediment moved in to the bay at rates between 40,000 and 50,000 m^3 $year^{-1}$, and has remained remarkably consistent though the mid- to late Holocene. They further suggest that while the sediment supply has been constant, a decrease in the rate of progradation is due to increasing accommodation space as the beach progrades into deeper water. They also suggest that changes in foredune morphology and orientation reflect changes in wave and wind climate, with wave approach shifting from north of west to slightly south of west in the mid- to late Holocene. This SC has property at risk at Pelican Point (SA 35); Southend (SA 69) where part of the caravan park has been eroded and series of groynes built; while Port Office Rocks (mentioned above) continue to erode; and the Robe town beaches (SA 138-140) appear to be receding and may need nourishment.

26.11.3 PC Overview

This PC is an exposed high energy relatively long and straight coast with variable inshore wave energy owing to the presence of limestone reefs and the partly submerged Robe Range, with breaker wave energy ranging from low to fully exposed. The higher energy sections have received large volumes of sand which have moved into the transgressive dune systems, particularly along the Canunda section, and to a lesser extent into the three large regressive bay systems (Rivoli, Guichen and Wrights). Much of this sand was reworked from the shelf and the partly submerged and heavily eroded Woakwine and Robe ranges. While there is evidence of continuing limited longshore and onshore transport into sheltered locations (Port Macdonnell, Beachport and Robe), volumes are expected to be small, and overall the shoreline appears to be stable on the open calcarenite coast and stable to perhaps slightly progradational in at least Guichen Bay. What is unknown is the rate of supply of new carbonate material from the shelf and nearshore. At the same time sand is being lost to the extensive transgressive dunes which are presently 60% unstable (Fig. 26.6a). However, while the dunes have been active since the PMT, some of the recent activity is a legacy of European settlement, grazing practices and rabbits. This activity is however being countered since the 1980s by the colonisation of much of the foredunes by the introduced sea wheat grass and removal of rabbits leading to rapid stabilisation of large areas of the dunes (Moulton et al. 2018). Consequently, the contemporary sediment budget, both positive and negative, remains to be resolved. Rising sea level will allow higher waves and potentially increased transport into the bays which could balance any rise-induced shoreline recession.

26.12 PC:01.02/SC01.02.01 The Coorong (Younghusband and Sir Richard peninsulas)

The Coorong is Australia's longest continuous beach-barrier system extending for 194 km from Cape Jaffa to Murray Mouth and then another 18 km to Middleton Rocks; in all this PC-SC is a 212 km long system containing just two long beaches (Figs. 26.3 and 26.4b). Most of the Coorong barrier is located in the Coorong National Park, with the only towns in the south at Kingston SE (1500) and north at Goolwa (2200). The Holocene barrier is part of a regressive barrier sequence that extends for up to 400 km inland and dates back to the Pliocene. This system has been described by Sprigg (1952) and investigated and dated by Cook et al. (1977), Indrum and Cook (1980), Huntley et al. (1993), Huntley and Prescott (2001) and Murray-Wallace et al. (2001), with Murray-Wallace (2018) providing a comprehensive overview. Its preservation has been assisted by gradual uplift (0.07 mm $year^{-1}$) (Belperio and Cann 1990) and the carbonate-rich sediments that have lithified the barrier 'ranges'. Murray-Wallace et al. (2001) dated the outer twelve barriers which extend 180 km inland to Naracoorte (now at an elevation of 60 m), between >860 ka though to the Holocene, each barrier corresponding to a sea-level highstand. Murray-Wallace (2018) conclude that all past high stands have been within ±6 m of present sea level and that the plain contains the world's longest record of land interglacial and interstadial sea-level history records from Pliocene to present. Beside the overall uplift, northward tilting from Cape Jaffa and along the Coorong coast has led to the submergence of the northern Robe Range and subsidence at Murray

Mouth, resulting in overlapping of the Pleistocene barrier in this region (Murray-Wallace 2018). The 18 km long Sir Richard Peninsula extends west from the mouth to Middleton, while the ~170 km long Younghusband Peninsula (here called the Coorong) extends to the southeast and ranges in width from 0.73–3 km. It is backed by the highly saline Coorong Lagoon and a series of salt lakes for most of its length. Offshore the Lacepede shelf widens from 40 km at Cape Jaffa to 180 km off the Murray Mouth, while the northward titling gradually deepens the inshore leading to an increase in breaker wave height from zero in Lacepede Bay to >2 m at Murray Mouth (Short and Hesp 1982).

The Coorong beach (Cape Jaffa-Murray Mouth, SA 148) commences in the south at Cape Jaffa-Lacepede Bay where it faces northwest-west curving round by Kingston SE to face southwest for most of its length into the prevailing waves and winds (Fig. 26.4b). The beach sand is predominately fine sand throughout the system; however, the proportion of carbonate decreases from a high of 91% at Cape Jaffa to 20% at Murray Mouth and then rises to 40% at Middleton (Fig. 26.2). This dilution of the carbonate is related to proximity to Murray Mouth and the quartz-enriched beach and shelf sediments seaward of the mouth. Wave height average 2–3 m along the northern 100 km of the beach and then over a distance of 70 km gradually decreases southwards as the nearshore gradient decreases reaching zero deepwater waves by Kingston SE and in Lacepede Bay, which receive only local wind waves. Lacepede Bay contains about 20 shore transverse and attached sand waves extending up to 3 km offshore and aligned east-west and spread along the 20 km of bay shoreline (Fig. 26.7a), with the rhythmic shoreline within the bay reflecting their points of attachment. While they are covered in dense seagrass, the sand waves appear to represent northward migration and transport of sand into the bay to feed the spits and beach ridges. Sand is presently moving along the shore as indicated by the trapping of ~120,000 m^3 of sand on the eastern side of the Cape Jaffa marina's attached breakwater and subsequent infilling of the marina entrance. The marina was built in 2008 with the build-up suggesting that on the order of 10,000 m^3 $year^{-1}$ is moving northwards along the shore. The bay has a low energy R beach state and a sand wave-rhythmic shoreline with seagrass growing to the shore for 20 km up to Kingston SE. Beyond Kingston the inshore gradient beings to steepen allowing wave height to slowly increase causing the beach to transform to a very low gradient (fine sand) LTT, then TBR-RBB inner bar with stationary then mobile shoreline rhythms generated by points of inner bar attachment for the next 70 km. Finally, as the inshore continues to steepen, it becomes increasingly exposed to waves averaging 2.5 m. These combine with the fine sand to maintain a shore parallel D double bar with a 500 m wide surf zone that extends for the final 100 km to Murray Mouth (Short and Hesp 1984), the D beach continuing on the western side for another 18 km to the PC boundary at Middleton Rocks.

The Coorong barrier systems also reflects a transition in wave energy. In the southern sheltered Lacepede Bay is a regressive barrier system that has been supplied with sand moving northwards via Cape Jaffa into the bay and depositing an up to 3 km wide series of low crenulate north-trending spits and beach ridges. North from Kingston SE these transform into increasingly higher regressive foredune

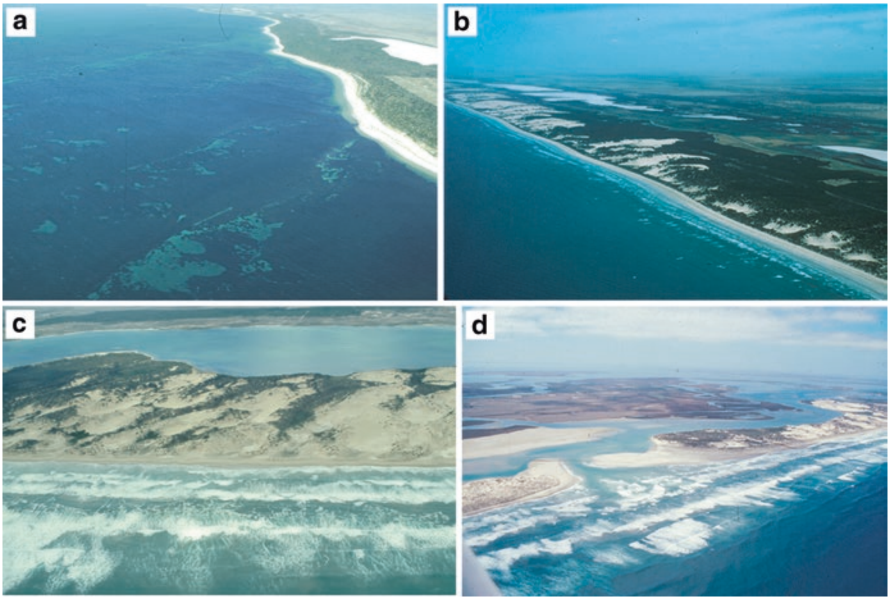

Fig. 26.7 (**a**) Shore-attached sand waves largely covered in seagrass in Lacepede Bay (SA 148); (**b**) beginning of dune transgression north of The Granites and the southern end of the Coorong Lagoon (263 km, SA 148); (**c**) dune transgression and part of Coorong beach with the lagoon behind (380 km, SA148); and (**d**) the narrow, dynamic Murray Mouth and the dissipative double bar system that extends continuously for 100 km to the south (SA 148-149). (Photos: AD Short)

ridges, which north from The Granites become increasingly reworked and transgressed by both stable and active dune systems (Fig. 26.7b, c). The barrier can be divided into three sections, the regressive Lacepede Bay, the regressive to transgressive main Coorong system and the Murray Mouth-Middleton section. They have total volumes and per metre volumes of 180 M m^3 (8180 m^3 m^{-1}), 6400 M m^3 (37,210 m^3 m^{-1}) and 150 M m^3 (8823 m^3 m^{-1}), respectively. If we assume all the Lacepede Bay sand has moved longshore into the bay over the past 7 ka, this would represent a rate of ~25,000 m^3 year^{-1}, which is comparable to the estimated present rate of transport of 10,000 m^3 year^{-1}. While the Lacepede Bay barrier is well vegetated and stable, the Coorong barrier is presently 35% unstable and the northern Sir Richard Peninsula 20% unstable, indicating sand is still being lost into the dune systems. However, as mentioned above Moulton et al. (2018) have found that since the eradication of rabbits from the peninsulas and colonisation of the foredune by the introduced sea wheat grass, there has been an increase in vegetation cover from 7% to 40% along a selected 5 km long survey area.

The evolution of northern regressive then transgressive Sir Younghusband Peninsula section was investigated by Short and Hesp (1984) who obtained a date of 6.6 ka from the base of an outer ridge, suggesting there was rapid shoreline regression during and following the PMT and stillstand ~7 ka. They also obtain a date of an outer buried soil of 1 ka, suggesting the massive and ongoing dune transgression is fairly recent and presented a five-stage model of barrier evolution. Harvey (2006) and Harvey et al. (2006) reviewed the evolution of the northern Coorong, and while agreeing in principle with the two-dimensional Short and Hesp (1984) model, they proposed a three-dimensional addition showing how the 100 km + long barrier commenced as a series of barrier islands and inlets, which were then closed to form the long continuous barrier and backing long narrow Coorong lagoon. Bourman et al. (2000) noted the barrier is continuing to retreat as indicated by ongoing dune transgression and exposures of lagoonal peat and aboriginal middens along the ocean beach, while offshore Short and Hesp (1984) found clays and coarse shell lag exposed on the seafloor seaward of 20 m depth, indicating that the inner shelf sands were exhausted. The central-northern barrier section has therefore gone through an initial period of rapid regression, followed by the massive dune transgression, with the initially abundant shelf sand now depleted, and as sand is continuing to be lost to the dunes and Murray Mouth flood tide delta, shoreline recession is occurring. At 42 Mile Crossing on the Coorong beach (300 km) the recession has degraded 4WD vehicle access to the beach, while at Murray Mouth the inlet and adjoining beaches are highly dynamic.

Murray-Wallace et al. (2010) examined the Quaternary history of the lower Murray River-Murray Mouth and called it as a 'failed' delta, as at low sea-level river sediments are transported to the edge of the Lacepede Shelf, while during highstands, any sand is transported onto the barrier and into the dune systems, with the present river depositing its bedload in the Lake Alexandria settling basin. The Murray Mouth region has been subject to a number of recent studies including its geological evolution (Bourman et al. 2019b), Quaternary history (Ryan 2015), geomorphological evolution (Bourman et al. 2019c) and its recent history (Bourman et al. 2019a), which are discussed below.

In the past 100 years, the Goolwa-Murray Mouth region has had a series of anthropogenic impacts resulting from Murray River regulation and water extraction and construction of the Goolwa barrages between 1930 and 1940. These works have reduced river discharge by 76% and the tidal prism by 90% leading to increased salinity in the Coorong Lagoon and the initiation of closure of the Murray Mouth (Bourman and Barnett 1995; Bourman et al. 2000). The mouth has also been caught up, and largely ignored, in the management/mis-management and politics of the Murray-Darling basin, much to its detriment (Harvey 1988; Thom et al. in press). Possible solutions to the mouth closure and degradation of the Coorong lagoon include ongoing dredging, training walls and increasing river discharge (Wentworth Group 2017).

The modern Murray Mouth is highly dynamic (Fig. 26.7d) with highly variable longshore transport to both the east and west. Reissen and Chappell (1993) used hindcasting models to estimate transport along the Sir Richard Peninsula which ranged from net 260,000 $m^3 year^{-1}$ to the east between 1940 and 1990, with a 1 M m^3 $year^{-1}$ westerly reversal in 1941–1942, as well as other reversals. They also examined records back to 1839 and found there are considerable variation in transport rate and direction from year to year resulting in the mouth shifting both to the east and west and noted a reduction in the width of the mouth from 800 to 350 m post the barrage construction in 1914. However, in the longer term, Bourman and Murray-Wallace (1991) found that easterly transport has dominated and has resulted in a 6 km east migration of the river mouth including 1.4 km of migration in historic times. Bourman et al. (2000) concluded that swell waves may transport sand from Murray Mouth west along the beach to Goolwa, while storm waves transport it in the opposite direction. At best these results are inconclusive with sediment predicted to be transported east and west, with Bourman et al. (2000) concluding there is a net westerly transport towards Murray Mouth, based on the westerly migration of the mouth and the recurved nature of the western inlet shoreline. It appears that net transport along the Sir Richard and Sir Younghusband Peninsulas is negligible, with the possibility of slight switching in direction causing alternating erosion and accretion to manifest itself along Middleton beach, as a form of beach rotation. If climate change induces a slight change in swell wave direction and/or the intensity and frequency of westerly storms, these would impact the direction and rates of longshore transport, which would affect shoreline stability and the location and size of the Murray Mouth. The mouth also acts as a sediment sink with sand transported into the mouth and deposited in a 16 km^2 flood tide delta, which should hold several 10's M m^3 of sand. Furthermore, as the mouth migrates, it opens more accommodation space for marine sand.

Sea level along the northern Coorong area has been rising at between 0.5 and 0.6 mm $year^{-1}$, aided by down-warping related to neotectonics (Harvey and Belperio 1994). CPB (1992) predicts shoreline recession of between 50 and 100 m for a 1 m rise, while Bourman et al. (2000) attribute erosion along Middleton Beach to the rise. Webster (2009) modelled the impact of a 0.2 and 0.5 m sea-level rise on the Murray Mouth and concluded that such a rise would result in the 1 m level AHD, presently exceeding 11 hours a year, being exceeded 97 hours a year for a 0.2 m rise and 1228 hours a year for a 0.5 m rise. This would result in a substantially greater flow of tidal water into the Murray Mouth would result in the reactivation and expansion of the flood tide delta. A 0.5 m rise could be expected to result in 8 M m^3 of sand moving into the mouth, while a 1 m rise could result in up to 16 M m^3 of sand. As all such sand would be sourced from the adjacent beaches, net beach erosion would be expected. If extrapolated along the entire beach between Middleton and Kingston SE, this would be the equivalent to erosion of 84 m^3 m^{-1} (Short and Cowell 2009). The Murray Mouth is therefore likely to remain a dynamic inlet with expansion of the flood tide delta under a rising sea level acting as a sink for sediment from the adjacent beach systems. In addition, the increased tidal prism would assist in lowering salinity in the 110 km long hypersaline Coorong Lagoon.

Coastal erosion has been well documented at Middleton where between the 1860s and 1974, up to 45 m of shoreline recession was recorded, eroding the foredune and exposing a low bluffline cut into terrestrial alluvial sediments (Bourman 1978). This recession appears to have stabilised since the 1970s with dune building at the base of the bluffs. The initiation of the Middleton beach erosion cannot be attributed to the Murray Mouth infilling as the erosion predates the construction of the barrages, though no doubt sand lost between 1940 and 1970s could have entered the mouth. Given the amount of sand already deposited in the mouth since 1940 and the now narrow, shallow entrance (Bourman and Harvey 1983; Reissen and Chappell 1993), it is likely only small amounts of sand are now moving permanently into the entrance. Bourman et al. (2000) suggest the recession may be due to localised tectonic subsidence/sea-level rise. Another possible cause could be a slight rotation of the shoreline owing to a temporal (decadal) change in wave direction, as occurs regularly on beaches in eastern Australia (Harley et al. 2015). The switch in longshore transport direction also noted by Bourman et al. would also support rotation. More recently Fotheringham (pers. comm.) reported beach erosion and foredune scarping along much of the Sir Richard Peninsula. While the cause of this erosion remains unknown, it does appear that the northern Coorong at least is in a contemporary recessional phase.

26.12.1 PC Overview

The Coorong is a long, exposed beach and barrier system and site of the Murray River mouth. It is also the outermost of a regressive barrier system with a history going back to the Pliocene. It has been supplied with massive volumes of carbonate-rich shelf sand during the early to mid-Holocene, a supply that appears to have ceased with the nearshore stripped down to calcarenite and cohesive lagoonal mud (Short and Hesp 1984; Short and Cowell 2009), leading to shoreline stabilisation in the south and recession in the central north. The future of the Coorong in the face of rising sea level was investigated by Short and Cowell (2009). They modelled the beach-barrier response to a sea level scenario rising up to 1.5 m by 2010. They found that there was a 99% probability the barrier could recede by 38 m and a 1% probability of 265 m, neither large enough to breach the barrier and impact the backing Coorong lagoon. However, as mentioned above the rising sea level would increase the tidal prism and flow into the Coorong Lagoon reactivating the flood tide delta leading to a loss of beach sand into the lagoon, as well as potentially eroding the foredune and activating more sand loss to the dunes. The increased tidal prism will also decrease salinity which will also have ecological implications for the lagoon (Matthews 2005). In Lacepede Bay a rise would allow higher waves to reach the shore accelerating longshore transport and potentially activating sand waves which if moving would generate major oscillation in the shoreline, parts of which have beachfront roads and houses.

26.13 PC:SA01.03 Fleurieu Peninsula–South Coast

This PC occupies the 74 km long southern shore of the Fleurieu Peninsula between Middleton Rocks and its tip at Cape Jervis together with the 37 km long northeastern coast of Kangaroo Island, the two coasts separated by 14 km wide Backstairs

Table 26.8 PC:SA01.03 Beach types and states

BS	BS	No.	%	km	%	mean (km)	σ (km)
3	RBB	2	4.1	4.3	12.0	2.2	–
4	TBR	11	22.4	10.7	29.9	1.0	1.6
5	LTT	16	32.7	11.6	32.4	0.7	1.1
6	R	20	40.8	9.2	25.7	0.5	0.7
		49	100	35.8	100.0	0.7	–

Passage (Fig. 26.3). The 30–35 m deep passage was flooded by rising sea level between 9.5 and 9.3 ka cutting off the island from the mainland (Belperio et al. 1983). Unlike the exposed PCs to either side, this PC has an increasingly sheltered mainland shore, located to the lee of Kangaroo Island, and a generally sheltered north-facing island shore, the entire PC containing 49 predominately sheltered lower energy R and LTT beaches occupying 36 km (49%) of the shore (Table 26.8). This is the most highly developed section of the south coast with the Victor Harbour region having a population of 15,000, together with 1500 at Penneshaw on Kangaroo Island. Aspects of the natural history of the island are provided by Tyler et al. (1979). It contains two SCs which are discussed below.

26.13.1 SC:SA01.03.01 Middleton Rocks–Newland Head

SC:SA01.03.01 commenced at the low Middleton Rocks and trends generally southwest for 30 km to Newland Head, the southeast tip of the peninsula (Fig. 26.8). The coast is dominated by sedimentary rock of the Kanmantoo Group which increases in height to the southwest peaking at 110 m at Newland Head, together with some granite at Port Eliot and Granite Island. There are 20 beaches (mean length 0.78 km) occupying 16 km (53%) of the shore. The beaches are moderately well sheltered by their orientation, Granite Island and a series of headlands, with most of them low-energy R (Fig. 26.9a), together with four LTT and just two TBR, a marked contrast to the long high-energy D beaches to the east. There is also a variable but noticeable coarsening in sand to medium along this SC (428–458 km, Fig. 26.2) which assists the maintenance of R beaches. Likewise, there are no substantial barrier systems along the coast, apart from the low Victor Harbour Police Point cuspate foreland (Fig. 26.9b) which has formed in lee of Granite Island and has a small volume of ~1.5 M m^3 (520 m^3 m^{-1}). The low-lying foreland is however highly developed and will become increasingly exposed to inundation as sea level rises. Bourman et al. (1989) reported that the foreland had until 1970 been prograding using sand delivered by the adjacent Inman River. Following improved catchment management and training of the entrance sediment delivery has been reduced and the foreland initially stabilised. However, both sides of the foreland has since experienced erosion. The sheltered and enclosed Port Eliot beach (Fig. 26.9a) also appears to be receding.

Fig. 26.8 SCs SA01.03.01-2 includes the southern Fleurieu Peninsula coast and the northeast tip of Kangaroo Island separated by Backstairs Passage. (Source: Google Earth)

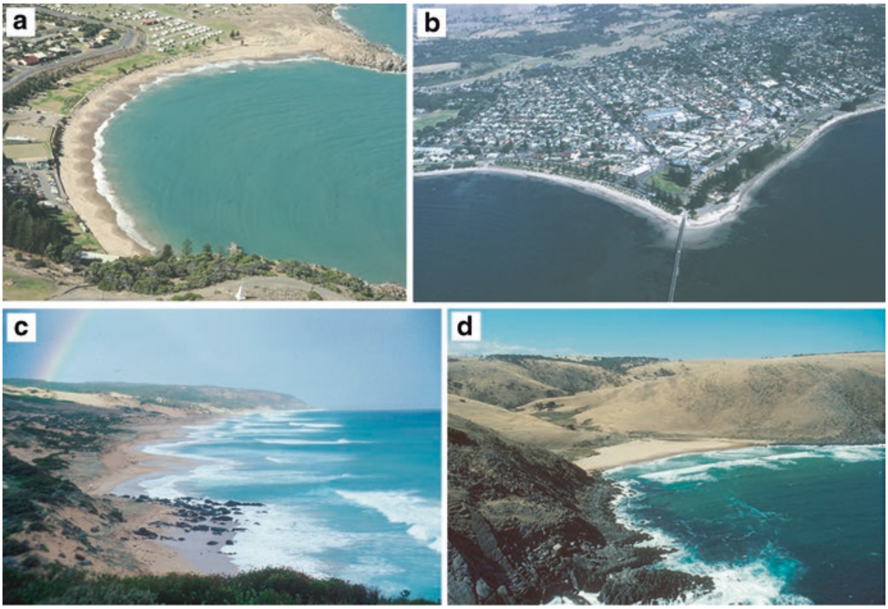

Fig. 26.9 (**a**) The embayed, sheltered and cusped Port Eliot R beach (SA 153); (**b**) Victor Harbour township is located on a low sandy cuspate foreland connected by a bridge to Granite Island (SA 159-160); (**c**) the highly rhythmic shoreline of rip-dominated Waitpinga Beach (SA 170); and (**d**) the exposed but embayed Ballapanudda beach (SA 174). (Photos: AD Short)

26.13.2 SC:SA01.03.02 Newland Head–Cape Jervis

SC:SA01.03.02 contains the southern shore of the Fleurieu Peninsula extending for 44 km between Newland Head and Cape Jervis and also including 37 km of the northeastern coast of Kangaroo Island between Kangaroo Head and the eastern tip at Cape Willoughby (Fig. 26.8), a total shoreline of 81 km. The entire coast is dominated by resistant metasedimentary rocks of the Kanmantoo Group which form generally steep vegetated slopes along the mainland and island coasts. There are no towns or communities along the mainland section, with the Deep Creek Conservation Area in the west, while the island's second town of Penneshaw is located on its northeast coast. The southern peninsula is oriented due south into the prevailing swell; however, moving westwards the coast becomes increasingly sheltered by the island with wave height dropping accordingly. In total there are 17 embayed mainland beaches occupying 12.5 km (28%) of the coast, the remainder generally steep vegetated slopes rising to over 100 m in the east and up to 250 m in the west. The beaches are composed of fine to medium sand with carbonate increasing westwards from 20–40% to 70% (Fig. 26.2). Beginning in the east, there are the exposed, longer high-energy Waitpinga (Fig. 26.9c) and Parsons, both RBB with their massive rips, gradually reducing to TBR by Tunk Head (Fig. 26.9d) and then LTT west from Boat Harbour to the cape. The only barriers are transgressive dune systems in lee of Waitpinga and Parsons with respective volume of 90 M m^3 (29,932 m^3 m^{-1}) and 15 M m^3 (12,500 m^3 m^{-1}), both of moderate side with relatively high per metre volumes. The Waitpinga dunes climb up and partly blanket the 100 m high Newland Head. To the west of the steep slopes, lack of accommodation space and combined with lower waves preclude barrier development.

The northeastern Kangaroo Island section extends for 37 km between 60 m high Kangaroo Head and lighthouse-capped Cape Willoughby (Fig. 26.8), the eastern tip of the island. Apart from the curving Hog Bay at Penneshaw and the eastern Antechamber Bay, this is a steep rugged coast with vegetated slopes rising to a 50–100 m dissected plateau. It faces generally north to northeast, making it a leeward coast that receives only substantially lowered and refracted southerly swell and local wind waves, with the dominant south though northwest winds blowing offshore. There are 13 generally small (40–250 m long) beaches along this coast which occupy just 8 km (21%), the rest of the coast dominated by the steep slopes. There are only three substantial beaches at Hog Bay (600 m) (Fig. 26.10a) and in Antechamber Bay (6.5 km) (Fig. 26.10b). Most of the beaches are short, embayed and R, with the bay beaches LTT, all with seagrass growing close to shore. There are two small regressive barriers both associated with the two main beaches, namely Hog Bay (volume 0.3 M m^3, 500 m^3 m^{-1}) and Antechamber Bay (3.2 M m^3, 800 m^3 m^{-1}). Antechamber Bay has an inner wetland (backbarrier depression), then an inner series of Pleistocene ridges and an outer Holocene barrier composed of north-trending spits/recurved spits that widen to the north suggesting northerly sand transport, as would be expected on this coast. However, in 2018 the northern Lashmar Creek mouth, which drains the wetland, was deflected 0.5 km to the south

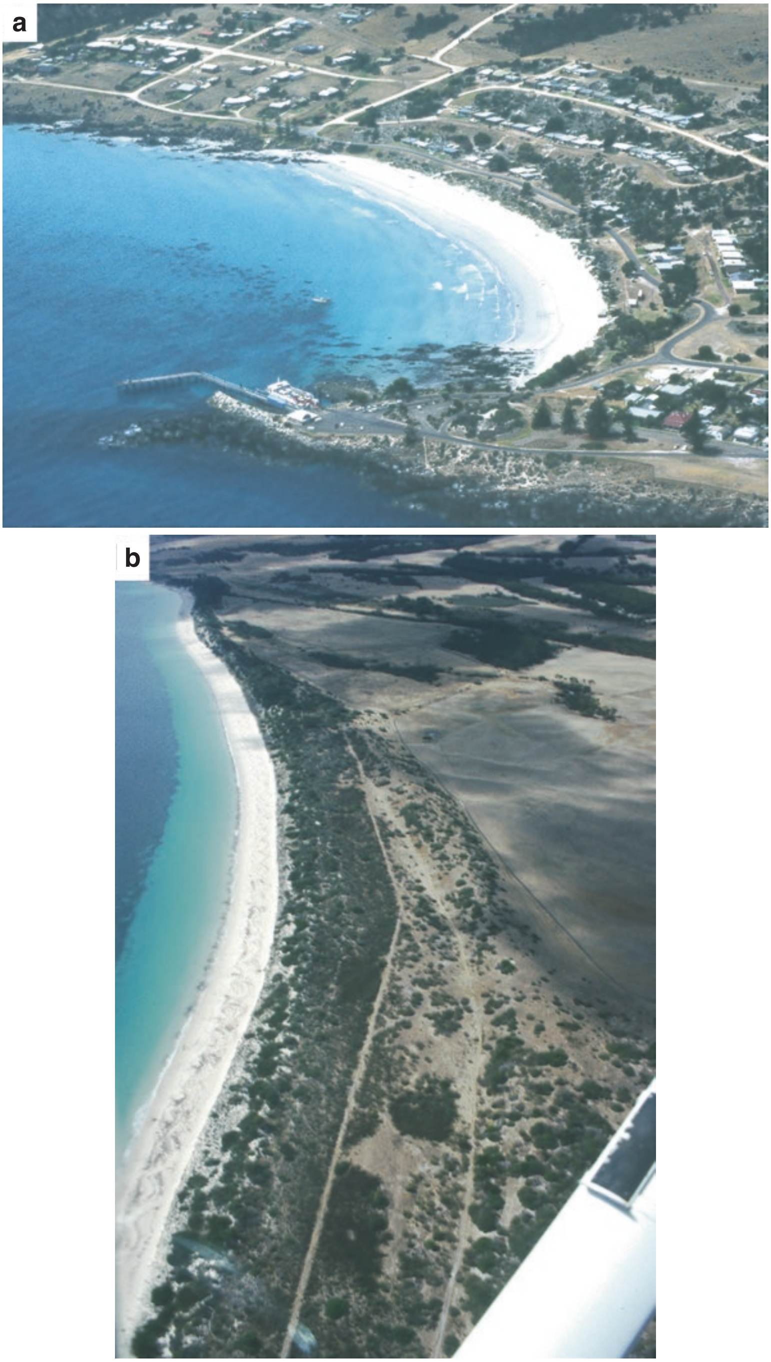

Fig. 26.10 (**a**) Hog Point and Bay with Penneshaw township on the backing slopes (KI 47) and (**b**) view south along the Antechamber Bay foredune ridges (KI 54). (Photos: AD Short)

suggesting there may be reversals in transport. In addition, off the southern end of the beach are a series of about eight shore transverse sand waves, partly covered in seagrass, that may be related to strong currents moving southwards towards Cape St Albans-Cape Willoughby and indicative of slow southerly sand transport.

26.13.3 PC Overview

This is a highly variable PC with shoreline orientation ranging from south to north and wave energy from high to low and with an overall dominance of the steep sloping sedimentary rocks that form the peninsula and eastern end of Kangaroo Island. Much of the coast is lightly undeveloped, with the only substantial development located between Port Eliot-Victor Harbour-Encounter Bay on the mainland and at Penneshaw on Kangaroo Island. Victor Harbour is built on the low-lying cuspate foreland which will be at increasing risk to sea-level rise-induced recession. However, most of this rugged coast will be resilient to sea-level rise.

26.14 PC:SA01.04 Kangaroo Island–South and West Coast

Kangaroo Island is an extension of the Fleurieu Peninsula, separated from the mainland by Backstairs Passage. It is basically a 100–200 m high plateau that is highest along the north coast and slopes towards the southeast and has been incised by numerous streams and small rivers which form small steep V-shaped valleys at the coast. It is rectangular in shape and has 457 km of coast and an area of 4350 km^2. Kanmantoo sedimentary rocks extend the length of the island and are exposed along the steep northern coast, together with intrusive granite outcrops at the Eastern Cape Willoughby and along the south coast between Vivonne Bay and Cape du Couedic. The south and west coast is largely blanketed by Pleistocene dune calcarenite which has been eroded to form cliffs up to 150 m high.

The island has a Mediterranean climate with a pronounced winter rainfall maxima, with orographic rainfall decreasing from 900 mm in the higher northwest to 500 mm at Kingscote. Winds are predominately from the west ranging from northwest through to the south. The Cape du Couedic waverider recorded a mean wave height of 2.7 m, period 12 s, which arrives year-round from the southwest, with a summer minimum (2.2 m) and winter maxima (3.4 m), resulting in a year-round high energy wave climate (Fig. 16.4). Tides are micro with a ~1 m spring range. Beach sediment is composed of well-sorted, carbonate-rich (mean = 71%) fine to medium (mean = 0.26 mm) sand (Table 26.2 and Fig. 26.11). The PC has 88 beaches which occupy 62 km (27%) of the shore, the remainder predominately steep calcarenite cliffs. By number sheltered R (42) and LTT (8) beaches dominate, however, they average only 0.3 and 0.4 km in length, respectively, and the more exposed TBR and RBB dominate by length (47 km, 76%) (Table 26.9). See Short (2001) for a description of the island's beaches. The island has a population of 4300 with just two towns Kingscote (1800) and Penneshaw and few small communities.

The entire south and west coast of the island is blanketed by Pleistocene calcarenite averaging about 50 m in height and rising to 100 m at Cape du Couedic and 150 m at Cape Borda. On the south coast, the calcarenite begins on the western side of Cape Hart and apart from embayments and valleys extends continuously to Cape du Couedic and then up the west coast to Cape Borda. Sitting on top of the calcarenite are Holocene clifftop dunes extending in places up to 4 km inland (Short and Fotheringham 1986a, b). The 232 km long south and west coasts (Fig. 26.3) have three SCs which are discussed below.

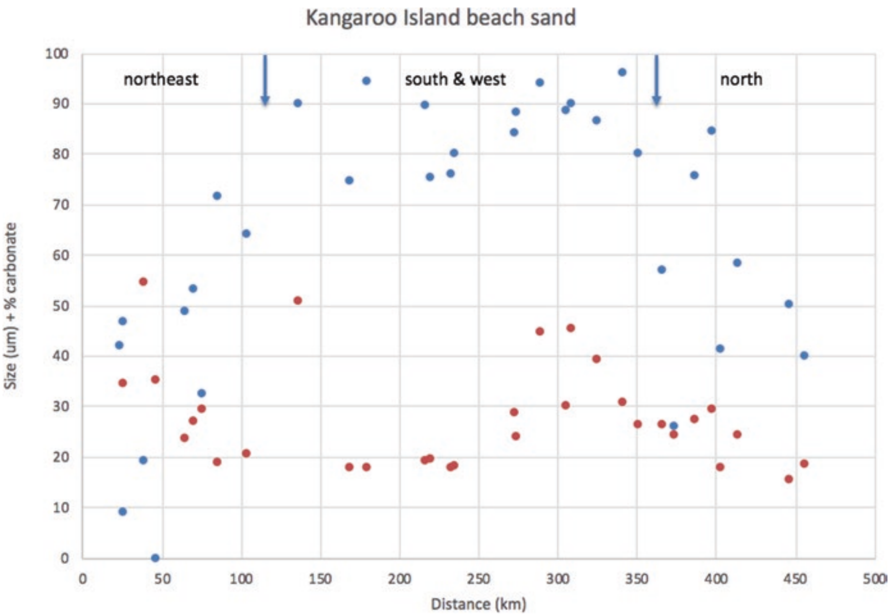

Fig. 26.11 Sediment characteristics of Kangaroo Island beach sand. Red = sand size (μm), blue = % carbonate. Arrows mark the three major shoreline boundaries

Table 26.9 PC:SA01.04 beach types and states

BS	BS	No.	%	km	%	mean (km)	σ (km)
3	RBB	18	20.2	20	32.4	1.1	1.5
4	TBR	20	22.5	27	43.7	1.4	2.8
5	LTT	8	9.0	3.1	5.0	0.4	0.4
6	R	42	48.3	11.7	18.9	0.3	0.2
		88	100	61.8	100	0.7	–

26.14.1 SC:SA01.04.01 Cape Willoughby–Cape Gantheaume

This SC occupies the southeast corner of the island extending from the eastern tip at Cape Willoughby to the southern tip at Cape Gantheaume at a distance of 87 km and includes the open Pennington Bay and the larger curving D'Estrees Bay (Fig. 26.12). There is no development on the coast apart from a carpark overlooking Pennington Bay and a few houses in D'Estrees Bay. This is a reasonably exposed generally south-facing coast, with a sheltered section in the western corner of D'Estrees Bay. The coast has 26 beaches which occupy 33 km (38%) of the shore, the remainder a mix of 50–100 m high cliffs cut in granite between Cape Willoughby and Cape Hart, with sedimentary rocks between Cape Hart (Fig. 26.13a) and False Cape, and then near continuous calcarenite cliffs averaging 50 m high to Cape Gantheaume, usually with well-developed rock platforms at their base. Both Twidale et al. (1977) and Short and Fotheringham (1986a, b) reported elevated Pleistocene platforms on the island located between 3 and 6 m above sea level.

The beaches are composed of carbonate-rich (mean = 73%) fine-medium sand (mean = 0.28 mm). Most are short (0.1–0.5 km) with just two longer beaches in Flour Cask (6.3 km) and D'Estrees (12.3 km) bays. The beaches range from sheltered R in small embayed beaches in amongst the cliffs, to more exposed TBR and RBB (Table 26.9) between False Cape and Flour Cask Bay, including the popular Pennington Bay surfing beach (Fig. 26.13b). One small river, the Wilson, flows through a narrow, exposed valley to reach the sea, the valley chocked with transgressive dunes that extend 700 m up the valley.

Barrier systems occupy 51 km (59%) of the coast, most consisting of essentially stable and well-vegetated transgressive clifftop systems, likely dating to the PMT. Most are contained in four main barriers centred around False Cape (600 M m^3,

Fig. 26.12 SA:SA01.04.01 extends along the southeast coast of Kangaroo Island from Cape Willoughby to Cape Gantheaume. (Source: Google Earth)

Fig. 26.13 (**a**) View west from Cape Willoughby with granite outcrops in the foreground (KI 58) and (**b**) Pennington Bay is dominated by calcarenite bluffs, platforms and cliffs (KI 70-72). (Photos: AD Short)

30,000 m^3 m^{-1}), Sandhurst (200 M m^3, 13,300 m^3 m^{-1}), Pennington Bay (80 M ^{3}, 40,000 m^3 m^{-1}) and D'Estrees Bay (100 M m^3, 7140 m3 m^{-1}), the latter backed by a Pleistocene dune calcarenite extending up to 4 km inland. In D'Estrees Bay, the outer Holocene barrier transforms from transgressive to regressive as it curves into the sheltered southern part of the bay. All these barriers have high per metre volumes reflecting their exposure to the southerly swell and winds.

The erosion of most of the beaches and sand ramps that supplied the clifftop dunes indicates that the initial supply of shelf sand has diminished or ceased. However, the southern shore of D'Estrees Bay to Point Tinline and Cape Linois is drift aligned, and there is potential for sand to move along this shore into the southern corner of the bay. While this appears unlikely at present, there are a few seagrass-covered shore transverse sand waves in the southern corner of the bay that may indicate past or even present northerly sand transport.

26.14.2 SC:SA01.04.02 Cape Gantheaume–Cape du Couedic

This SC includes the exposed south-facing southern coast of the island between Cape Gantheaume and Cape du Couedic a distance of 93 km (Fig. 26.14). The only development on the coast is the formal access to the seal colony at Seal Bay (KI 101), the small community at Vivonne Bay and its sheltered jetty (KI 111), a small resort overlooking Western Hanson Bay (KI 127) and the Cape du Couedic lighthouse. This is a very exposed, high energy predominately cliffed coastline, containing 52 predominately small embayed beaches, with 5 small rivers flowing through steep valleys to reach the coast in Vivonne Bay, the Eleanor and Harriet, Boom River, Northwest River (Sanderson Bay) and Southwest River (Hanson Bay, Fig. 26.15b), each with small sand-blocked river mouths. Thirty-one of the beaches are short (mean length = 0.24 km) R beaches located in amongst the cliffs, rocks and reefs, while 21 are more exposed and longer (0.79 km), TBR and RBB (Fig. 26.15a), the longest 5 km long Vivonne Bay. The beaches are composed of carbonate-rich (mean = 79%) fine to medium sand (mean = 0.25 mm). The beaches occupy 24 km (26%) of the coast, the remainder steep calcarenite cliffs rising to between 50 and 100 m and capped by Holocene clifftop dunes that at Cape Gantheaume extend 10 km inland as multiple parabolics. Most of the dunes are now well vegetated and stable, with only 4% unstable, mainly located in the Little Sahara dune field behind Bales Beach (KI 93-95).

There are three main Holocene barriers that occupy 35 km (38%) of the coast. They largely consist of transgressive clifftop dunes and are centred on Cape Gantheaume (west), Vivonne Bay (east) and Hanson Bay (Fig. 26.15b) and have respective volumes and per metre volumes of 5000 M m^3 (360,000 m^3 m^{-1}), 1480 M m^3 (99,000 m^3 m^{-1}) and 800 M m^3 (133,000 m^3 m^{-1}), all extremely high and reflecting the exposed high energy southern island coast. Like the rest of the south and west coast, the beaches and sand ramps that supplied the dunes have been eroded indicating a reduction or cessation is sand supply.

Fig. 26.14 SC:SA01.04.02 occupies the south coast of Kangaroo Island between Cape Gantheaume and Cape du Couedic. (Source: Google Earth)

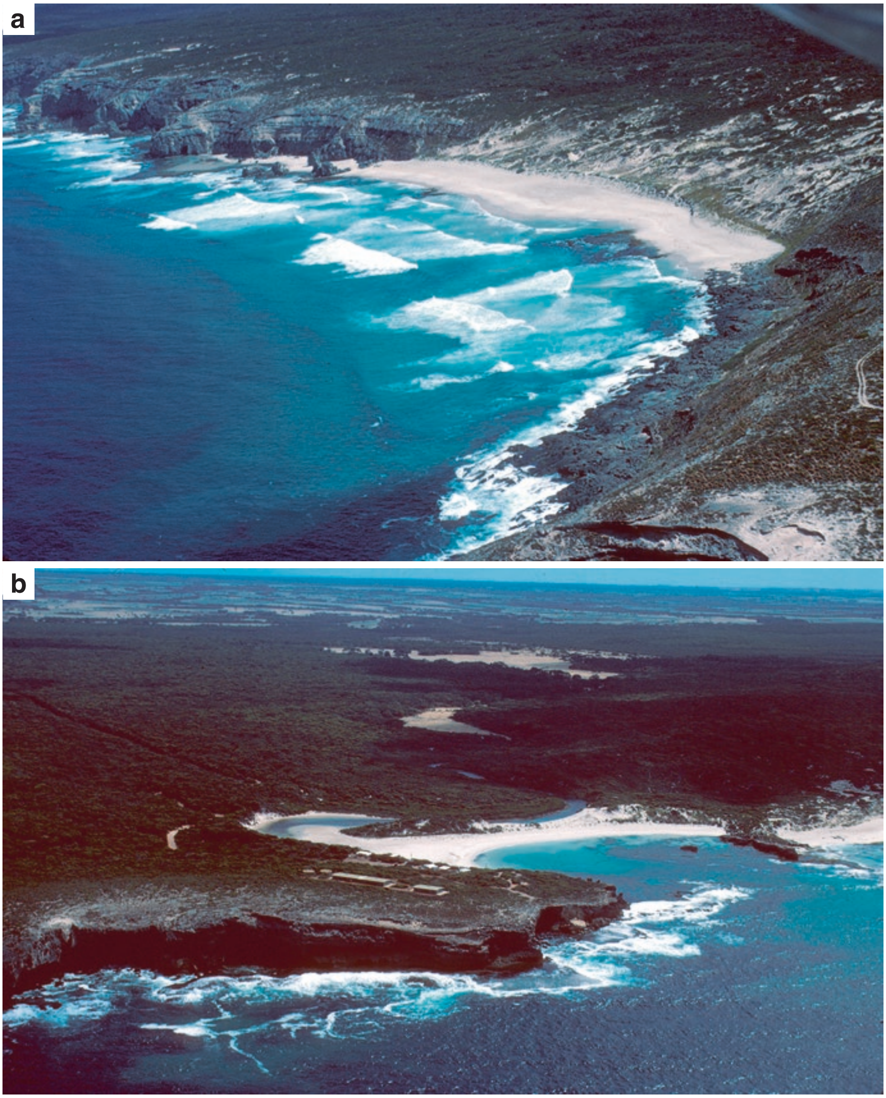

Fig. 26.15 (**a**) Rip-dominated beach and climbing parabolic dunes at Cape Gantheaume (KI 84) and (**b**) the sheltered Hanson Bay and mouth of the South West River (KI 125). (Photos: AD Short)

26.14.3 SC:SA01.04.03 Cape de Couedic–Cape Borda

The west coast of the island faces west-southwest squarely into the Southern Ocean waves and winds. It extends for 51 km between 100 m high Cape du Couedic and the northwestern tip of the island at 150 m high Cape Borda (Fig. 26.16), both capped with lighthouses. The entire coast and the western third of the island are

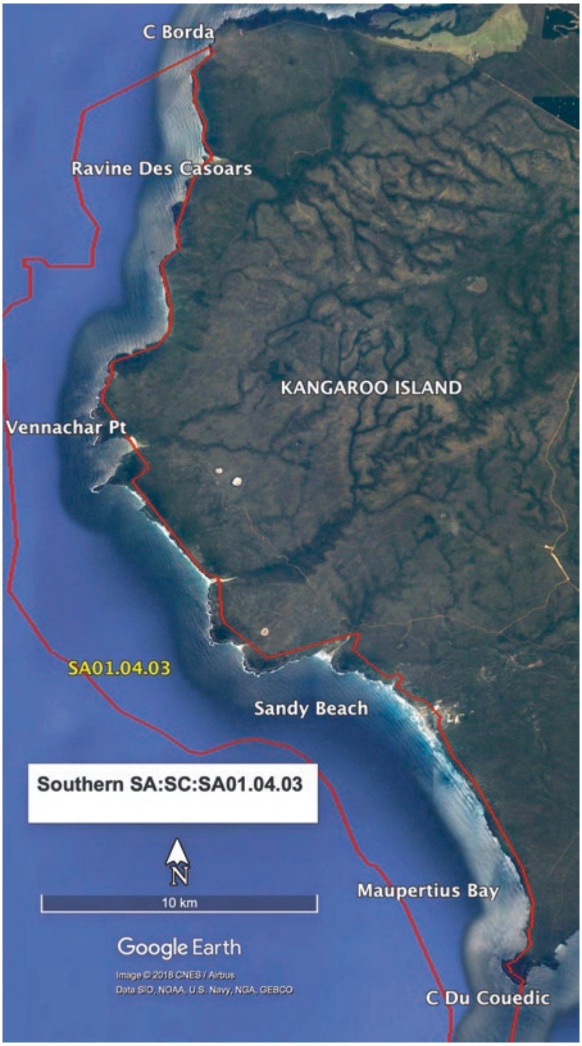

Fig. 26.16 SC:SA01.04.03 occupies the rugged west coast of Kangaroo Island between Cape du Couedic and Cape Borda. (Source: Google Earth)

located within Flinders Chase National Park and the Ravine Des Casoars Wilderness Area. In between the capes is a steep, rugged exposed coast blanketed in Pleistocene dune calcarenite which average 50 m in height and rise to 150 m at Cape Borda. The cliffs are cut by several small rivers which flow though steep V-shaped valleys with beach and dune sand blocking their mouths. There are just 10 beaches along this primarily steep cliffed coast with a total length of just 5 km (9%). They are located in the open reef-fringed Maupertuis Bay (Fig. 26.17a) and in the mouths of the small rivers/creeks (Rocky River, Sandy River, Knapmans Creek, Breakneck River, West Bay and Ravine des Casoars (Fig. 26.17b)). Apart from vehicle access to the capes and West Bay (KI 144), the coast is undeveloped.

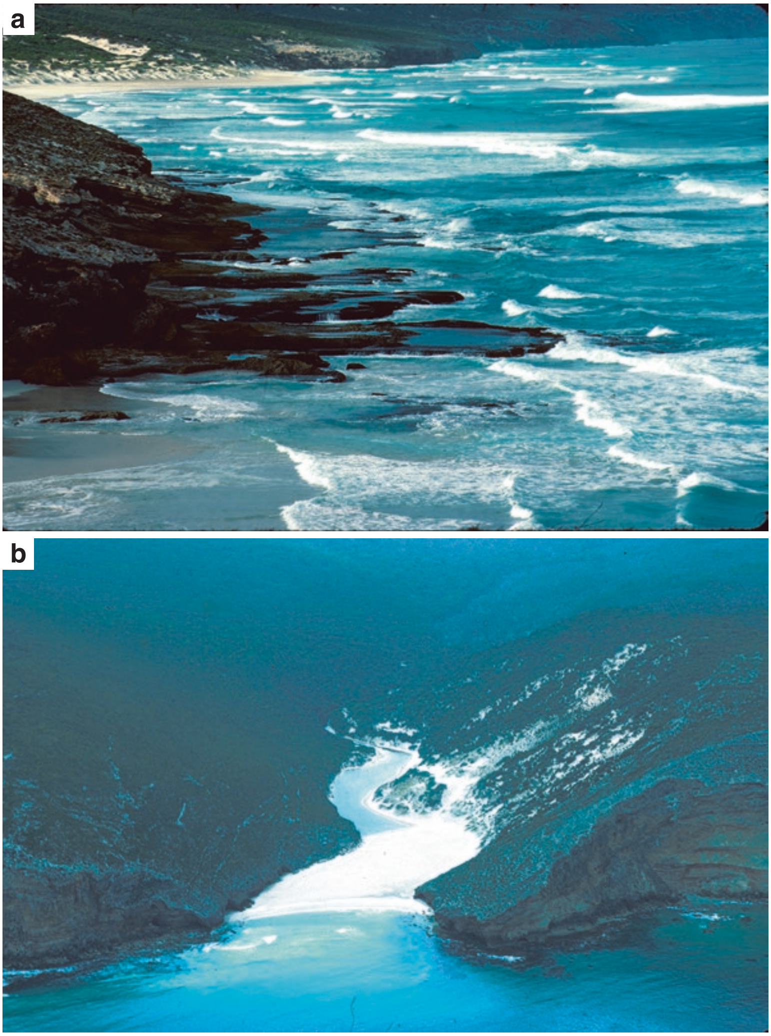

Fig. 26.17 (**a**) The high energy reef-dominated Maupertuis Bay beach (KI 139) and (**b**) the narrow sand-draped Ravine des Casoars (KI 125). (Photos: AD Short) PC Overview

The main Holocene barrier is in the 11 km long Maupertuis Bay and consists of climbing and clifftop dunes extending up to 9 km inland. It has a volume of 1600 M m^3, which represents a massive 145,450 m^3 m^{-1}, one of the largest per metre volumes on the island. However, apart from the sand and dune-filled valleys, for most of this coast the cliffs proved too high to be climbed by the Holocene ramps and remain Pleistocene in age with no Holocene capping.

26.14.4 PC Overview

The southern coast of Kangaroo Island is one of the most exposed and highest energy on the southern Australian and Australian coast, a fact manifest in the massive volumes of Pleistocene and Holocene carbonate-rich sand which almost entirely blankets the south and west coasts, with calcarenite cliffs averaging 50–100 m and reaching as high as 150 m, many also blanketed with Holocene clifftop dunes (Short and Fotheringham 1986a, b). There are 88 small beaches located in gaps in the cliffs but none are developed, apart from the fishing jetty in the sheltered section of Vivonne Bay. This is one of the most high energy but more resilient sections of the Australian coast and will remain that way as sea level and climate change.

26.15 Regional Overview

The southern SA coast is a generally exposed high energy coast, with the only lower energy sections either due to local sheltering by the calcarenite rocks, reefs and islets, or coastal orientation. The predominately exposed sections have accommodated massive volumes of carbonate-rich Pleistocene and Holocene sand, the latter totalling ~21,000 M m^3 (44,100 m^3 m^{-1}) (Table 26.5), most in the form of massive transgressive dune systems which occupy 479 km (63%) of the coast and four major regressive barriers (Rivoli, Guichen, Wright and Lacepede Bays). The massive delivery of sand to the coast has produced a range of Holocene barrier types, whose characteristics are related to both accommodation space and exposure to waves and wind. These are: large regressive barriers deposited in the partly sheltered bays and interbarrier depressions; transgressive dunes blanketing Pleistocene barriers in the south (Canunda-Robe Range) in lee of an eroding calcarenite shoreline; along the Coorong initial barrier formation and regression followed by the loss to the transgressive dunes and shoreline recession; while on Kangaroo Island, where suitable another clifftop layer of sand has been added to the already massive calcarenite cliffs.

The present high level of wave energy allows for rapid coastal change, as has been seen at a number of locations including longshore transport and accretion at Port Macdonnell, longshore transport and erosion at Post Office Rocks, Beachport and Cape Jaffa and erosion at Middleton. These indicate the coast will respond rapidly to changing conditions induced by climate change, particularly rising sea level and change in wave climate. The most at-risk areas are the low-lying sheltered areas, some of which like Kings Camp (Cape Jaffa), Boatswain and Port Macdonnell have shacks and property located within the inundation/erosion hazard zone, together with farmland located in lee of actively transgressing dunes (Short and Hesp 1980). Other locations where property and/or infrastructure is at risk includes Pelican Point, Southend, Beachport, Wyomi, Port Elliot and Policemans Point.

Modelling by Short and Cowell (2009) indicates the long Coorong barrier could retreat between 38 m (99% probability) and 265 m (1% probability) by 2109, an indication of the potential shoreline recession to come on the sandy, non-calcarenite shoreline. The calcarenite is also retreating at rates, depending on exposure, between 2 and 30 mm year^{-1} (Fotheringham 2009a), rapid for a rocky coast, and this is likely to accelerate with sea-level rise. However, this is a lightly developed coast with little property at immediate risk.

Harvey and Belperio (1994) found that owing to down-warping related to neotectonics, sea level has been rising along the southern coast at between 0.5 and 0.6 mm year^{-1}. Harvey et al. (2002) examined sea-level changes at all seven major SA tidal stations and found it was rising at 0.76 mm year^{-1} at Port Macdonnell and 0.67 mm year^{-1} at Victor Harbour, twice national average rate of ~0.3 mm year^{-1} (Watson 2011). If this is the case then the southern SA coast will feel the impacts of sea-level rise in advance of much of the country. Along its southern region, this will be most evident at Murray Mouth, in the Coorong lagoon and along the hundreds of kilometre of exposed sandy beaches, all of which should experience shoreline recession which could lead to a reactivation of the numerous dune fields.

References

Belperio AP, Cann JH (1990) Quaternary excursion of the Robe-Naracoorte coastal plain. Department of Mines and Energy, South Australian, Report 90/27

Belperio AP, Hails JR, Gostin VA (1983) A review of Holocene sea levels in South Australia. In: Hopley D (ed) Australian sea levels in the last 15,000 years, Monograph series: Department of Geography. James cook University, Townsville, pp 37–47

Belperio AP, Hails JR, Gostin VA, Polach HA (1985) The stratigraphy of the coastal carbonate banks and Holocene sea levels of northern Spencer Gulf, Australia. Mar Geol 61:297–313

Belperio AP, Harvey N, Bourman RP (2002) Spatial and temporal variability in the Holocene palaeo sea-level record around the South Australian coastline. Sediment Geol 150:153–169

Bourman RP (1978) Geomorphological contributions to coastal management. In: Cobertt (ed) Focus on Southern Heritage, Adelaide

Bourman RJ, Barnett EJ (1995) Impacts of river regulation on the terminal lakes and mouth of the River Murray, South Australia. Aust Geogr Stud 33:101–115

Bourman RP, Harvey N (1983) The Murray Mouth flood tide delta. Aust Geogr 15:403–406

Bourman RP, Murray-Wallace CV (1991) Holocene evolution of a sand spit at the mouth of a large river system: Sir Richard Peninsula and the Murray Mouth, South Australia. Ziets Fur Geom NF (Suppl 81):63–83

Bourman RP, Murray-Wallace CV, Harvey N (2016) Coastal landscapes of South Australia. University of Adelaide Press, Adelaide, 405 p

Bourman RP, Murray-Wallace CV, Belperio AP, Harvey N (2000) Rapid coastal geomorphic change in the River Murray estuary of Australia. Mar Geol 170:141–168

Bourman RP, Harvey N, James KF, Murray-Wallace CV, Belperio AP, Ryan D (2019a) The mouth of the River Murray, South Australia. In: Mosley L, Ye Q, Shepherd S, Hemming S, Fitzpatrick R (eds) Natural history of the Coorong, Lower Lakes, and Murray Mouth region (Yarluwar-Ruwe). Royal Society of South Australia, Adelaide. https://doi.org/10.20851/natural-history-cllmm-2.3

Bourman RP, Murray-Wallace CV, Ryan DD, Belperio AP (2019b) Geological evolution of the River Murray estuary region. In: Mosley L, Ye Q, Shepherd S, Hemming S, Fitzpatrick R (eds) Natural history of the Coorong, Lower Lakes, and Murray Mouth region (Yarluwar-Ruwe). Royal Society of South Australia, Adelaide. https://doi.org/10.20851/natural-history-cllmm-2.1

Bourman RP, Murray-Wallace CV, Ryan DD, Belperio AP, Harvey N (2019c) Geomorphological evolution of the River Murray estuary, South Australia. In Mosley L, Ye Q, Shepherd S, Hemming S, Fitzpatrick R (eds) Natural history of the Coorong, Lower Lakes, and Murray Mouth region (Yarluwar-Ruwe). Royal Society of South Australia, Adelaide: https://doi.org/10.20851/natural-history-cllmm-2.2

Bourman RP, Scobie D, Tscharke MJ (1989) The origin and development of Police Point Spit, Victor Harbour, South Australia. S Aust Geogr J 89:25–45

Boreen TD, James NP (1993) Holocene sediment dynamics on a cool-water carbonate shelf: Otway, southeastern Australia. J Sediment Petrol 63:574–588

Boreen TD, James NP, Wilson C, Heggie D (1993) Surficial cool-water carbonate sediments on the Otway continental margin, southeastern Australia. Mar Geol 112:35–56

Bristow CS, Pucillo K (2006) Quantifying rates of coastal progradation from sediment volume using GPR and OSL: the Holocene fill of Guichen Bay, south-east South Australia. Sedimentology 53(4):769–788

Brooke B (2001) The distribution of carbonate eolianite. Earth Sci Rev 55:135–164

CPB (1984) Fleurieu coast protection district management plan. Coast Protection Board, Department of Environment Heritage, Adelaide

CPB (1992) Coastline: coastal erosion, flooding and sea level rise standards and protection policy. Coast Protection Board, Department of Environment Heritage, Adelaide, Coastline 26, 7 pp

CPB (2005) Adelaide's living beaches: a strategy for 2005–2025. Technical report, Coast Protection Board, Department of Environment Heritage, Adelaide, 206 pp

Cook PJ, Colwell JB, Firman JB, Lindsay JM, Schwebel DA, Von der Bosch CC (1977) The late Cainozoic sequence of southeast South Australia and Pleistocene sea-level changes. BMR J Aust Geol Geophys 2:81–88

Davies M, Twidale CR, Tyler MJ (1979) Natural history of Kangaroo Island, 2nd edn. Royal Society of South Australia Inc, Adelaide, pp 1–22

Detmar S, Tucker R, Fotheringham D (2005) Sand-filled geotextile breakwater at Beachport, South Australia. In: 17th Australasian conference on coastal and ocean engineering, Adelaide, pp 685–690

Drexel FK, Preiss WV (1995) The geology of South Australia. v2 The Phanerozoic. South Australia Geological Survey. Bulletin 54, 347 pp

Flocard F, Ierodiaconou D, Coghlan IR (2016) Multi- criteria evaluation of wave energy projects on the south-east Australian coast. Renew Energy 99:80–94

Fotheringham DG (2009a) Cliff top erosion adjacent Cape Dombey, Robe, South Australia. Coastal Management Branch technical report 2009/08, 17 pp

Fotheringham DG (2009b) Shoreline erosion at Port Office Rock near Beachport, South Australia. Coastal Management Branch technical report 2009/09, 29 pp

Gostin VA, Hails JR, Belperio AP (1984) The sedimentary framework of northern Spencer Gulf, South Australia. Mar Geol 61:111–138

Harvey N (1988) Coastal management issues for the mouth of the Murray River, South Australia. Coastal Mgt 16:139–149

Harvey N (2006) Holocene coastal evolution: barriers, beach ridges and tidal flats of South Australia. J Coast Res SI 22:90–99

Harvey N, Belperio AP (1994) Implications of climate change for the South Australian coastline. In: Davies M (ed) Climate change and its implications for South Australia. Roy Soc S Aust 118:45–52

Harvey N, Belperio AP, Bourman RP, Mitchell W (2002) Geologic, isostatic and anthropogenic signals detecting sea level records at tide-gauge sites in southern Australia. Glob Planet Chang 32:1–11

Harvey N, Bourman R, James K (2006) Evolution of the Younghusband Peninsula, South Australia: new evidence from the northern tip. S Aust Geogr J 105:37–50

Harley MD, Turner IL, Short AD (2015) New insights into embayed beach rotation; the importance of wave exposure and cross-shore processes. J Geophys Res Earth Surf 120(8). https://doi.org/10.1002/2014JF003390

Huntley DJ, Prescott JR (2001) Improved methodology and new thermoluminescence ages for the dune sequence in south-east South Australia. Quat Sci Rev 20(5-9):687–699

Huntley DJ, Hutton JT, Prescott JR (1993) The stranded beach-dune sequences of South-east South Australia: a test of thermoluminescence dating 0-800 ka. Quat Sci Rev 12:1–20

Indrum M, Cook PJ (1980) Palaeomagnetism of beach ridges in South Australia and the Milankovitch theory of ice ages. Nature 2867:699–702

James NP, Bone Y, Hageman SJ, Feary DA, Gostin VA (1997) Cool-water carbonate sedimentation during the terminal Quaternary sea-level cycle: Lincoln Shelf, southern Australia. In: James NP, Clarke JAD (eds) Cool-water carbonates. Society for Sedimentary Geology, Tulsa, pp 53–75

James N, Bone Y, Joury M, Malcolm I, Kyder TK (2018) Diagenesis and compositional partitioning of quaternary cool-water carbonate aeolianites: southeastern Australia. J Sedimentary Res 88:431–448. https://doi.org/10.2110/jsr.2018.22

Joury M, James NP, James C (2018) Nearshore cool-water carbonate sedimentation and provenance of Holocene strandline dunes, southeastern Australia. Australian J Earth Sciences, 22 p

Matthews C (2005) Sea level rise and climate change: implications for the Coorong and Lake Alexandria and Albert Ramsar site. A preliminary investigation. South East Regional Conservation, Department of Environment and Heritage, Adelaide, 74 p

Moulton MAB, Hesp PA, Mior da Silva G, Bouchez C, Lavy M, Fernandez GB (2018) Changes in vegetation cover on the Younghusband Peninsula transgressive dunefields (Australia0 1949–2017. Earth Surf Processes Landf. https://doi.org/10.1002/esp4508

Murray-Wallace CV (2018), Quaternary history of the Coorong coastal plain, Southern Australia. Springer, 229 p. https://doi.org/10.1007/978-3-319-89342-6_3

Murray-Wallace CV, Banerjee D, Bourman RP, Olley JM, Brooke BP (2002) Optically stimulated luminescence dating of Holocene relict foredunes, Guichen Bay, South Australia. Quat Sci Rev 21:1077–1086

Murray-Wallace CV, Belperio AP (1991) The last interglacial shoreline in Australia – a review. Quat Sci Rev 10:441–461

Murray-Wallace CV, Belperio AP, Bourman RP, Cann JH, Price DM (1999) Facies architecture of a last interglacial barrier model for Quaternary barrier development from the Coorong to Mount Gambier Coastal Plain, southeastern Australia. Mar Geol 158:177–195

Murray-Wallace C, Bourman RP, Prescott J, William F, Price DM, Belperio AP (2010) Aminostratigraphy and thermoluminescence dating of coastal aeolianites and the later Quaternary history of a failed delta: the River Murray mouth region, South Australia. Quat Geochronol 5:28–49

Murray-Wallace CV, Brooke BP, Cann JH, Belperio AP, Bourman RP (2001) Whole-rock aminostratigraphy of the Coorong Coastal Plain, South Australia: towards a 1 million year record of sea-level highstands. J Geol Soc Lond 158:111–124

Ohmori H, Endo K, Vesigi Y, Horikoshi M (1987) Stratigraphy and geomorphic history of Holocene dune field near Millicent along the southeastern coast of South Australia. Geo-Sci J (Japan) 96:1–22

Oliver TAN, Murray-Wallace CV, Woodroffe CD (in press) The drivers of Holocene shoreline progradation at Guichen and Rivoli Bays, South Australia. Holocene

Provis DG, Radok R (1979) Sea-level oscillations along the Australian coast. Aust J Mar Freshw Res 30:295–301

Reissen A, Chappell JF (1993) Murray Mouth littoral drift study. In: 11th Australasian conference on coastal and ocean engineering, Townsville, Institution of Engineers Australia, pp 651–654

Ryan D (2015) The quaternary geomorphological evolution of the River Murray mouth and lakes region, southern Australia. Ph.D. thesis, School of Environmental and Earth Science, University of Wollongong, 460 p

Short AD (1988a) The South Australian coast and Holocene sea-level transgression. Geogr Rev 78:119–136

Short AD (1988b) Holocene coastal dune formation in southern Australia – a case study. Sediment Geol 55:121–142

Short AD (2001) Beaches of the South Australian Coast and Kangaroo Island. Sydney University Press, Sydney, 346 pp

Short AD (2013) Australia's temperate carbonate coast: sources, depositional environments and implications. In: Martini P, Wanless HR (eds) SP388 Sedimentary coastal zones from high to low latitudes: similarities and differences. The Geological Society of London SP388, London. https://doi.org/10.1144/SP388.5

Short AD, Cowell P (2009) Coorong sea level rise vulnerability study. Coastal studies report CS0902 for the SA Department of Environment and Heritage, 55 p

Short AD, Fotheringham DG (1986a) Morphodynamic, hazard and development impact assessment – Kangaroo Island Coast Protection District. Coast Protection Board, Department of Environment and Planning, Adelaide, 183 p plus appendices and maps

Short AD, Fotheringham DG (1986b) Coastal morphodynamics and Holocene evolution of the Kangaroo Island coast, South Australia. Coastal Studies Unit Tech Report 86/1, Coastal Studies Unit, University of Sydney, Sydney, 112 p

Short AD, Hesp PA (1980) Coastal engineering and morphodynamic assessment of the coast within the South East Coast Protection District, South Australia. Final report. Coastal Protection Board, Department of Environment and Planning, Adelaide, 234 p

Short AD, Hesp PA (1982) Wave, beach and dune interactions in south eastern Australia. Mar Geol 48:259–284

Short AD, Hesp PA (1984) Beach and dune morphodynamics of the south east coast of South Australia. Coastal Studies Unit Technical Report 84/1, University of Sydney, Sydney, 142 p

Short AD, Woodroffe CD (2009) The coast of Australia. Cambridge University Press, Melbourne, 288 p

Short AD, Fotheringham DG, Buckley R (1986a) Morphodynamic hazard and development impact assessment – Eyre Peninsula, Coast Protection District. Coast Protection Board, Department of Environment and Planning, Adelaide, 230 p plus appendices and maps

Short AD, Fotheringham DG, Buckley R (1986b) Coastal morphodynamics and Holocene evolution of the Eyre Peninsula coast, South Australia. Coastal Studies Unit Tech Report 86/2, Coastal Studies Unit, University of Sydney, Sydney, 178 p

Sprigg RC (1952) The geology of the south-east Province, south Australia, with special reference to Quaternary coastline migrations and modern beach development. Department Mines South Australia, Bulletin, 29, 120 p plus photos and maps

Thom BG, Bowman GM, Gillispie R, Temple R, Barbetti M (1981) Radiocarbon dating of Holocene beach-ridge sequences in southeast Australia. Monograph 11, Department of Geography, University of New South Wales, RMC, Duntroon, ACT, 36 p

Twidale CR, Burnes JA, Twidale N (1977) Shore platforms and sea level changes in the gulfs region of South Australia. Trans Roy Soc S Aust 101:63–74

Tyler MJ, Twidale CR, King J (1979) Natural history of Kangaroo Island: Adelaide. Royal Society South Australia Inc, Adelaide, 184 p

Watson PJ (2011) Is there evidence yet of acceleration in mean sea level rise around mainland Australia. J Coast Res 27:368–377

Webster IT (2009) A preliminary assessment of the impact of sea level rise on water levels in the Coorong. CSIRO, Report to the Murray-Darling Basin Natural Resources Management Board, 11 p

Wentworth Group (2017) Review of water reforms in the Murray-Darling basin. Wentworth Group of Concerned Scientists, Sydney, 86 p plus appendices

Wynne AA (1980) Yorke coast protection district study report, prepared or coast protection board. Department of Environment and Planning, Adelaide

Chapter 27
South Australian Gulfs Region

Abstract The South Australia gulfs, St Vincent and Spencer, are bounded by the Fleurieu, Yorke and Eyre peninsulas. The gulfs protrude 160 and 320 km inland, respectively, and are largely sheltered from ocean waves, with fetch-limited waves and tides increasing to meso at the head of gulfs. They have a Mediterranean climate with very limited terrigenous input. Sediments are predominately carbonate supplied from the gulf floor and inter- to subtidal carbonate banks and their extensive seagrass meadows. Wave energy decreases into the gulfs as tides increase with beaches ranging from wave-dominated to tide-modified to tide-dominated in the upper gulfs. There are a few transgressive dune systems in southern exposed locations, with most barriers being low and regressive. This chapter examines the gulfs coastal processes, beaches, barriers, sediment transport and sediment compartments.

Keywords St Vincent Gulf · Spencer Gulf · Fleurieu Peninsula · Yorke Peninsula · Eyre Peninsula · Meso-tides · Beaches · Barriers · Sediment transport · Sediment compartments

27.1 Introduction

The South Australian gulfs – St Vincent and Spencer – are two V-shaped embayments that penetrate 160 km and 320 km, respectively, to the north into the more arid interior of the State and cover an area of ~7000 km^2 and 22,000 km^2, respectively (Fig. 27.1). St Vincent is an intercratonic basin bordered by the Adelaide Geosyncline-Fleurieu Peninsula and the Mount Lofty Range to the east and Yorke Peninsula in the west, with Kangaroo Island lying across its southern entrance, restricting ocean access to 40 km wide Investigator Strait and 14 km wide Backstairs Passage. Spencer Gulf is part of the Pirie Basin which is bounded by Yorke Peninsula to the east and the Eyre Peninsula to the west, the latter part of the ancient Gawler Craton. While Spencer Gulf widens to 80 km in the south, a series of islands block most southerly swell from entering the gulf. Both gulfs are shallow marine re-entrants penetrating into the arid interior of the continent. They have limited freshwater inflow which results in salinity rising to the north and the formation of

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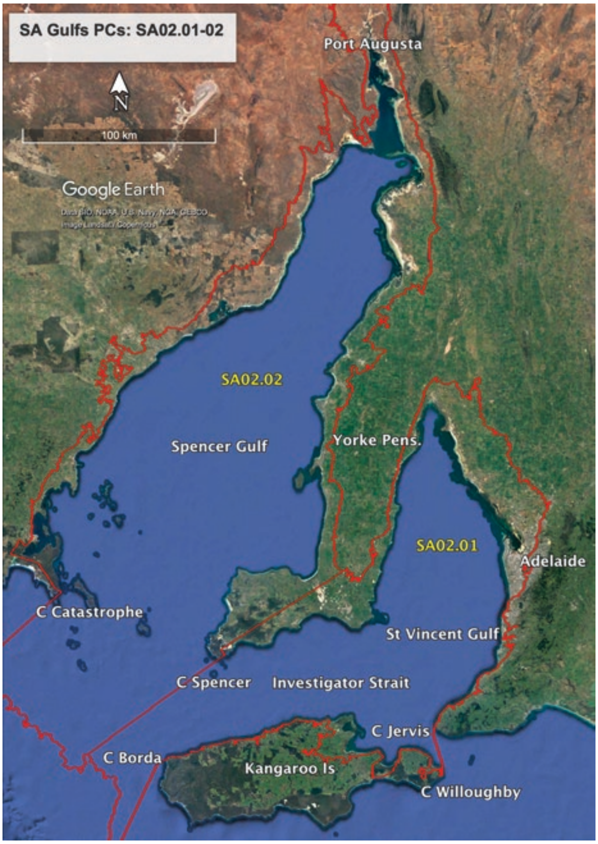


Fig. 27.1 The South Australian gulf region includes PCs SA02.01 (St Vincent Gulf including northern Kangaroo Island) and SA02.02 (Spencer Gulf). (Source: Google Earth)

inverse estuaries. The low Yorke Peninsula which separates the gulfs is composed of a mix sedimentary rocks associated with Adelaide Geosyncline in the north and east and the granites and metasedimentary rocks of the Gawler Craton in the south and west.

The gulfs are also part of the Great Australian Bight shelf. They are shallow <50 m in the south and <25 m in the north, together with extensive shallow carbonate banks in the north. Their sediments are a mix of terrigenous-carbonate sand dominated by biogenic carbonate consisting of shell, gastropod, bivalve, foraminifera, coralline algae and quartz grains (Richardson et al. 2005). Subtidal sediments support seagrass meadows and megaripple fields containing shell-rich sands, while the intertidal zone contains muddy gastropod-rich sediments, inhabited by cyanobacterial mats and mangroves.

The SA gulf region (SA02) includes the 117 km long northern coast of Kangaroo Island and on the mainland commences at the tip of the Fleurieu Peninsula at Cape Jervis, which also forms the eastern boundary of St Vincent Gulf. It trends generally west heading into the two gulfs and around Yorke Peninsula for 1612 km to Cape Catastrophe the southern tip of the Eyre Peninsula and the western entrance to Spencer Gulf (Fig. 27.1) and represents 49% of the state's mainland coast. The region is divided into 2 PCs, St Vincent (PC:SA02.01) and Spencer gulfs (PC:SA02.02), and 13 SCs, which are all discussed below.

27.2 Climate

As the gulfs trend due north into more arid conditions, the climate ranges from Mediterranean in the south (Csb) with rainfall between 600 and 800 mm to semi-arid in the north (BSk) as rainfall decreases to 300–400 mm (Fig. 1.5a, b). The rainfall also becomes more uniform in the north with just a slight winter maximum. Temperatures are warm to hot during summer and cool to mild during winter (Fig. 1.5c, d). Winds are predominately westerly ranging from south through west to northwest, with northwesterly more prevalent in winter and southwesterlies in summer.

27.3 Rivers and Creeks

Only a few small rivers and creeks drain into the gulfs, most draining into the eastern St Vincent Gulf from the Mount Lofty Ranges and into the southwestern Spencer Gulf. Most are usually dry and only flow following winter rains. On the Fleurieu Peninsula, these are from the south the Yankalilla, Onkaparinga (544 km^2), Patawalonga-Sturt (200 km^2), Torrens (500 km^2), Port Adelaide (346 km^2), Gawler, Light and Wakefield and on the southern Eyre Peninsula the Driver, Dutton and Todd. Only the small Driver and Dutton appear to be delivering small quantities of bedload to the coast, with the Dutton River in the past 100 years building a 200 m wide plain, capped by beach-foredune ridges composed of quartz-rich (99%) sand (Short et al. 1986b).

27.4 Sediment

The gulfs are part of the south coast cool-water carbonate province, with seabed sediment composed of mixed terrigenous-carbonate material, but dominated by biogenic carbonate including bryozoans, coralline algae, molluscs and foraminifers (Gostin et al. 1984a; Burne and Colwell 1982). Along the eastern Spencer Gulf, Fuller et al. (1994) described the sediment facies as 'molluscan-bryozoan sand' or 'mixed bioclastic sand', with the *Posidonia* and *Amphibolis* seagrass meadows (Fig. 16.8) also supplying bivalves and gastropods. Beach sediment in the gulfs is typically moderately well-sorted, medium sand with ~50% carbonate (Table 27.1).

Table 27.1 Beach sand characteristics in St Vincent (SA02.01) and Spencer (SA02.02) gulfs

SA02	SA02.01	SA02.02
n	63	96
Size (mm)	0.4	0.41
σ (mm)	0.32	0.49
Carbonate (%)	51	49
σ (%)	34	36
Range (%)	5–98	1–99
Sorting	0.93	0.8
σ *(sorting)*	0.59	0.46

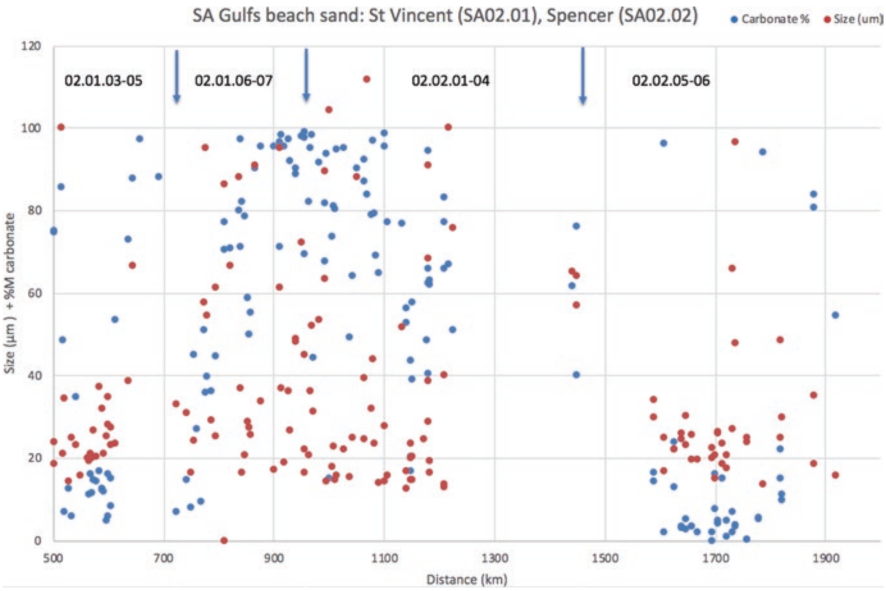


Fig. 27.2 Beach sand size (µm) and percent carbonate for the SA gulfs. Arrows indicate compartment boundaries (see Table 27.4). Distance from VIC/SA border. (See Fig. 26.11 for Kangaroo Island beach sand)

Compared to the open ocean coast, the sediment is coarser with lesser sorting which is typical of low wave environments as found in the gulfs. There is also less carbonate on average owing in part to the lack of ocean-shelf supply and a reliance on solely local supply from the seagrass meadows, together with dilution by the quartz-derived Permian fluvial-glacial deposits in the Mount Lofty Ranges which have been delivered to the gulf floor at low sea levels, as well as from reworking of the desert ‘glacial’ dunes and some bluff erosion. However, as Fig. 27.2 indicates, there is an underlying trend of fine to medium sand (0.15–0.4 mm), with considerable longshore variation in both sand size and percent carbonate, with size ranging from fine to very coarse, carbonate from 1 to 99% and sorting from well to poorly. The lowest carbonate occurs along the northern coast of Kangaroo Island and the western shore of Spencer Gulf south of Lucky Bay, though even in these environments high proportions do occur. The highest carbonate and some of the coarsest sand occur in northern St Vincent Gulf and around the Yorke Peninsula (600–1250 km; Fig. 27.2). The longshore variation in sediment texture is also an indication of limited longshore transport, with limited wave energy to transport sand and most sand derived from local sources, including terrigenous sand from the gulf floor, desert dunes and bluff erosion and carbonate sand from either the extensive intertidal sand flats or the adjacent seagrass meadows (Fig. 16.8).

27.5 Waves

Both gulfs are substantially blocked from ocean swell by Kangaroo Island and the lower Spencer Gulf islands (Fig. 27.3), coupled with their orientation and distance from the open ocean. Furthermore, what waves are received or generated within the gulfs are attenuated by the often wide intertidal zones, as well as being tidally modulated in the northern gulfs. The highest energy sectors are the southeastern shore of St Vincent Gulf and the lower western Yorke Peninsula which can both receive ocean swell when it arrives from southwest (250°) and is able to move through the 40 km wide Investigator Strait to reach the southwest coast of Yorke Peninsula as moderate to occasionally high swell. On the Fleurieu coast, it arrives between Sellicks and Semaphore as low to occasionally moderate swell, decreasing in height northwards. In Spencer Gulf, the low refracted swell penetrates along the western shore between Tumby Bay and Franklin Harbour, peaking at south-facing Mills Beach. Figure 27.3 illustrates the H_s and H_{max} wave height for the gulfs and bight coast.

The gulfs' wave climate, particularly the eastern shores, is dominated by locally generated wind waves which tend to arrive from the northwest in winter and southwest in summer, with heights usually 1 m or less and period 3–5 s. Wave energy is greatest in the south where fetch is greater and decreases northwards as fetch decreases, sand banks increase in extent and tide range increases. At Semaphore Riedel et al. (2005) found the sea waves averaged 0.5–1 m (H_{max} = 1.5–3.5 m), while the swell rarely exceeded 0.5 m. However, occasional severe winters (e.g. 1953, 2016) can bring a number of westerly storms that deliver high waves, storm surge and strong winds that impact the entire eastern shore of the gulf (Townsend and Guy 2017).

27.6 Tides and Sea Level

Tides are amplified and slowed in the gulfs by their shallow gulf floor and funnel-shape (Fig. 27.4). The tidal wave after entering the gulfs takes 4 hours to reach Clinton at the head of St Vincent Gulf and 7 hours to reach Port Augusta at the head

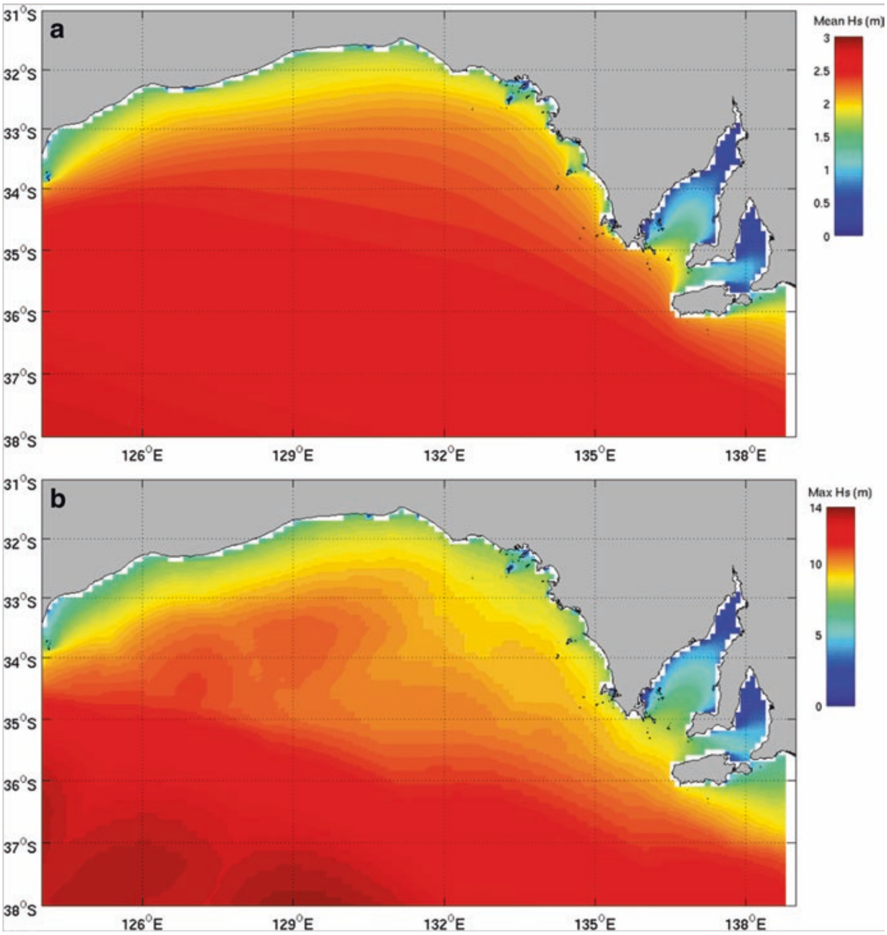


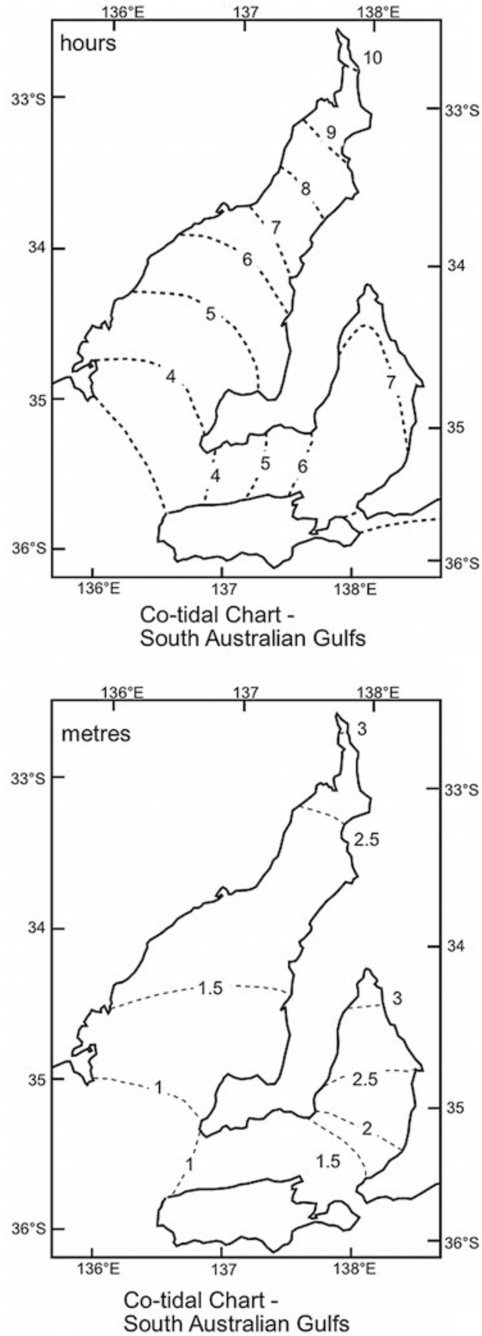
Fig. 27.3 Mean and maximum significant wave height for the Great Australian Bight and Spencer and St Vincent gulfs, with predominant direction from the southwest (Source: Richardson et al. 2005, reproduced with permission of Geoscience Australia under the Creative Commons Attribution 4.0 International Licence)

of Spencer Gulf. At the same time, they are amplified from ~1 m on the open coast to 3 m at Ardrossan and 3.5 m at Port Augusta (Fig. 27.4).

Both gulfs are exposed to storm surges which can reach 2 m in St Vincent Gulf and 3 m in Spencer Gulf (Fig. 1.14; CPB 1992; Deans 1997). The most damaging surges occur when they accompany high waves, a spring high tide and shelf wave crest.

Sea level along the SA coast during the PMT reached its peak between 6.6 and 6.4 ka, reaching +2.5–3.8 m in the northern Spencer Gulf (Burne 1982) and + 1 m in the southeast and Eyre Peninsula (Belperio et al. 1983a, 2002; Harvey et al. 2001), following which it fell to its present level after 2 ka. The fall in sea level

Fig. 27.4 Co-tidal and co-range lines for St Vincent and Spencer gulfs. (Source: Short 2001)



increases into the gulfs from 1 to 3 m with distance for the open coast, which can be explained by hydro-isostatic adjustment of the shelf and coast (Belperio et al. 2002).

Quaternary sea levels were first investigated in northern Spencer Gulf by Hails et al. (1984) who recorded five marine transgressions, with the Holocene transgression reaching an elevation of +2.5 m between 8 and 7 ka. The last interglacial sea level (MIS 5e) has been recorded at a range of levels above present along the SA coast. Murray-Wallace and Belperio (1991) recorded levels in the gulfs ranging from +2 m in Spencer Gulf to +3 m in St Vincent Gulf and + 2–3 m on the Fleurieu Peninsula and Kangaroo Island. Twidale et al. (1977) also reported evidence of a + 5–6 m high Pleistocene sea level on Kangaroo Island, while Short and Fotheringham (1986b) found evidence of a + 3 m Pleistocene sea level on the southern shore of the island. More recently Pan et al. (2018) found that on the tectonically stable lower Yorke Peninsula the last interglacial sea level reached between +1.8 and 1.9 m and then rose to 2.9–4.8 m above present, the latter proposed as the maximum elevation of the last interglacial on the southern Australia coast. As a result of the higher Pleistocene sea levels there are abundant Pleistocene shorelines and deposits located around the coast.

Sea temperature in Spencer Gulf ranges from 24 to 12 °C, however due to limited mixing the shallow gulf waters cooler in winter and warmer in summer compared to adjacent shelf waters (Fig. 1.17). Water circulation is clockwise with shelf waters flowing up the western side and outflow along the eastern side of the gulfs (James et al. 1997; Richardson et al. 2005).

27.7 Coastal Ecology

The South Australian coast has a range of rich coastal ecosystems including seagrass meadows, mangroves, samphire flats and coastal dune vegetation. The coast has the most extensive mangrove systems in the southern province totalling 152 km^2 in area with the mangrove systems in the gulfs and the western bays consisting solely of *Avicennia marina* (Butler et al. 1977; Burton 1982) and Davenport Creek on the western Eyre Peninsula site of the most western mangroves on the southern coast. The mangroves grade landwards into extensive inter- to supratidal samphire flats vegetated with salt marsh grasses, succulents and low shrubs, beyond which are bare supratidal flats. The combined area of mangroves and salt marsh totals 852 km^2 (Table 27.2).

South Australian waters have extensive temperate seagrass meadows particularly in the gulfs and western bays and are the most extensive on the southern coast with a total area of 9630 km^2 (Table 2.11). Thirteen temperate seagrass species have been recorded along the coast (Table 2.12). As discussed in Sect. 16.5.3, the meadows are a major source of carbonate sand (Burne and Colwell 1982; Gostin et al. 1988; Fuller et al. 1994) for the adjacent beaches and sand flats systems. In the gulf the meadows are responsible for the development of the extensive sand banks/tidal flats averaging 0.6 km in width ($\sigma = 0.7$ km) whose evolution and stratigraphy is described

Table 27.2 Area of South Australian intertidal communities

Habitat	Area (km^2)
Beach ridges, tidal creeks, salt pans	209
Supratidal salt marsh	267
Intertidal salt marsh	226
Mangroves	152
Total	852

Source: Fotheringham (2000)

by Gostin et al. (1984a) and Belperio et al. (1984, 1988). In northern Spencer Gulf Gostin et al. (1984) found the lower intertidal dominated by bare sand flats (52%), then mangrove and samphire flats (27%) and supratidal flats (21%), while the subtidal was dominated by seagrass meadows out to 15 m depth (77%), below which are megaripple fields, channels and depressions (33%). They also found that skeletal carbonate decreased landwards from a maximum of 70% in the subtidal to <10% in the supratidal, while terrestrial sand and mud increased landwards. While the seagrass is a vital part of the coastal ecosystems and source of sediment, they do pose problems for beach and coastal management as seagrass debris is deposited on the high tide beach. In places the debris form berms 10 m wide and up to 1–2 m high, with the debris, its smell and the insects it attracts, detracting from beach access and amenity. During a series of storms in 2016, masses of seagrass debris were deposited along the Adelaide coast including the Glenelg and West Beach marinas. The seagrass debris blocked navigation to the marinas and proved to be difficult, time-consuming and expensive to remove (Townsend and Guy 2017).

The SA coast has 1826 km of coastal dune systems totalling 2286 km^2, all of which are vegetated to varying degrees by dune vegetation, with presently 71% vegetated. The vegetation succession typically begins with *Cakile maritima* and *Spinifex sericeus* on the incipient foredune, grading to a mix of salt bush species and tea tree on the foredune, with mallee trees growing in sheltered locations in lee of the foredune. Oppermann (1999) provides a detailed inventory of all SA coastal vegetation and its regional variation.

27.8 Beaches

The gulfs have total mainland shoreline of 1422 km of which 1028.5 km (72%) is sandy beaches. In addition, the region contains 190 km of northern Kangaroo Island coast where beaches occupy 84 km (44%) of the coast. The gulf beaches are generally low energy, meso-tidal and composed of medium sand which combine to produce a range of WD through TD beach types and states. As Table 27.3 indicates, PC:SA02.01 (St Vincent Gulf–northern Kangaroo Island) has a mix of 51% (by length) WD beaches and 49% TD beaches, the former in the southern and eastern

Table 27.3 Beach types and states in (a) PCs:SA02.01 (St Vincent Gulf) and (b) PC:SA02.02 (Spencer Gulf)

BS	BS	No.	%	km	%	mean (km)	σ (km)
(a)							
4	TBR	11	3.4	14.7	4.1	1.3	1.4
5	LTT	43	13.4	94.8	26.3	2.2	3.9
6	R	129	40.1	74.1	20.5	0.4	2.1
10	B + RSF	15	4.7	20.1	5.6	1.3	1.6
11	B + SF	112	34.8	120.6	33.4	1.1	1.9
12	B + TSF	12	3.7	36.4	10.1	3	3.4
		322	100	360.7	100	1.1	–
(b)							
4	TBR	20	4.9	28.2	4.2	1.4	2.1
5	LTT	55	13.3	35	5.2	0.6	1.1
6	R	119	28.9	117.7	17.6	1	1.9
7	R + LTT	35	8.5	42.7	6.4	1.3	1.4
10	B + RSF	7	1.7	5.4	0.8	0.8	1.2
11	B + SF	140	34.0	308.7	46.2	2.2	3.2
12	B + TSF	36	8.7	130.1	19.5	3.6	5
		412	100	667.8	100	1.6	–

gulf and the latter in the northern and western gulf and in Kangaroo Island's sheltered Shoal and Western Cove bays. Likewise, PC:SA02.02 (Spencer Gulf) has 27% WD and 1.3% TM and is dominated by the TD (66.5%), particularly in the upper and western gulf. More details of the beach system will be provided in the following descriptions of the 13 gulf SCs. Also see Short (2001) for a description of all the beaches in this region.

27.9 Barriers

The gulfs have 99 barrier systems which occupy 619 km (44%) of the coast, with 26 are located in St Vincent Gulf and 73 in Spencer Gulf (Table 27.4). Most are low energy stable to regressive beach ridge to foredune ridges, with just a few areas of generally minor to moderate dune transgression on lower Yorke Peninsula and parts of western Spencer Gulf totalling 2240 ha or 7.5% in area. The barriers have a total volume of 2769 M m^3, which represents a relatively low per metre volume of 4430 m^3 m^{-1}, both an order of magnitude smaller than the SA open coast systems (Tables 26.5 and 27.3).

Table 27.4 PC:SA02 beach dimensions

SA02	SA02.01 St Vincent	SA02.02 Spencer	SA02 Region
No.	26	73	99
Total length (km)	147	472	619
Mean min width	100	200	–
Mean max width	500	850	–
Mean height (m)	7.5	9	–
Area (ha)	6410	23,276	29,686
Unstable (ha)	37	2203	2240
Total volume (M m^3)	459	2326	2769
Unit volume (m^3 m^{-1})	2998	4933	4473

27.10 Sand Transport

The St Vincent Gulf receives occasional southwest swell along its southeastern shores, and Spencer Gulf along is central southwest-facing western shore, together with alternating northwest and southwest wind waves, along their eastern shores, all with the potential to drive longshore sand transport, even if energy levels are relatively low. As will be seen in the following SCs, there are a major northerly swell and sea-driven sand transport along the Adelaide coast, a long southeast-trending spit off Kingscote on Kangaroo Island and evidence of easterly longshore transport on the north and south sides of the Yorke Peninsula 'foot', together with evidence of northerly transport along parts of the eastern Spencer Gulf shore, such as at Franklin Harbour.

The SA gulf region consists of 2 PCs – St Vincent (SA02.01) and Spencer (SA02.02) gulfs – which contain 13 SCs (Table 27.5; Fig. 27.1). The PCs and SCs are each described below.

27.11 PC:SA02.01 Northern Kangaroo Island and St Vincent Gulf

PC:SA02.01 includes the northern coast of Kangaroo Island, all of St Vincent Gulf, together with the southern coast of Yorke Peninsula, all of which face into the gulf and/or Investigator Strait (Fig. 27.1). The geology of eastern coast consists of the curving folded rock belt of the Kanmantoo Group which forms the Mount Lofty Range reaching the coast along the Fleurieu Peninsula as well as making up much of 100–200 m high plateau of Kangaroo Island, with the St Vincent Basin forming the gulf. The Yorke Peninsula consists of a low (<100 m) plateau of rocks of the Adelaide Geosyncline in the east and Gawler Craton granites in the south and west that form the foot-shaped base of the peninsula. A more detailed description of the geology is provided by James and Clark (2002) and Bourman et al. (2016), while

Table 27.5 The South Australia gulf region its PCs and SCs

SA Gulfs		Boundaries	Beaches	No.	km[a]	Total
SA02.01.01	Kangaroo Is (N)	C Borda-Marsden Pt	KI 146–218	73	KI 345–459	114
SA02.01.02	Nepean Bay	Marsden Pt-Kangaroo Hd	KI 1–44	44	KI 0–76	76
SA02.01.03	Fleurieu Pen. (SW)	C Jervis-Sellicks Beach	SA 187–213	27	502–548	46
SA02.01.04	Adelaide coast	Sellicks -North Haven	SA 214–233	20	548–616	68
SA02.01.05	St Vincent (NE)	North Haven-Clinton	SA 234–245	12	617–715	99
SA02.01.06	Yorke Pen. (E)	Clinton-Sultana Pt	SA 246–335	90	715–840	125
SA02.01.07	Yorke Pen. (S)	Sultana Pt-C Spencer	SA 336–391	56	840–945	105
SA02.01	*KI + SA Gulfs*	*C Borda-C Spencer*	*KI 146–44*		*KI 345–76*	
			SA 187–391	*322*	*SA 502–945*	*633*
SA02.02.01	Yorke Pen. (SW)	C Spencer-Corny Pt	SA 392–448	57	945–1012	67
SA02.02.02	Yorke Pen. (W)	Corny Pt-Pt Pearce	SA 449–482	34	1012–1120	108
SA02.02.03	Yorke Pen. (NW)	Pt Pearce-Fisherman Bay	SA 483–546	64	1120–1268	148
SA02.02.04	N Spencer(W)	Fisherman Bay-Port Augusta	SA 547–564	18	1268–1430	162
SA02.02.05	N Spencer (E)	Port Augusta-Shoalwater Pt	SA 565–613	49	1430–1587	157
SA02.02.06		Shoalwater Pt-C Catastrophe	SA 614–803	190	1587–1924	337
SA02.02.	*SA Gulfs*	*C Spencer-C Catastrophe*	*SA 392–803*	*412*	*945–1924*	*979*
		Region sub-total		734		1612

[a]Distance from VIC/SA border and on Kangaroo Island distance clockwise from North Cape

Short and Fotheringham (1986a, b) and Short et al. (1986a, b) provide a description of the coastal morphodynamics and Holocene evolution of Kangaroo Island and the western Spencer Gulf coasts, respectively, and Wynne (1980) reviews the nature and management of Yorke Peninsula Coastal Protection District (Table 26.1). The coast has considerable variation in development and population, with the small Emu Bay (120) the only community on Kangaroo Island's north coast, while the eastern shore of St Vincent Gulf contains Adelaide city (1.2 M) with 71% of the State's population, with the smaller towns and communities of Normanville-Carrickalinga (2000) to the south and to the north Port Gawler (100) and Port Wakefield (650). The PC contains seven SCs: two along the north coast of Kangaroo Island and the remainder around the gulf shores. Each SC is described below.

27.11.1 SC:SA02.01.01 Cape Borda–Point Marsden

SC:SA02.01.01 extends for 114 km along the east-northeast trending northern coast of Kangaroo Island, between the northwestern tip at 150 m high Cape Borda and the northern tip at 70 m high North Cape-Point Marsden (Fig. 27.5). In between is a predominately steep rugged, cliffed coastline rising sharply to heights of over 200 m in the west (Fig. 27.6a) gradually decreasing to around 150 m in the east. The steep terrain and backing plateau have been heavily dissected by small streams and one small river which have eroded steep V-shaped valleys occupied by small beaches and barriers. Amongst the cliffs are 73 short mainly embayed beaches, with a mean length of 0.3 km ($\sigma = 0.65$ km). They occupy 21 km (19%) of the coast, the remainder steep rocky slopes, cliffs and rock platforms. The beaches are composed of generally fine well-sorted sand which averages 50% carbonate, which is highly variable longshore and substantially less than the south and west coast island beaches (Fig. 26.11). The beaches receive refracted swell round Cape Borda which arrives as low to occasionally moderate westerly swell (Fig. 27.3), and local northerly wind waves, while tides are ~1 m. The generally lower wave conditions and sheltered nature of many of the beaches result in a dominance of R beaches, with 57 R, 11 LTT and just 5 TBR including the Snellings (Fig. 27.5b), Stokes and Emu Bay. In addition, there are a few active and possibly elevated inactive cobble and boulder beaches composed of sediment derived from erosion of the adjacent cliffs.

There are just two regressive barrier systems on this coast at Middle River (Fig. 27.6b) and Emu Bay with volumes of 0.4 M m^3 (666 m^3 m^{-1}) and 15 M m^3 (2750 m^3 m^{-1}). The larger Emu Bay barrier curves to face northwest which has resulted in minor dune transgression driven by the westerly winds. The small north coast barriers and their low volumes (Table 27.4) are in sharp contrast to the large massive south and west coast barriers (Table 26.5), with the island's south and west

Fig. 27.5 SA:SCs:02.01.01-02 extend along Kangaroo Island's north coast. (Source: Google Earth)

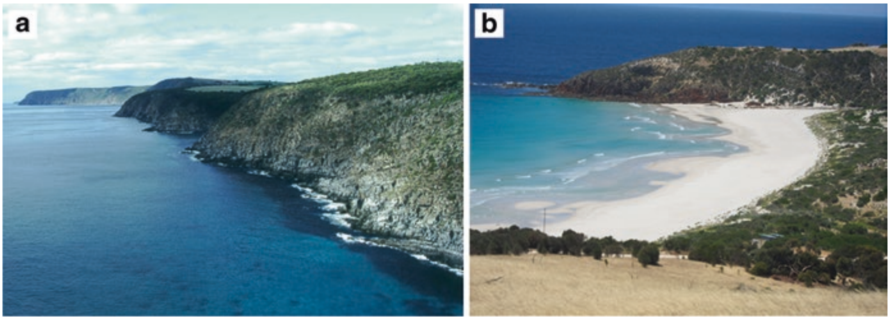


Fig. 27.6 (**a**) The steep cliffed north coast of Kangaroo Island looking towards Cape Torrens and (**b**) Snellings Beach with well-developed rip channels and the closed mouth of Middle River against the far rocks (KI 166). (Photos: AD Short)

coast having two orders of magnitude more sand. This can be attributed to the lower wave energy combined with a lack of accommodation space owing to the generally steep terrain, together with predominately long to offshore winds. While there is no morphological evidence of longshore transport along this coast, as will be seen in the next SC, there is a large accumulation of sand immediately downdrift of North Cape which appears to be a sink for sand moving eastwards along the north coast.

27.11.2 SC:SA02.01.02 Point Marsden–Kangaroo Head

SC:SA02.01.02 commences at North Cape-Point Marsden and includes the curving Shoal Bay and Eastern and Western coves terminating in the east at Kangaroo Head. The three bays are part of a northeast-facing three-armed embayment with a 30 km wide entrance and a shoreline distance of 76 km (Fig. 27.5). In contrast to the island's north coast, this SC has a lower coastline either consisting of low bluffs (<10–20 m) or beach and barrier deposits. It is also a very low energy north to east-facing lee coast with the wind predominately blowing offshore and the shoreline well protected from ocean swell and receiving only local wind waves, while tides increase slightly but remain micro (~1.4 m). The beaches are composed of medium (mean = 0.32 mm, σ = 0.11 mm), moderately sorted (mean = 0.77, σ = 0.35) sand, with an average of 28% carbonate (σ = 20%), though it ranges from 0 to 53%. The lower carbonate is a product of local terrigenous sources particularly from the small Cygnet River and erosion of the unconsolidated Quaternary bluffs in the Bay of Shoals and along Eastern Cove (0% carbonate) (Fig. 27.7b), the absence of waves to deliver shelf carbonate and a reliance solely on seagrass carbonate production. It is however a sedimentary shoreline with 44 beaches occupying 63 km (83%) of the shore. Owing to the very low wave height, the beaches are predominately low energy WD or TD. There are just three TBR's located on the more exposed Point

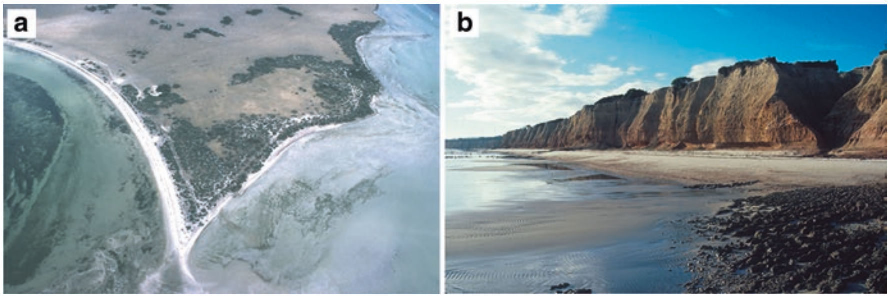


Fig. 27.7 (a) Cape Rouge at the northern tip of Kangaroo Island and its wide sand flats (KI 1–2); and b) the eroding red bluffs at Red Banks (KI 17). (Photos: AD Short)

Morrison and Kangaroo Head, including the 5.5 km long Island beach (KI 35), 14 R-LTT occupying 16% of the beaches by length, with B + RSF occupying 32% and B + SF (42%), indicating the dominance of the TD beaches (74%) (Fig. 27.7a). The ridged sand flats have an average of three ridges but range from 1 to 8.

While this is a low energy coast there is evidence of substantial longshore sand transport. A 10 km long very low energy sand spit extends southeast from North Cape-Marsden Head enclosing the shallow Bay of Shoals. It has an area of 15 km^2 and a potential volume in excess of 15 M m^3. The location and size of this spit would suggest the sand has been transported along the drift-aligned north coast bypassing the predominately cliffed shoreline at rates on the order of 2500 m^3 $year^{-1}$. In Eastern Cove the small Cygnet River has deposited an ~10 km^2 delta with river mouth spits indicating northerly sand transport. Short and Fotheringham (1986b) dated two inner shelly ridges on the delta at 2.6 and 2.3 ka and suggest that following their deposition the shoreline prograded as tidal flats for up to 1 km before the present outer ridges were deposited, possibly owing to a fall in sea level. Along the southern shore of the cove is the 6 km long Morrison Beach barrier (KI 16) which consists of a 1.6 km wide series of west-trending recurved spits and 200–800 m wide sand flats, all indicative of westerly sand transport into the cove. Short and Fotheringham (1986b) dated the innermost swale at 4.6 ka indicating that the wide series of ridges commenced rapid progradation after this date. Morris (1976) suggested a higher sea level eroded the strand plain following which a fall in sea level deposited the ridges which contain heavy minerals, possibly derived from the Cygnet River and transported longshore to the ridges. Short et al. also surveyed shelly beach ridges at Brownlow, the Brownlow golf course and the Cygent River and found there was no evidence to suggest a Holocene fall in sea level. However, at Pennington Bay on the southern side of the island, they also surveyed the Holocene rock platform which has an upper and lower level of planation, suggesting there has been a 0.5 m fall in sea level since the upper platform was formed. However, more detailed investigations are required to resolve the Holocene sea-level history on the island.

In Western Cove the higher energy Island beach (KI 35) has built westwards across the mouth of the American River estuary to form a regressive barrier that widens to 600 m in the west as well as supply sand to the 4 km^2 flood tide delta.

Based on the volume of the barrier and the tidal delta, this would represent westerly longshore transport at rates since the PMT (~7 ka) between 800 m^3 $year^{-1}$ for Morrison beach and 650 m^3 $year^{-1}$ for Island beach, both appropriately low rates for this low energy coast. Based on all the barriers in the SC, it has a total barrier volume of 6 M m^3 (340 m^3 m^{-1}), the low volume again indicative of the low wave energy and low rates of supply in these otherwise large sediment sinks in Bay of Shoals and Western and Eastern coves. There is also likely to be a larger volume supplied to and deposited in the flood tide deltas, Cygnet River delta and the tidal flats.

27.11.3 SC:SA02.01.03 Cape Jervis–Cactus Canyon

SC:SA02.01.03 is located along the southwestern end of the Fleurieu Peninsula and extends for 63 km from the southern tip at Cape Jervis to the northern end of the cliffs at Sellicks Beach/Cactus Canyon (Fig. 27.8), beyond which are near continuous beaches up to Adelaide. This is a generally steep shore composed of 80 m high

Fig. 27.8 SC:SA02.01.03 the southwest Fleurieu Peninsula. (Source: Google Earth)

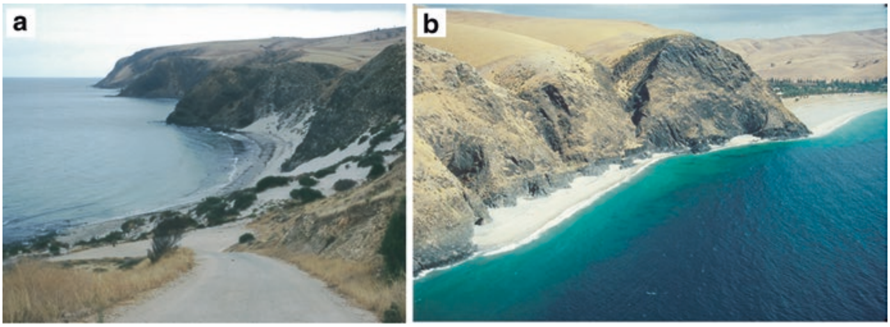


Fig. 27.9 (**a**) Climbing dunes at Morgans Beach (SA 188) and (**b**) the cobble-filled Rapid Bay leaking sediment northwards along the base of the cliffs (SA 201-2). (Photos: AD Short)

metasedimentary cliffs and slopes rising inland to between 100 and 200 m (Fig. 27.9a). The slopes are heavily dissected by small streams and the small Yankalilla River at Normanville. Rock platforms and cobble-boulder beaches fringe the base of the cliffs, while there are 20 small sandy beaches located at the mouths of the valleys, which occupy 25 km (37%) of the rocky coast. They tend to be composed of moderately well-sorted medium to coarse sand, with an average of 43% carbonate (range 7–86%), and include some cobble and boulder beaches, the coarse material derived from the eroding cliffs (May and Bourman 1984; Mitchell and Lee 1987). The beaches are all sheltered from most westerly swell by Kangaroo Island (Fig. 27.3), receiving predominately westerly wind waves which maintain either low energy R or LTT beaches. At Rapid Bay, Bourman (1988, 1990) recorded the progradation of the cobble beach shoreline owing to the dumping of quarry waste from the adjacent limestone quarry, which prograded up to 250 m into the gulf by 1975. When waste dumping ceased in 1982, the beach began to rapidly recede as the gravel was transported northwards on this drift-aligned coast (Fig. 27.9b) and has reached Second Valley located 2 km to the north. Further north at Wirruna, a small boat harbour (St Vincent Marina) (Chappell 1989) constructed in 1997 has begun trapping sand against its western updrift attached breakwater, with proposals to extend the breakwater.

There are three embayed regressive barrier systems along this rocky coast at Rapid Bay, Normanville and Myponga, with a combined length of 9 km and total volume of 8 M m^3 (910 m^3 m^{-1}). The largest is the 200 m wide, 15 m high Normanville barrier which is backed by an interbarrier depression and then inner Pleistocene barrier (125 ka) and backing Pleistocene cliffline (Bourman et al. 1999). The small barrier volume reflects both the lack of accommodation space and generally low wave energy. Sand and gravel are however being transported northeast along the base of the cliffs at what are assumed to be low rates. In doing so this is the start of a major longshore transport system that extends all the way to Adelaide.

27.11.4 SC:SA02.01.04 Cactus Canyon–North Haven

SC:SA02.01.04 encompasses the highly developed Adelaide coast, extending for 68 km from Sellicks Beach generally northwards to Adelaide's North Haven-Outer Harbour (Fig. 27.10). The coast is part of the Adelaide coastal plain composed of undifferentiated Cainozoic sediments derived from the backing Mount Lofty Ranges which have deposited an extensive outwash plain that widens to 25 km in the north. Along the coast the southern 40 km of the 100 m high plain has been cliffed between Sellicks and Seacliff, while to the north it reaches the coast at a low gradient. While this coast is located further into the gulf, its westerly orientation and position relative to Investigator Strait allow it to receive low to occasional moderate westerly ocean swell, together with westerly wind waves (Riedel et al. 2005). Tide range also

Fig. 27.10 SC:SA02.01.04 the Adelaide coast. (Source: Google Earth)

increases up the gulf rising from 1.4 m on northern Kangaroo Island to 1.9 m at Port Noarlunga, 2.5 m at Adelaide and 3 m at the head of gulf. This is a predominately sandy SC with 20 beaches occupying 57 km (84%) of the shore, the remainder the eroding bluffs in the south, some of which have required stabilisation. The coast's exposure to the occasional swell and westerly seas results in an increase in wave height along this section peaking in the south between Sellicks and O'Sullivan beaches, where the beaches range from LTT to TBR, and decreasing northwards towards Adelaide where they are LTT. However more importantly the southerly swell and southwest summer waves drive a northerly longshore transport system along this coast to its terminus at Outer Harbour.

The Adelaide coast is therefore a drift-aligned coast with sand moving northwards and being deposited in three regressive barrier systems: the smaller Sellicks-Aldinga and Southport both with volumes of 5 M m^3 and the large 100 M m^3 LeFevre Peninsula, the ultimate sink for the sand. All three barriers and shorelines have been heavily modified by development and along the LeFevre Peninsula by shoreline protection and dune management together with sand nourishment, back-passing and bypassing (Tucker et al. 2013). Sand transport along the LeFevre Peninsula is manifest along the beaches as a series of shore-attached northward-trending bars which migrate northwards and around Semaphore form three shore-parallel bars (Fig. 27.11b), the bars produced by a combination of the low gradient surf zone, occasional higher waves and the northerly transport. This highly developed and in places at-risk metropolitan coast has been intensively monitored and investigated and is one of the most managed sections of the Australian coast. For an overview of the coast and its processes and management, see CPB (2005), Harvey and Bowman (1987), Short (2012) and Bourman et al. (2016).

The Holocene evolution of the coast was investigated by Harvey and Bowman (1987) and Harvey (2006) who traced the evolution of the LeFevre Peninsula a 16 km long 2.5 km wide series of recurved spits and beach-foredune ridges that represents the sink for the northerly sand transport. The southernmost ridges date 7–6.5 ka indicating the development started with the sea-level stillstand when sea level stood 2.1 m above present (Harvey et al. 2002). It then continued to build

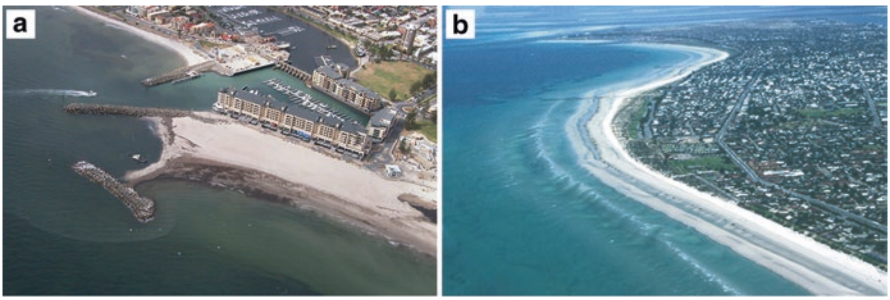


Fig. 27.11 (**a**) The trained mouth of the Patawalonga River at Glenelg (SA 231) with sand accumulating against the southern breakwaters (Photo: S Daw) and (**b**) multiple bars at Semaphore with the LeFevre Peninsula behind (SA 232) (Photo: AD Short)

northerly at decreasing and fluctuating rates, with the transport rate peaking at 6.5 ka at around 80,000 m^3 $year^{-1}$ and then fluctuating between 40,000 and 10,000 m^3 $year^{-1}$ between 5.5 and 1 ka, and is now close to zero at the Outer Harbour terminus. This trend is confirmed by ongoing monitoring of the coast and its sediment transport by CPB (2005). This report indicates that transport decreases northwards in line with the decreasing wave height, from a maximum of 50,000–75,000 m^3 $year^{-1}$ at Kingston Park to 40,000–50,000 m^3 $year^{-1}$ between Glenelg and Semaphore Park and > 25,000 m^3 $year^{-1}$ north of Semaphore (Thom et al. 2018). The final sink for the sand is the Adelaide harbour; however, this has ceased since construction of the Outer Harbour training walls between 1903 and 1905 which lead to 250 m of shoreline progradation against the southern wall, followed by construction of the North Harbour Marina 1.5 km to the south in 1974 which resulted in 200 m of shoreline accretion. To reduce this sand accumulation, a detached breakwater was constructed 7 km to the south at Semaphore in 2005 (Townsend 2005; Guy 2009). Sand is trapped in lee of the breakwater and then removed and piped and trucked south to be backpassed and recycled into the Adelaide beach sand transport system.

This SC is also paralleled by seagrass meadows which have been dying back in recent decades (Thomas 1982, 1983) and releasing more sand for onshore and alongshore transport, which has resulted in an increase in sand transport from 40,000 m^3 $year^{-1}$ to between 50 and 70,000 m^3 $year^{-1}$ (Deans and Townsend 2003). As only 5000 m^3 $year^{-1}$ is estimated to enter the system from the south, the updrift system is unable to supply this rate and is supplemented by recycling and sand nourishment from onshore and nearshore dredged sand, with 4 M m^3 of recycled and/or nourishment sand added to the system between 1973 and 2005 (Byrne et al. 1983; Tucker and Penny 1989; Deans 1999; Deans et al. 2003). The northerly transport is both assisted with sand trapping and inlet sand bypassing at Glenelg (Fig. 27.11a) and West Beach, while further north it backpassed by both trucks (10–50,000 m^3 $year^{-1}$) and pipes (75,000 m^3 $year^{-1}$) to a number of locations along the coast (Thom et al. 2018). Rising sea level and increased water depth in the gulf are expected to lead to a further increase in wave energy and sand transport (CPB 2005). The northern end of this SC is also experiencing a rise in sea level due in part to land subsidence (−1.8 to −2.2 mm $year^{-1}$) around the Adelaide harbour owing to groundwater extraction (Belperio 1993), with a sea level rise of 0.21 mm $year^{-1}$ at Adelaide's Outer Harbour, increasing to 0.59 mm $year^{-1}$ in the Inner Harbour (Harvey et al. 2002).

In summary, the Adelaide coast has experienced major longshore transport since the PMT which has built the extensive LeFevre Peninsula. Since European settlement, development of the coast has impinged upon this system leading to infrastructure and property being placed at risk. This has been addressed by a range of hard and soft management options including sea walls, groynes, detached breakwaters and sand bypassing, nourishment and backpassing. Given the present shortfall in sediment, rising sea level and predicted increase in transport rates the entire system will require ongoing management to maintain the beaches and safeguard assets, which Townsend and Guy (2017) concluded will mean ongoing sand management and in places hard protection measures.

27.11.5 SC:SA02.01.05 North Haven–Clinton

SC:SA02.01.05 commences immediately north of Adelaide's Outer Harbour and trends roughly north-northwest for 99 km to Clinton at the head of the gulf (Fig. 27.12). Once north of Adelaide the coastal plain widens to as much as 80 km, causing the coastal gradient to decrease while wave energy decreases dramatically owing to lack of south swell and the narrowing gulf fetch which limits wind wave generation (Fig. 27.3), combined with the increasing tide range and extensive intertidal sand flats. As a consequence, this is a very low energy TD sedimentary coast with a mix of TD beaches and kilometre wide sand-mangroves-samphire and supratidal flats. There are a few small low-lying coastal communities and towns spread along the coast including Middle Beach, Webb Beach, Parham (Fig. 27.13a) and Port Wakefield. The coast contains 12 beaches which occupy 49 km (69%) of the shore. The beaches are all either B + SF or B + TSF, with their sand flats often a few kilometre wide. The remainder of the coast is mangrove-fringed sand flats grading gulfwards into subtidal seagrass meadows and landwards into samphire and supratidal flats, in places the flats reaching 8 km in width. The beaches are composed of coarse poorly sorted shelly sand (70–98% carbonate) deposited in the high tide

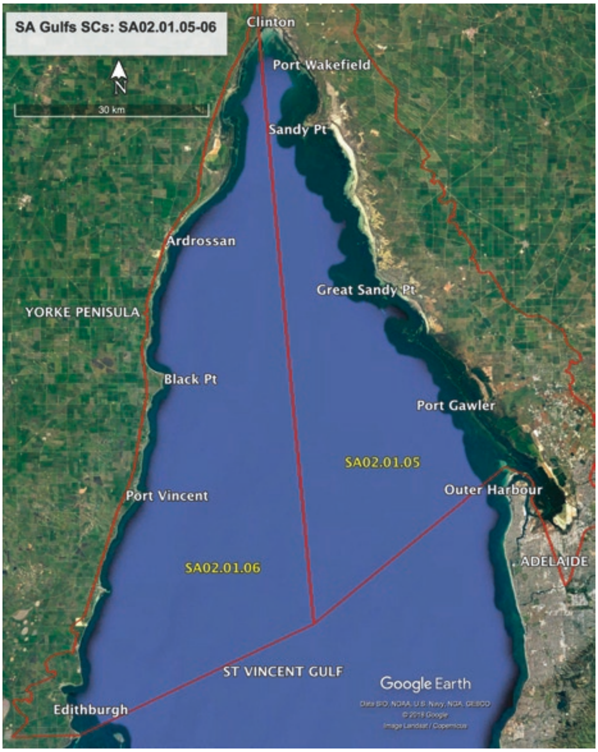


Fig. 27.12 Northern St Vincent Gulf contains SCs:SA02.01.05 and 02.01.06. (Source: Google Earth)

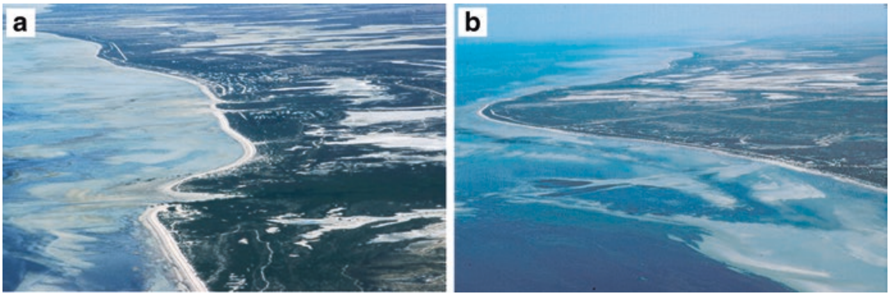


Fig. 27.13 (**a**) View north towards Thompsons-Praham beaches (SA 238) and (**b**) the wide low gradient Great Sandy Point (SA 238). (Photos: AD Short)

zone by periodic high wind wave events, with some sited to the rear of the mangroves where they form beach ridges. The supra- to intertidal flats can be up to 3–4 km wide, their width assisted by the ~2 m fall in sea level since the PMT (Harvey et al. 2002). The wide inter- to subtidal zone represents the accumulation of primarily organic detritus derived from the seagrass meadows which produce a range of calcareous algae, foraminifers and molluscan and which over time have aggraded the banks vertically to reach sea level and prograded horizontally 1–2 km out into the gulf. There is very little terrigenous sediment in the gulf owing to the surrounding aridity of the landscape (precipitation = 200–300 mm). The northern gulf is locally referred to as the Samphire coast owing to the extensive salt marshes which total 6000 ha in area (Fotheringham and Coleman 2008).

Mangroves occupy the first 40 km of shoreline north from Barker Inlet up to Light Beach. This is followed by 35 km of discontinuous low shelly ridges, with several areas of regressive shelly ridges forming low strand plains up to several hundred metre wide (Fig. 27.13b). These occur at Light-Prime beach, Thompson-Webb-Parham beaches, north of Parham (where they are mined for shell grit) and Middle Spit (SA 236–241). North from Bald Hill beach (SA 242), mangroves run continuously for the final 20 km to the head of gulf. At the head are the very low energy Clinton beaches (SA2 46–8) which curve around the head for 6 km and are backed by up to 300 m of regressive shelly ridges, then 1.5 km wide supratidal flats, while the intertidal sand flats extend up to 3 km into the bay. While there has been considerable shoreline regression in the vicinity of the ridges as well as the extension of the sand flats, there is little evidence of longshore transport, with the ridges at Light Beach indicating both northerly and southerly trending ridges. Rather this low energy system is accumulating in situ produced carbonate detritus to build both upwards and outwards.

Given the very low gradient of the inter- to supratidal flats, any rise in sea level will result in inundation of the upper flats, major shoreline recession and landward migration of the sub-, inter- and supratidal ecosystems. At Port Gawler Cann and Jago (2018) observed a rapid spreading of mangroves between 1995 and 2016 that they attribute to increased sedimentation on the tidal flats, as well as possible assistance from sea level rise of 3 mm year^{-1} in the region. Further north at Port Wakefield, Fotheringham et al. (2018) resurveyed vegetation transects and found that between

2000 and 2018, there has been a small landward shift in plant species and plant communities, which they expect to be related to sea-level rise.

27.11.6 SC:SA02.01.06 Clinton–Sultana Point

SC:SA02.01.06 occupies the northwestern shore of St Vincent Gulf which is also the eastern shore of Yorke Peninsula. It extends for 125 km from the head of gulf at Clinton to the southeast 'heel' of the foot-shaped peninsula at Sultana Point (Fig. 27.12). The coast is aligned to the south-southwest along a series of faults and consists of low cliffs and bluffs cut into the folded Cainozoic limestone overlying Hindmarsh Clay. Where the clay is exposed, as at Ardrossan (Fig. 27.14a), the 20 m high cliffs are eroding rapidly at rates between 3 and 30 cm year^{-1} (Bourman et al. 2016), while the limestone is more resilient, and elsewhere the cliffs are protected by regressive ridges and beaches.

This is a low energy lee shore sheltered from ocean waves and with the dominant westerly winds blowing offshore. As a consequence, wave energy is very low, while tides increase from 2 m at Edithburgh to 3 m at head of gulf, resulting in a TD coastline. There are a number of shack communities and small coastal towns and former ports strung along the eastern shore from the north; these are Port Clinton (260), Ardrossan (1200), Rouges Point (shacks), Pine Point (90, shacks), Port Julia (50, shacks) (Fig. 27.14b), Sheoak Flats (180, shacks), Port Vincent (500), Stansbury (550), Wool Bay (600), Coobowie (220) and Edithburgh (500).

Mangroves occupy the northern 30 km of shore, with the remainder of the coast to the south a near continuous series of 90 low energy TD beaches. The beaches begin in the north as B + TSF, with the majority (84) B + SF. The intertidal sand flats are up to 1 km wide in the north and decrease southwards where they range from 200–300 m. The beaches and sand flats occupy 70 km (56%) of the shore, with mangrove-fringed sand flats in the north and series of low sedimentary bluffs along

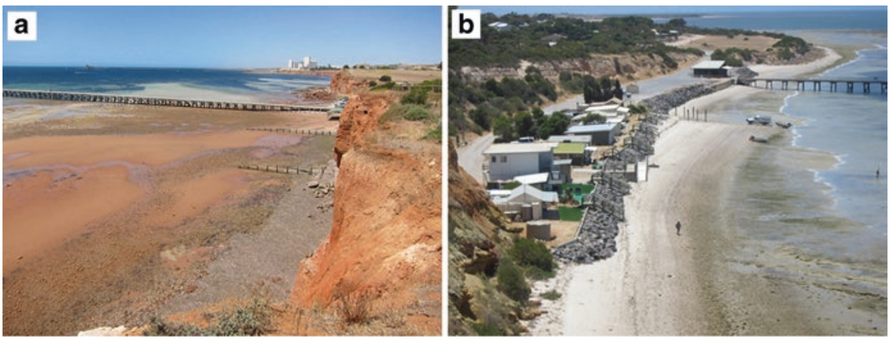


Fig. 27.14 (**a**) Eroding red bluffs of Hindmarsh Clay at Ardrossan (SA 250) and (**b**) shacks and a protective seawall and jetty at Port Julia (SA 279). (Photos: AD Short)

the rest of the shore, which also back most of the beaches. The beaches are composed of poorly sorted, medium to coarse sand with a considerable range in carbonate (mean, 46%; range 5–97%) (Fig. 27.2). The carbonate is derived from the adjacent seagrass meadows, while the lithic material has probably originated from the gulf floor, northerly longshore transport, erosion of the bluffs and cliffs and supply from the small streams and gullies that drain the bluffs.

There are six low energy barrier systems along this coast. Three are a crenulate series of low regressive 100–200 m wide beach ridges at Parara-Rouges points, Pine Point and She Oak Point, together with three 1 km wide cuspate forelands at Black, Surveyor and Oyster points. They occupy just 14.5 km (12%) of the shore and have a total volume of 15.5 M m^3 (1070 m^3 m^{-1}). There is evidence of limited northerly longshore sand transport with sand flats building out on the southern side of the forelands, and bypassing around Black and Surveyor points, and now building up on the southern side of the Port Vincent Marina built in 2002. There is also evidence in the form of small north-trending spits at Port Clinton, Parara, Rouges Point and Black Point and sand building up against the groyne at Port Julia. All this indicates ongoing northerly transport at what would be very low rates perhaps on the order of 100's m^3 $year^{-1}$.

Like the eastern gulf shore, this coast is susceptible to sea-level rise owing to the extensive intertidal flats and backing low beach ridges, which are all prone to inundation. The coastal communities have mixed risk, with some are located on top of the coastal bluffs and clear of coastal impacts, while a number are located on the low-lying ridges and at considerable risk from both erosion and inundation including Port Clinton, Pine Point, Port Julia, She Oak Flat, Port Vincent, Stansbury and Coobowie. A number of these communities have already constructed seawalls (Fig. 27.14b) and groynes to prevent both contemporary erosion and inundation.

27.11.7 SC:SA02.01.07 Sultana Point–Cape Spencer

SC:SA02.01.07 represents a transition in the gulf coast as wave energy increases and tides decrease. This section of the coast is located along the base of the 'foot' of Yorke Peninsula and generally faces south (Fig. 27.15). It extends for 105 km from Sultana Point (Fig. 27.16a) to Cape Spencer the exposed southwestern tip and toe of the peninsula. The only development on the coast are the shacks at Foul Bay (50) and the small communities of Port Moorowie (60) and Marion Bay (180). In between are the four-curving south-facing Waterloo, Sturt, Foul and Marion bays, each bordered by resistant Precambrian and Cambrian rocks. The beach sediment is predominately well-sorted, medium carbonate-rich sand (83%) (Fig. 27.2), which combines with the low tide range (~1 m) and increasing wave height (~1 m) to maintain a series of 56 beaches which range for TD B + SF in the west and in the sheltered western end of the bays, to cusped WD R along most of the coast. The beaches dominate the coast occupying 77 km (73%) of the shore, mainly in the four bays but also some of the rocky section, particularly between Foul Bay and Cape

Fig. 27.15 SCs:SA02.01.07 and SA02.02.01 – the foot of Yorke Peninsula. (Source: Google Earth)

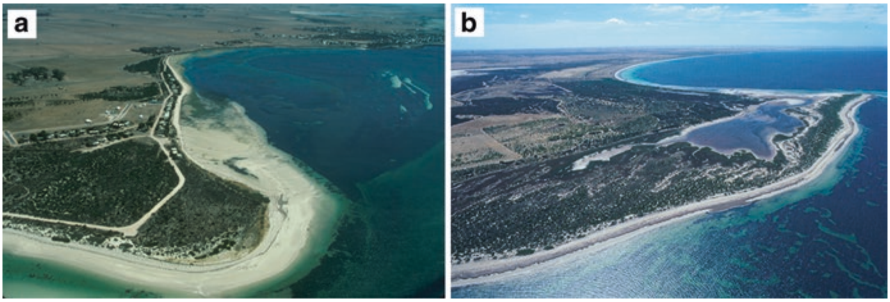


Fig. 27.16 (**a**) Sand is bypassing around Sultana Point (SA 335-6) as indicated by the north-trending sand waves; and (**b**) the eastern end of the series of east-trending spits that from Point Davenport (SA 356). (Photos: AD Short)

Spencer where there are 32 small embayed beaches averaging 0.34 km in length, together with the 10 km long Marion Bay beach.

This SC becomes increasingly more exposed to the west with the southwest swell running along the south-facing drift-aligned shore delivering carbonate-rich shelf sand to the shore, which in places faces into the prevailing westerly winds. This has led to considerable easterly longshore sand transport and the development of eight main barrier systems that occupy 61 km (58%) of the shore. They have a total volume of 245 M m^3 (3990 m^3 m^{-1}). Beginning in the east, the barriers consist of the Sultana Point regressive cuspate foreland (Fig. 27.16a); the Salmon Beach crenulate foredune; minor dune transgression including clifftop dunes along Waterloo Bay; transgressive and then regressive foredunes in Sturt Bay; an up to

900 m wide series of foredune ridges in Foul Bay which also contains the 2.5 km long series of recurved spits that have formed Point Davenport (Fig. 27.16b); and moderate but stable dune transgression including clifftop dunes along Salmon Beach and Marion Bay. There is considerable evidence of the easterly sand transport not just at Davenport Point but also the easterly orientation of the Sultana Point ridges and sand waves in lee of Troubridge Point, Point Gilbert, Point Davenport, Point Yorke and Penguin Point at Marion Bay. Given the low to moderate level of wave energy along the coast, rates of easterly transport would be expected to be on the order of <10,000 m^3 $year^{-1}$, with rates decreasing to the east.

27.11.8 PC Overview

St Vincent Gulf PC contains four distinct shores. Along the northern coast of Kangaroo Island, it grades east from the rugged resilient northern coast to the sheltered sediment-filled bays; likewise the eastern Gulf St Vincent begins in the south with steep cliffs, followed by the barriers and beach of the heavily managed Adelaide coast. North of Adelaide is the very low gradient, low-lying shore dominated by wide intertidal sand flats, backed by mangroves in the north and south and crenulate regressive shell-rich beach ridges systems along the centre, with sediments derived from the seagrass meadows. The eastern Yorke Peninsula coast is a likewise low energy TD coast but with steeper gradients leading to near continuous low bluffs and cliffs fronted by low narrow regressive beach ridges, some cuspate forelands and sand flats that narrow from 1 km in the north to a few hundred metres in the south and sediment sourced from the seagrass meadows, cliff erosion and stream supply. Cliff erosion is an issue in places, and CPB (2014) presents a management strategy for managing cliff erosion hazards, which threaten 7000 sites state wide. Along the more exposed southern peninsula coast, wave energy increases, as tide decrease which is reflected in the supply of carbonate-rich finer shelf sand, pronounced easterly sand transport and barrier ranging from regressive foredunes to moderate dune transgression including clifftop dunes, all now stable. As sea level rises, the deeper water will allow wave energy to increase within the gulf, accelerating longshore transport and shoreline retreat. The low-lying, low gradient parts of this coast are already exposed to inundation and are most susceptible to rising sea level which will threaten the already at risk low-lying shacks and communities, accelerate cliff erosion as well as generate landward migration of the tide-dependent seagrass, mangrove and salt marsh ecosystems.

27.12 PC:SA02.02 Spencer Gulf

Spencer Gulf is a large shallow (50 to <20 m deep) funnel-shaped gulf with a 78 km wide island-cluttered entrance between the eastern Cape Spencer and western Cape Catastrophe, which extends for 320 km north-northeast to Port Augusta (Fig. 27.1), with the eastern shore extending for 485 km and western for 494 km. The gulf is part of the Pirie Basin in the north with a structurally-controlled west coast which exerts considerable bedrock control, while the east coast is dominated more by Pleistocene and Holocene marine sediments. In the south the Gawler Craton dominates the western gulf and the entrance islands and central-eastern Yorke Peninsula shore, with sedimentary rocks forming the southern Yorke Peninsula coast (Gostin and Hill 2014). There is considerable evidence of ~5 m higher Holocene sea level a result of regional uplift with extensive elevated shingle ridges that were deposited when both sea level and wave energy was higher (Gostin and Hill 2014; Bourman et al. 2016). The climate ranges from Mediterranean in the south with rainfall reaching 600 mm at Port Lincoln reducing to 250 mm at Port Augusta which has a semi-arid climate. As a result of the low rainfall, there are just a few small usually dry streams along the southwest coast (Driver, Dutton and Todd). Because of the restricted circulation, little freshwater inflow and high evaporation rates, the gulf is an inverse estuary with salinity increasing northwards and reaching 34–49°/$_{oo}$, as well as water warming to 28 °C in summer. Tides also increase northwards from 1.5 m at Port Lincoln to 1.8 m at Port Neil, 2.6 m at Whyalla and 3.2 m at Port Augusta. Ocean waves are restricted to the southeast corner of the gulf and part of the central-western shore (Fig. 27.3), with south through westerly wind wave prevailing through most of the gulf, producing a predominately TD shore with some exposed sections having WD beaches. The gulf, particularly the northern gulf, has extensive intertidal sand flats and subtidal seagrass meadows, the latter acting as a carbonate factory to supply carbonate detritus (algae, seagrass, molluscs and bryozoans), part of four depth-dependent carbonate environments identified by Burne and Colwell (1982). The detritus from the seagrass meadows contributes to the sand flats and backing beach ridges. The gulf contains six SCs, four on the eastern Yorke Peninsula shore and two on the western Eyre Peninsula shore, all of which are discussed below.

27.12.1 SC:SA02.02.01 Cape Spencer–Corny Point

SC:SA02.02.01 is the most southern, most exposed and highest energy of the gulf SCs. It extends for 67 km along the west-facing toe of Yorke Peninsula between 80 m high Cape Spencer and 20 m high Corny Point (Fig. 27.15). The southwestern corner from Marion Bay around to Gleesons Landing is located in Innes National Park, while the rest of the coast is undeveloped apart from access roads, cleared farmland and lighthouses at either end. The coast is dominated by calcarenite covered Gawler Craton granite forming the prominent 20–80 m high headlands and cliffs with generally moderate to occasionally high energy beaches in between (Fig. 27.17). Tides are micro (~1 m), and as the coast faces due west-northwest across the gulf entrance, it is able to receive ocean swell from this quarter, which tends to run up the west coast and along the southern coast. It is also exposed to the full forces of the predominately westerly winds.

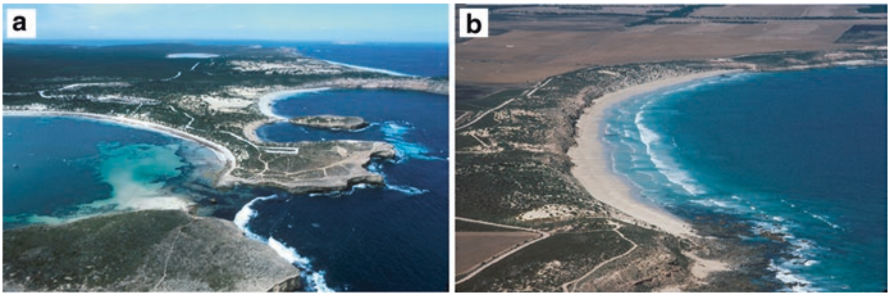


Fig. 27.17 (**a**) Groper Bay (right) and Pondalowie Bay are located in lee of breaches in the Pleistocene dune calcarenite (SA 404–6); and (**b**) Berry Bay is backed by a bulge of blufftop dunes (SA 446). (Photos: AD Short)

The exposed location of the shore has enabled the waves to deliver large volumes of carbonate-rich shelf sand to the shore and beaches which throughout the Pleistocene has been deposited in now lithified transgressive dune systems which at Cape Spencer form 80 m high calcarenite cliffs. The modern beach sand is carbonate-rich (79%) moderately well-sorted medium sand (Fig. 27.2). There are 57 beaches along this section with a total length of 44 km (66%); they average 0.8 km in length with Formby Bay (SA 432) the only long beach at 6.5 km. The beaches range from 20 exposed longer (1.1 km) TBR-RBB (Table 27.3; Fig. 27.17b), while the remainder are shorter (0.65 km) lower energy R-LTT which are afforded with some protection by the headlands, points, rocks and reefs (Fig. 27.17a).

The entire south Innes National Park section is blanketed by Pleistocene dune calcarenite extending in places for 9 km inland and to heights of 20–80 m, most of it cliffed along the coast. There are 13 exposed barriers along this section occupying 40 km (70%) of the coast, including all west- to southwest-facing shores. They are all backed by both Pleistocene dune calcarenite and Holocene transgressive dunes, the latter extending on average 1.3 km inland with some to 2.5 km, of which 22% are presently unstable. They have a large total and per metre volumes of 1030 M m^3 and 25,866 m^3 m^{-1}, an order of magnitude greater than the neighbouring south coast SC and two orders greater than the peninsula's west coast SC. James et al. (2015) examined the Cape Spencer calcarenite and found it consists of two distinct late Pleistocene complexes. The lower complex which forms the bulk of the cliff consists of a series of stacked palaeodunes and intervening palaeosols. The dune sediments are predominately bivalves, echinoids, bryozoans and small benthic foraminifera, which is similar to sediments forming offshore today on the adjacent shelf in a warm-temperate ocean. In contrast, the upper dune complex is dominated by bivalves, geniculate coralline algae and benthic foraminifera, together with sparse peloids and ooids. They concluded that these formed when palaeocean temperatures were sub-tropical, somewhat warmer than offshore carbonate factories in the region today. They tentatively correlated the lower complex with Marine Isotope Stage 11 (~420-330 ka) and the upper with Stage 5e (~90 ka).

27.12.2 SC:SA02.02.02 Corny Point–Point Pearce

SC:SA02.02.02 begins at Corny Point, which is composed of resilient ancient gneiss, where the coast turns and trends generally east for 40 km towards Hardwicke Bay, where it turns again and trends north for 60 km to Pearce Point, a total shoreline of 108 km (Fig. 27.18). There are a few small communities along this section at Corny Point (270), The Pines (110), Point Souttar (30), Port Turton (350), Hardwicke Bay (130), Port Rickaby (260) and the small town of Port Victoria (350). This is a generally low-lying coast with either beaches and dunes or low calcrete bluffs, with an extensive 15 km long dry lagoon behind Hardwicke Beach which may have linked to the Sturt Bay in the past truncating the western part of the peninsula. Sediments in this lagoon as discussed in Sect 27.6 were dated by Pan et al. (2018) to reconstruct the last interglacial (5e) highstand. The coast north of Hardwicke Bay is composed of erodable glacial sediments which have resulted in the low-lying low gradient coast that rises gently inland to over 100 m. More resilient rocks outcrop northwards from Renowden Rocks and form a series of low headlands.

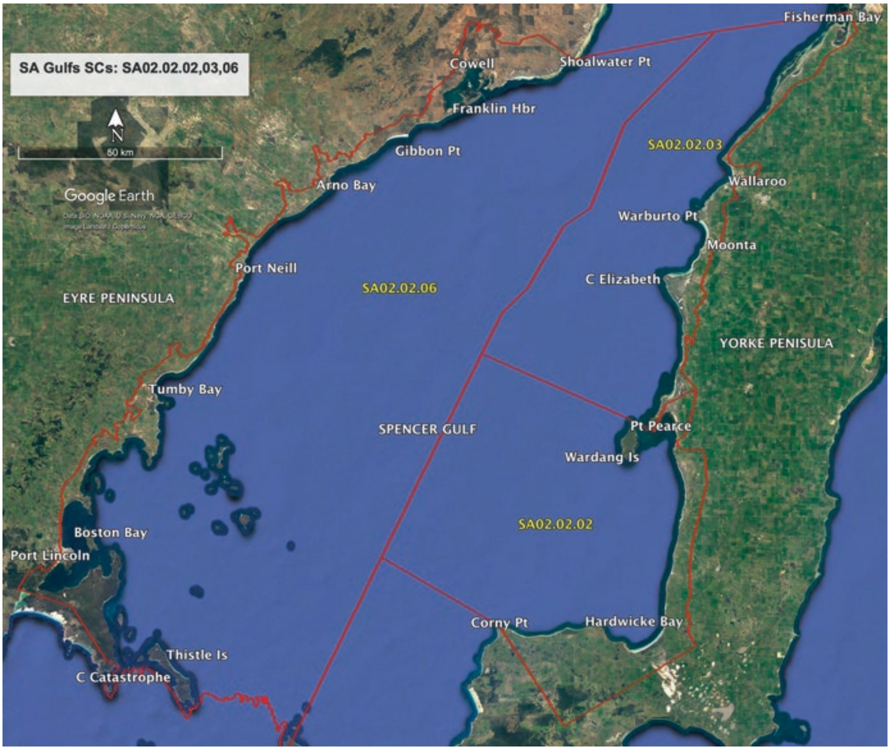


Fig. 27.18 The lower Spencer Gulf contains the western Yorke Peninsula SCs SA02.02.02-03, and eastern Eyre Peninsula SC:SA02.02.06. (Source: Google Earth)

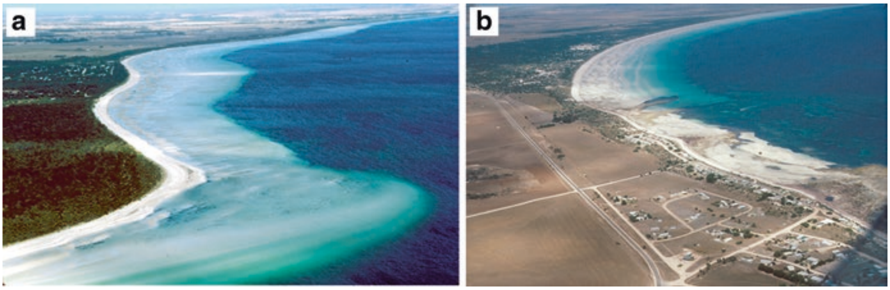


Fig. 27.19 (**a**) 400 m wide sand flats at Couch Beach (SA 454) and (**b**) view south along Hardwicke Bay shacks and beach with ridged sand flats (SA 464). (Photos: AD Short)

This coast is partly sheltered from waves by its initial northerly orientation and then as its turns to face west by the distance from the gulf entrance, with little ocean swell reaching the shore (Fig. 27.3). Rather it is exposed to westerly wind waves with a fetch of more than 100 km, the longest in the gulf, while tides remain micro between 1.3 and 1.4 m. Beach sediments along this section are medium, moderately sorted, carbonate-rich (78%) sand (Fig. 27.2) most likely derived from both the inner shelf and the seagrass meadows that fringe all the beaches. The low to occasionally moderate wind waves and micro-tide combine to maintain a predominately TD coast with B + SF (Fig. 27.19a) and some TSF including a mix of R + RF, with one well-developed B + RSF in the curving Hardwicke Bay (Fig. 27.19b), together with a few WD R beaches. The predominately TD beaches reflect the dominance of the micro-tides over the low waves.

There are eight barrier systems along the coast with a total volume of 325 M m^3 (5030 m^3 m^{-1}) that range from regressive to stable transgressive. Just inside Corny Point are a series of small transgressive dunes that soon grade eastwards into the beginning of a near continuous series of regressive foredunes which reach their maxima just past The Pines, 20 km to the east, where 60 ridges extend 3 km northwards into the gulf. In the southeast corner of the bay is the next transition which commences at the western end of a curving 10 km long barrier consisting of a 1 km wide regressive system, which as the beaches swings to face the northwest the ridges have been overrun by now stable parabolics that extend 1.4 km inland. The remainder of the coast faces due west with minor 100–300 m wide dune transgression along a 15 km long section of coast between Bluff beach and Port Rickaby and then for 20 km between Port Rickaby and Port Victoria where some of the dunes widen to 1.5 km. As soon as the coast reaches the shelter of Pearce Point and Wardang Island and begins to curve to the west, the dunes are replaced by 20 low regressive beach ridges on a 500 m wide strand plain fronted by 1.5 km wide sand flats.

The nature, location and size of the barriers indicate that there has been substantial onshore and longshore transport along the southern shore past Corny Point to The Pine and into Hardwicke Bay. There has been massive sand accumulation on

The Pines cuspate foreland which has an area of 20 km^2 and a conservative volume on the order of 40 M m^3. The alignment of the ridges indicates that the apex of the foreland has been migrating eastwards as it progrades into the gulf, at the same time eroding truncating the ridges on the western side of the foreland. This erosion is manifest in ongoing shoreline recession along The Pines shoreline. Further east sand is moving around the attached breakwater at Port Turton followed by a 1.5 km long series of south-trending intertidal ridges that have contributed to Hardwicke Bay sand flats and barrier which total 60 M m^3 (6315 m^3 m^{-1}). To the north of Hardwicke Bay, the eastern shore appears to have received limited sediment from the adjacent gulf with possibly minor northerly transport with the ultimate sink in the 2 km wide sand flats of Port Victoria and its backing regressive beach ridges. The present stability of all the transgressive dunes suggests that either the sediment supply has ceased or the development of the sand flats has attenuated and decreased breaker wave energy, assisted by the fall in sea level.

Most of the communities along this SC are either located on the low calcarenite bluffs or well set back from the beaches resulting in few properties at risk, apart from the beachfront properties at Hardwicke Bay and Port Rickaby, which will become increasingly prone to erosion and inundation.

27.12.3 SC:SA02.02.03 Point Pearce–Fisherman Bay

SC:SA02.02.03 occupies the 148 km long northwestern coast of Yorke Peninsula that faces generally northwest across the gulf and is bordered by Point Pearce in the south and Fisherman Bay in the north, with protruding Point Pearce, Cape Elizabeth, Warburto Point and Point Riley in between, the latter three bordering Moonta and Wallaroo bays (Fig. 27.18). This is the most developed section of the peninsula coastline with the communities and towns of Balgowan (70), Port Hughes-Moonta (650), the large Wallaroo (4000), Tickera (320) and Port Broughton (1000) with farmland extending along the coast. The coast is generally low-lying with the southern bluffs around Balgowan composed of the red Hindmarsh Clay. The protruding Cape Elizabeth is a low cuspate foreland with 20 m high dune flanking its exposed western shore. North from Port Hughes, resistant conglomerate outcrops along the shore forming rock platforms and low bluffs, followed by the eroding cliffs of Hindmarsh Clay. Further north is Bird Island (quartzite) and Point Riley (limestone, schist and granite), while north from Point Riley the 30 m high fault-aligned cliffs are composed of limestone.

This is predominately a sandy coast with 64 beaches occupying 128 km (86%) of the shore. The beaches are composed of carbonate-rich (58%), poorly sorted, coarse shelly sand (Fig. 27.2). The carbonate is derived from the seagrass meadows which fringe the entire coast and the quartz derived in part from erosion of the southeast-trending (225°) longitudinal dunes which were active during the last glacial period (25–13 ka) and which cover much of the land either side of the northern gulf (Bowler 1978; Hesse 2010). The beaches are predominately B + SF

(60%) with some WD R beaches in more exposed locations (20%) and B + TSF (20%) in more sheltered locations particularly in lee of the points and along the increasingly lower energy shoreline north from Tickera. The sand flats and in place rocks flats range from 10’s m to 300 m in width, beyond which are the seagrass meadows.

There are 12 barrier systems along this section occupying 85 km (57%) of the shore. They range from regressive to transgressive, with all the dunes presently well vegetated and stable. The regressive systems occur in the sheltered southern ends of

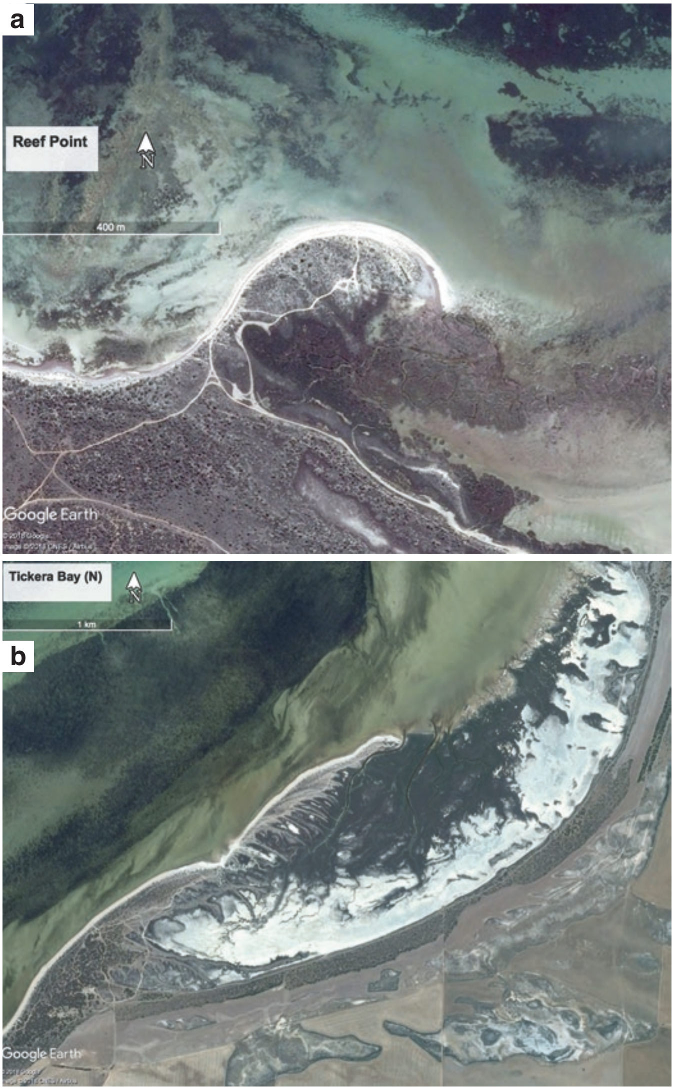


Fig. 27.20 (**a**) Recurved spit at Reef Point (SA 486) (**b**) and inner and outer elongate spits north of Tickera Bay (SA 541). (Source: Google Earth)

the embayed Chinaman Wells, Tiparra Bay and along the low energy crenulated coast north from Tickera where they form elongate north-trending spits. Most of the barriers are however transgressive with multiple parabolics extending a few hundred metre inland. Some of the barriers (Chinaman Wells) have inner transgressive parabolic dunes and outer more regressive foredune ridges, suggesting an initial higher energy phase followed by decreasing wave energy, which could be related to the development of the sand flats and consequent lower breaker wave energy, together with the fall in sea level. The barriers have a total volume of 390 M m^3 (4614 m^3 m^{-1}), a similar magnitude to the previous SC, but an order of magnitude less than the open coast barriers.

There is considerable evidence of northerly longshore sand transport along this northeast-trending coast, which allows the westerly wind waves to arrive at an angle to the shore. Active recurved spits are located in lee of Reef Point (Fig. 27.20a), in lee of Cape Elizabeth where they are 1.2 km wide, at Bird Island and along the coast north from Tickera (Fig. 27.20b). These are all indicative of northerly sand transport; however, rates would be expected to be very low, perhaps on the order of a few 100 m^3 $year^{-1}$, and decreasing to the north.

27.12.4 SC:SA02.02.04 Fisherman Bay–Port Augusta

SC:SA02.02.04 occupies the eastern side of northern Spencer Gulf between Fisherman Bay and the head of gulf at Port Augusta (Fig. 27.21). It is an irregular north-trending shoreline that extends for 162 km, with the gulf narrowing from 50 km in the south to 0.5 km at Port Augusta. As it narrows wave fetch and energy continues to decrease as tide range increases to over 3 m maintaining a TD coast. The coast is backed by a very low gradient coastal plain that extends east to the ranges and is covered in the south by vegetated longitudinal dunes and farmland. As a result of the low gradient, there are extensive salt flats up to 5 km wide backing the beaches and mangroves, while extending into the gulf are up to 3 km wide intertidal sand flats grading into seagrass meadows that dominate the shallow (<20 m) northern gulf floor. There are two major towns at Port Pirie (13,200) and Port Augusta (14,000), with the Weeroona Island shacks (110), Port Germein (400) and shacks at Miranda (50) and Chinaman Creek in between.

The shoreline is a mix of low shelly beach ridges which occupy 85 km (52%) along the southern and more exposed west too southwest-facing sections, the remainder mangrove woodlands backed by samphire and salt flats, all fronted by the wide intertidal sand flats. The PMT highstand stood at +2.2 m at Port Pirie (Harvey et al. 2002) with the subsequent sea level fall and shoreline regression leaving stranded beach ridges and flats. Sediments remain carbonate-rich (~60%, Fig. 27.2) derived from the seagrass meadows, with the quartz originating from the eroded longitudinal dunes. The beaches are entirely TD ether B + SF in the south grading to B + TSF to the north. There are five sets of regressive beach ridges (Fig. 27.22a) along this section with a total length of 69 km (43%) and volume of 140 M m^3

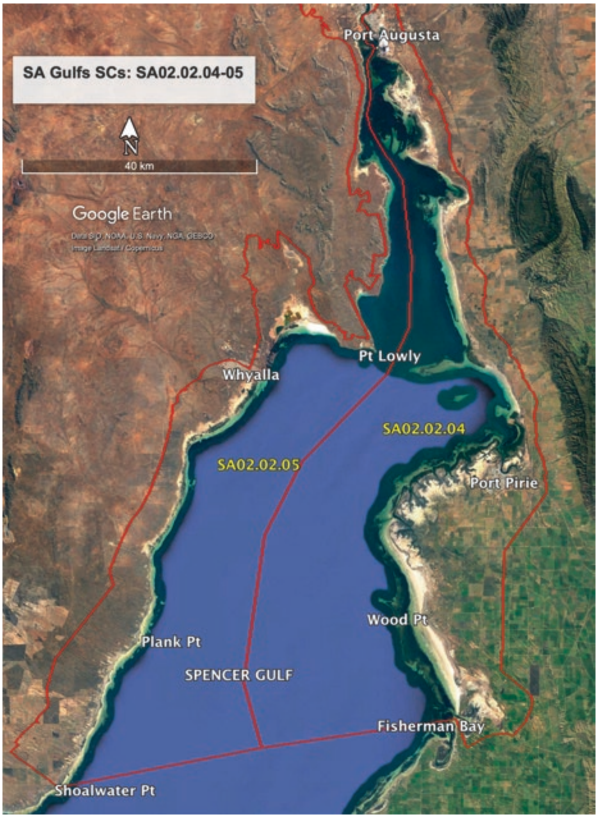


Fig. 27.21 Northern Spencer Gulf with SCs SA02.02.04-05. (Source: Google Earth)

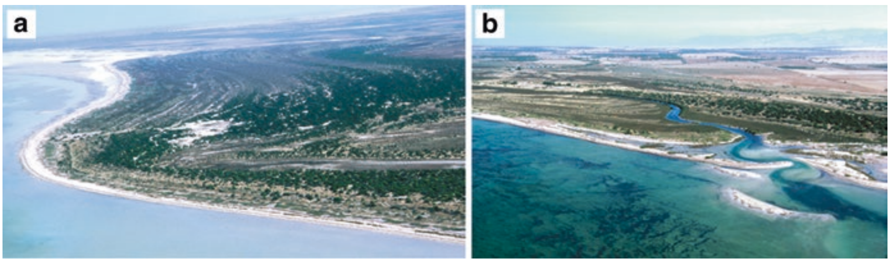


Fig. 27.22 (**a**) Multiple beach-foredune ridges at Wood Point (SA 549) and (**b**) north- and south-trending recurved spits and tidal creek at Port Germein (SA 554). (Photos: AD Short)

(2060 m^3 $year^{-1}$), half the per metre volume of the barriers to the south, indicative of the lower wave energy. The bulk of the sediment in this section is deposited and stored in the inter- to subtidal sand flat deposits, with only a minor portion deposited above sea level. There is evidence of both north and south longshore sand transport at the Fisherman Bay creek mouth and at Port Germein (Fig. 27.22b), with overall northerly transport to local sinks at Fisherman Bay and Davis Creek. Rates are however expected to be extremely low.

This northern gulf region was investigated by Belperio et al. (1983b) and Gostin et al. (1984a, b, 1988) and in the Port Pirie region by Harvey et al. (1999a). These studies revealed an aggraded and prograded sequence of subtidal *Posidonia* facies, overlaid by intertidal sand flats, then intertidal mangroves and samphire followed by supratidal salt flats, with shelly storm ridges in places. This 4–7 m thick sequence had also prograded up to 4 km into the gulf, with a ~1 m slope indicating the fall in sea level since the stillstand (Belperio et al. 1984; Harvey et al. 2002). The carbonate-rich sediments are derived from the seagrass meadows and from reworking of underlying Pleistocene marine facies and the longitudinal quartz dunes. This model applies to the entire northern gulf.

The gulf terminates at Port Augusta beyond which it meanders and narrows for another 10 km before reaching a dry salt-filled creek bed that continues to meander for another 40 km to the north. This is a low gradient, low wave energy TD section of coast, composed of wide supra-, inter- and subtidal sand flats fringed at the shore either by shelly beach ridges or increasingly to the north by mangroves. Rising sea level will generate inundation of the upper flats and initiate shoreward migration of the tide-dependent ecosystems (seagrass, mangroves and salt marshes), as well as the salt flats, as has already been documented at Port Gawler (Cann and Jago 2018) and at Port Wakefield by Fotheringham et al. (2018). The low-lying coastal plain and low-lying areas of Port Pirie, Port Germein and Port Augusta have been inundated by past storm surges and are at increasing risk to future inundation, with protective works constructed at Port Pirie in the 1990s (CPB 1997).

The western Spencer Gulf shore contains two SCs, with SC:SA02.02.05 covering the western side of the northern gulf and the long SC:SA02.02.06 the entire Eyre Peninsula gulf shore. The following section examines their beach and barrier systems. For a fuller description, see Short et al. (1986a, b) which details the coastal morphodynamics and Bourman et al. (2016) which provides an excellent description of this section of coast its geology and geomorphology. The western gulf contains two SCs which are described below.

27.12.5 SC:SA02.02.05 Port Augusta–Shoalwater Point

SC:SA02.02.05 commences on the western shore of Port Augusta and trends roughly south-southwest for 157 km to the bulging Shoalwater Point (Fig. 27.21), considered the southern boundary of the northern gulf. The coast initially trends due south to Lowly Point following the Torrens Hinge Zone, the shoreline dominated by alluvium and colluvium washed down by numerous small streams from the backing range of hills that rise to 250 m. South from Lowly Point, the coast curves west into

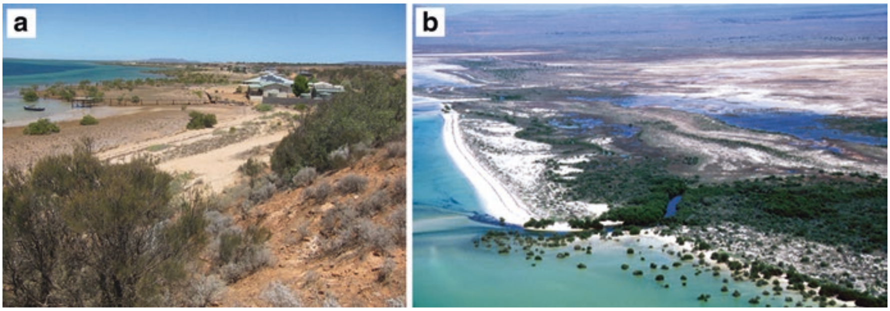


Fig. 27.23 (**a**) Shacks and mangrove-lined tidal flats at Commissariat Point (SA 567) and (**b**) recurved spit, mangroves and salt flats at Eight Mile Creek (SA 598). (Photos: AD Short)

the low gradient False Bay and down to Whyalla, south of which it trends south-south west to Shoalwater Point and largely consists of regressive beach ridges and wide sand flats, interspersed with mangrove-lined tidal creeks. South of Murninnie Beach (SA 605), the coast plain is covered with southeast-trending longitudinal desert dunes, which form truncated ridges and swales behind the regressive beach ridge plains, the swales occupied by salt flats. This coast just has one large town, the rejuvenated (2018) city of Whyalla (22,000), together with a number of shack communities scattered along 15 km of coast north from Blanche Harbour (Fig. 27.23a), between Black Stump Bay and Fitzgerald Bay, and south of Whyalla at Cowleds Landing and Murninnie, together with the gas loading port facility at Lowly Point with its 2.3 km long jetty, known as Port Bonython. The Whyalla shoreline has been heavily modified with the construction of a 7 km long series of structures including a small boat marina, ship building dock, and bundwalls for storing waste from the iron ore plant.

As this is a lee coast wave energy is very low and restricted to fetch-limited local wind waves, while tide range decreases from 3.2 m at Port Augusta to 2.6 m at Whyalla. A total of 49 beaches extend along this low energy TD coast. Roughly half lie between Port Augusta and Lowly-Black Point and occupy 50% of the shore, the remainder being rocky, while to the south the beaches occupy 70% of the shore particular south of Whyalla with the Whyalla seawalls and mangroves occupying the coast in between. The northern beaches are backed by stranded cobble ridges (3–5 m above sea level) that extend for several kilometre and were deposited during the last interglacial highstand sea level (~125 ka) and possibly reworked during the more recent Holocene highstand when wave energy was higher (Hails and Gostin 1978; Bourman et al. 2016).

Sediments along the coast vary considerably from coarse local outwash material between Port Augusta and Point Lowly to a mix of quartz and carbonate to the south (Fig. 27.2). The quartz is derived from erosion of the truncated longitudinal dunes, while the carbonate is derived from the extensive seagrass meadows which fringe the intertidal sand flats. The sediments are generally medium to coarse and poorly sorted as is typical of low energy TD environments (Short 2006).

Barriers occupy 103 km (66%) of the coast, with three small barrier systems in the north at Fitzgerald Bay, Lowly Point and Stony Point and then the regressive False Bay systems. False Bay has inter- to supratidal flats up to 7 km wide, with an up to 1.5 km wide series of beach ridge-spits filling the eastern side and small barrier island-spits and mangroves the more sheltered western side. Settling ponds related to the adjacent steel works cover 17 km^2 of the western supratidal flats. South of Whyalla are the longest and largest regressive beach ridges and spits (Fig. 27.23b) extending almost continuously from for 70 km to Shoalwater Point. Combined the barriers have a total volume of 140 M m^3 (1735 m^3 m^{-1}); 85% however contained in the southern regressive systems. Interestingly the small pocket Lowly and Stony point barriers both contain northeast-trending transgressive parabolic dunes which extend up to 1 km inland and have overpassed Lowly Point.

The 400 m wide beach ridge sequence at Glensea (SA 613, ~15 km north of Shoalwater Point) was investigated by Short et al. (1986b, 1989) who found the inner ridge dated 2.5 ka and the outer 2.1 ka, indicating that the sand flats had to be aggraded sufficiently to provide the platform for rapid deposition of the eight ridges. Their findings agree with Burne (1982) and Belperio et al. (1988) who both found that sand flat aggradation was required before ridges could develop, with Burne finding they did not commenced building until 4–3 ka, the latter date in agreement with the Glensea ridges. In addition, Short et al. found the proportion of carbonate in the ridges increased towards the gulf, from <5% to 70%, indicating the transition from quartz supply from the eroded longitudinal dunes to the growing role of biogenetic production to supply the ridges as the seagrass meadows and sand flats developed. It is likely the many kilometres of other ridges followed a similar evolution.

This section of coast has seen considerable sedimentation during the Holocene, with initially the eroded longitudinal dunes supplying quartz-rich sand and then carbonate material derived from the seagrass meadows being deposited as the 1 km wide intertidal flats were capped in places by shelly outer beach ridges, together with the local terrigenous material delivered by the small steep streams in the north. While the sediment has largely moved onshore to build the extensive sand flats, there is also considerable evidence of northerly sand transport in the form of north-trending recurved spits that commence well up in the gulf at Mangrove and Two Hummock points and in False Bay. In Whyalla sand has built out against the southern breakwater, and north-trending spits are located at the mouths of most tidal creeks all the way south to Shoalwater Point. Rates of transport are however expected to be very low.

Given the low-lying nature of much of this coast, it is already very susceptible to inundation and will become increasingly so as sea level rises leading to increased inundation and erosion (CPB 1997). A rise would also lead to a deeper inshore and an increase in breaker wave energy which could lead to greater mobilisation of the shoreline, leading to either erosion and/or increased rates of northerly sand transport. The rise would also initiate a landward shift in the inter- to subtidal ecosystems generating a coastal squeeze in some areas. There are also many shacks built on low beach ridges which are already prone to inundation and at risk erosion and/or greater inundation.

27.12.6 SC:SA02.02.06 Shoalwater Point–Cape Catastrophe

SC:SA02.02.06 continues south from Shoalwater Point (Fig. 27.4a) for 337 km to the southern tip of Eyre Peninsula at the rugged and exposed Cape Catastrophe (Fig. 27.18). This is a long and highly variable coast which generally trends southwest along the Lincoln Fault. However, there is considerable variation in orientation in the south and consequently variation in wave energy leading to a wide range of coastal systems. This is also the most highly developed part of both Spencer Gulf and the Eyre Peninsula. Beginning in the north there are communities at Lucky Bay (shacks, 30), Cowell (1100), Arno Bay (250), Port Neil (150), Tumby Bay (1200) and the large Port Lincoln (16,200) (Fig. 27.24c) the largest town on the Eyre Peninsula. All of the southern 270 km^2 Jussieu Peninsula is included in Lincoln National Park and Memory Cove Wilderness Area.

This section of coast undergoes considerably transition in processes from north to south. Rainfall increases from 300 to 600 mm, and tide decreases from 2.6 km at Whyalla to 1.5 m at Port Lincoln and 1.1 m at Thistle Island, while wave energy increases southwards with considerable variation in height based on width of sand flats, orientation and exposure to southerly swell. The coast consists of the regressive beach ridges in the north between Shoalwater Point and The Knob, south of which is a section of eroding Pleistocene sediments and then metasedimentary rocks exposed along the coast down to Dutton River, beyond which granites dominate the bedrock down to Cape Catastrophe, with dune calcarenite blanketing the cape.

The coast is a mix of sand and some cobble beaches and the range of bedrock forming generally low (<20 m) cliffs and headlands. Compared to the north and eastern gulf coast, the beach sand is both more variable longshore and more quartz-dominated, averaging 18% carbonate (σ = 28%) but ranging from 1 to 100% (Fig. 27.2). This variation in texture reflects the range of sources, with carbonate derived from the sand flats and nearshore and highest along the TD sand flats shores (north and south), quartz sand derived from erosion of the longitudinal dunes between Shoalwater Bay and Port Gibson and locally derived quartz eroded from the unconsolidated Pleistocene bluffs and delivered by the few small streams, all coupled with limited and interrupted longshore sand transport. There are 190 beaches occupying 227 km (67%) of the shore, which average 1.2 km in length and are a mix of predominately low energy WD (R-LTT, 52% by length), TM (R + LTT, 19%) and TD (B + SF and B + TSF, 29%), with the TD dominating along the northern sand flats and in the south along the sheltered northern shore of the Jussieu Peninsula. All have seagrass growing at or close to shore.

The beaches are backed by 30 barrier systems which occupy 134 km (40%) of the shore. In the north is a near continuous 36 km long regressive beach ridge plain between Shoalwater Point (Fig. 27.24a) and Franklin Harbour (SA 615–618). South from Franklin Harbour shoreline orientation plays a major role in barrier type. Sections of coast facing south to southeast face into southerly winds and occasional south swell and tend to have higher energy beaches (LTT-TBR) and be backed by minor to moderate north to northwest trending dune transgression, the largest and

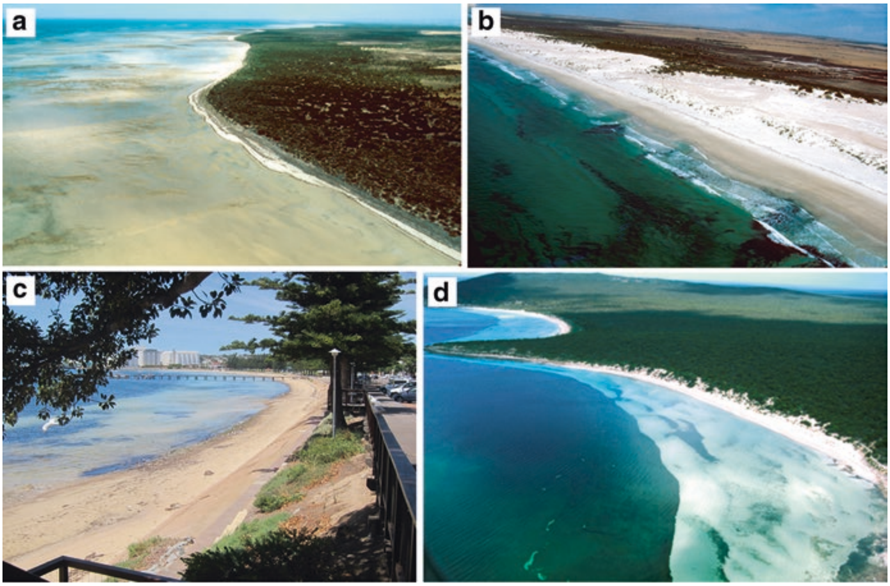


Fig. 27.24 (**a**) One kilometre wide sand flats extending south from Shoalwater Point (SA 614); (**b**) south-facing Mills Beach (SA 627) is the highest energy in the gulf with well-developed rip channels and active transgressive dunes; (**c**) the narrow high tide beach and seawall along the Port Lincoln foreshore (SA 754); and (**d**) 200 metre wide sand flats in Spalding Cove (SA 778). (Photos: AD Short)

most active extending 500 m inland at Point Gibbon (SA 623) and fronted by the highest energy beach in the gulf, the rip-dominated Mills Beach (SA 627) (Fig. 27.24b). Other more exposed beaches and transgressive dunes occur at: Poverty Bay (SA 631); along Red Banks (SA 634–637) which includes some blufftop dunes and at Cape Driver (SA 645); at Mokami (SA 650) which transitions from slight transgression to a 7 km long regressive system; northern Port Neil (SA 661); Carrow Wells (SA 670); Salt Creek (SA 702); northern Tumby Bay (SA 703); Massena Bay (SA717); eastern Peake Bay (SA 731), where the west-facing shore is backed by east-trending dunes; west of Peake Point (SA 735); and Louth Bay (SA 738–9). All of the dune systems are less than 500 m wide, and most are largely stable with only minor active dune activity. Along the more east-facing and sheltered shores and bays the barriers to be regressive, and consist of a few well-vegetated foredune ridges. The larger regressive barriers include Arno Bay (SA 640), Mokami, Tumby Bay (SA 703), Peake Bay (SA 732), Poonindie-Tod River (SA744–5) the widest at 600 m with 15 ridges, Spalding Cove (SA 778, Fig. 27.24d) and Taylors Landing (SA 795), and beach ridges at Tulka (SA 763). All the barriers have a combined total of 300 M m^3 (2254 m^3 m^{-1}), both of similar magnitude to the other gulf shores and at least an order or two of magnitude less than the high energy open coast.

There is considerable evidence of general northerly longshore sand transport north from The Knob, with northeast-trending spits extending east from Franklin Harbour and past Lucky Bay, and the 13 km long Windmill beach-spit that encloses the southern half of the harbour. Short et al. (1986b) dated the inner beach ridge at the northern end of Windmill beach at 3.2 ka, indicating the harbour was enclosed by this time, following which there was rapid progradation of three low (~3 m) beach ridges, followed by five 4–5 m high dune-capped foredunes suggesting a slower rate of shoreline progradation. At the southern end of Windmill beach where it ties to the mainland, they also surveyed an undated series of 11 cobble beach ridges, whose crest height decrease gulfwards by ~1 m. They may be indicative of the fall in regional seal level proposed by Belperio et al. (1984). In Arno Bay the tidal creek at the southern end of the bay periodically shifts up to 700 m to the north before relocating to the south, also indicative of northerly sand transport (Short et al. 1986b).

To the south of Dutton River (SA 655), the beaches tend to be short and embayed with little evidence of longshore transport, while Peake-Louth and Boston bays, Port Lincoln Proper and Spalding Cove (Fig. 27.24d) all act as local sediment sinks. The coast between Point Bolingbroke and Cape Colbert encompasses Louth and Boston Bay, and consists of a series of curving embayments and in the south the V-shaped Boston Bay Proper, the entire section having a high crenulation ratio of 5.5. Apart from the south-facing eastern North Shields beach (SA751), wave energy is low to very low with TD beaches and sand flats dominating in the embayments and rocky shore along the remainder. Port Lincoln is located at the sheltered southern end of Boston Bay with the port facilities, a 1 km long jetty and smaller jetty occupying 800 m of the shore. North of the port the east-facing shore consists of eroding bluffs of unconsolidated outwash along North Boston Bay; the material is being slowly transported northwards past North Shields, where the shoreline is receding, resulting in the construction of a 300 m long seawall either side of the jetty. The sink for this sand appears to be the ridged sand flats and backing barrier that links Point Boston to the mainland and has been undergoing accretion at its northeastern terminus since at least the 1950s (Short et al. 1986a). In the south, most of Port Lincoln is located on elevated ground apart from the canal estate and marina at Porter Bay.

Port Lincoln Proper consists of a series of curving embayed generally north-facing TD (B + SF and B + RSF) beaches, with seagrass growing to low tide. At Tulka Well located at the very low energy base of Port Lincoln Proper, Short et al. (1986b, 1989) dated a 150 m wide series of very low beach ridges, with the inner tidal flats dating 3.5 ka. Based on other dates, they found the flats have accreted very slowly at a rate of 0.04 mm year^{-1}, followed by bayward progradation of the ridge. The elevation of the inner flats also suggests a slight (~0.4 m) fall in sea level in agreement with De Deckker et al. (1982) dates for nearby by Pillie Lake. The remainder of the northern and eastern Jussieu Peninsula consists of a series of carbonate−/shell-rich TD beaches and sand flats along its sheltered northern coast and WD R-LTT beaches along its more exposed eastern shore, all embayed and separated by granite rocks and headlands. The entire peninsula is undeveloped and part of Lincoln National Park and Memory Cove Wilderness Area.

27.12.7 PC Overview

Spencer Gulf has a range of coastal sectors based on orientation, tide range and level of wave energy. The gulf commences in the southeast along the exposed western ‘toe’ of Yorke Peninsula, the only high energy section of the gulf. Once inside the gulf, ocean wave energy decreases to zero in most locations with local wind waves dominating, with these also decreasing northwards as the gulf narrows. Combined with the variation in geology and topography around the gulf shore, there is considerable variation in beach type, with TD tidal flats dominating (67%), and barrier type which while dominated by regressive beach and foredune ridge plains and spits also contains stable and active minor to moderate dune transgression. Sand has been primarily source from in situ biogenetic production in the seagrass meadows, together with local contribution from reworked longitudinal dunes, bluff erosion and limited stream supply of bedload. The response of the gulf shore to climate change and sea-level rise will be highly variable, a reflection in part of the variable morphology. Harvey et al. (1999b) mapped the northern Spencer Gulf in order to assess local and regional coastal vulnerability identifying 16 monogenous coastal geological units, which were then ranked according to their vulnerability. Bryan et al. (2001) utilised Harvey et al. results to conclude that in the northern gulf, elevation and exposure to waves are the main contributory to coastal vulnerability. The coast is already vulnerable to storm surges up to 3 m (Deans 1997; CPB 1997), and sea level is presently rising at 0.21 mm year^{-1} at Port Pirie and a higher 0.75 mm year^{-1} at Port Lincoln (Harvey and Belperio 1994; Harvey et al. 1999a, 2002). This will lead to inundation of the low-lying tidal and salt flats and shoreward migration of the inter- and subtidal ecosystems and expose many low-lying shack settlements and some larger communities to both erosion and inundation, as has already occurred at Lucky Bay (Short et al. 1986a) and Port Pirie (CPB 1997). While most of Port Lincoln is in elevated ground, the canal estate at Porter Bay will be the first to feel the impact of the rising sea level.

27.13 Regional Overview

The funnel-shaped St Vincent and Spencer gulfs protruded 160 km and 320 km, respectively, into the semi-arid interior of South Australia and in doing so undergo a transformation in climate and marine processes, together with the contrasting processes on either side of the gulfs. Overall tide range increases northwards as fetch and waves decrease, the latter permitting kilometre wide sand flats to develop with the sediment derived from the adjacent seagrass meadows. The gulfs have also undergone a temporal transformation from the early Holocene when sea level was 1–2 m higher and the water deeper, which combined with the initial absence of sand flats providing deeper inshore water, allowing higher waves to reach the shore. This was a period of higher energy beaches, more active dune transgression, more rapid longshore sand transport and most barrier construction. This was followed by the slow development and aggradation of the sand flats, followed by the deposition of regressive beach ridges from 3–2 ka and then a fall in sea level ~1.6 ka. Today the northern sand flats are well developed, and the waves much reduce at the shore, though overall northerly sand transport continues at very low rates. The biggest threat to the north gulf is inundation of the sand flats and beach ridge plains and their backing salt flats, coupled with accompanying deeper water and higher breaker waves.

The central-southern gulf shores are more variable with generally higher wave energy and lower tides. There is more pronounced northerly sand transport especially along the Adelaide coast and east of Corny Point. Sea level is presently rising at rates of 0.21 mm year^{-1} at Outer Harbour (Adelaide) and 0.75 mm year^{-1} at Port Lincoln (Harvey et al. 2002), and these rates are predicted to increase which will lead increased longshore transport and erosion along the sediment-deficient Adelaide shoreline requiring ongoing management. Elsewhere most of the gulf shores will be left to themselves, to be inundated, eroded and reworked, except where major property and/or infrastructure is at risk, as in some of the communities, towns and cities. A major issue in the gulfs is the number of beachfront shacks, often built on low beach ridges, located within the existing inundation and/or erosion hazard zone (Fig. 27.14b), a problem identified by Wynne (1978, 1989) and one that has been compounded since, resulting in considerable property being placed at increasing risk. Short et al. (1986a) concluded that the main threats to the western Spencer Gulf coast was marine inundation and in places shoreline erosion with all the low gradient sand flats-beach ridge-backbarrier/supratidal flats including the Franklin Harbour shoreline prone to storm surge inundation. Inundation hot spots include Port Pirie, shacks at Cowell, the Arno Bay foreshore, North Shields, Tulka North, Tulka West, while existing erosion hot spots include Ardossan (cliffs), Black Point, Sheoak Flats and Marion Bay in St Vincent Gulf and The Pines, Point Souttar-Point Turton (bluff erosion), Bluff Beach, Chinaman Well, Balgowan, Port Huighes-Moonta Bay, Port Broughton, Port Germein, Fitzgerald Bay, Whyalla foreshore, Lucky Bay, Tumby Bay and North Shields (Short et al. 1986a) in Spencer Gulf. While many of these are former shack communities, some are now quite substantial.

References

Belperio AP (1993) Land subsidence and sea level rise in the Port Adelaide estuary: implications for monitoring the greenhouse effect. Aust J Earth Sci 40:359–368

Belperio AP, Hails JR, Gostin VA (1983a) A review of Holocene sea levels in South Australia. In: Hopley D (ed) Australian Sea levels in the last 15,000 years, Monograph series. Department of Geography, James Cook University, Townsville, pp 37–47

Belperio AP, Hails JR, Gostin VA (1983b) Holocene sea levels of upper Spencer Gulf, South Australia. In: Hopley D (ed) Australian sea levels in the last 15,000 years, Volume monograph series. Department of Geography, Townsville, pp 48–53

Belperio AP, Hails JR, Gostin VA, Polach HA (1984) The stratigraphy of coastal carbonate banks and Holocene sea levels of northern Spencer Gulf, South Australia. Mar Geol 61:297–313

Belperio AP, Gostin VA, Cann JH, Murray-Wallace CV (1988) Sediment-organism zonation and the evolution of Holocene tidal sequences in southern Australia. In: de Boer PL et al (eds) Tide-influenced sedimentary environments and facies. D Reidel Publ Co, pp 475–497

Belperio AP, Harvey N, Bourman RP (2002) Spatial and temporal variability in the Holocene palaeosea-level record around the South Australian coastline. Sediment Geol 150:153–169

Bourman RP (1988) The formation of an artificial coastline at Rapid Bay, South Australia, by the disposal of quarry waste: South. Australian Geograph J 88:1–14

Bourman RP (1990) Artificial beach progradation by quarry waste disposal at Rapid Bay, South Australia. J Coastal Res, SL (6):69–76

Bourman RP, Belperio AP, Murray-Wallace CV, Cann JH (1999) A last interglacial embayment fill at Normanville, South Australia, and its neotectonic implications. Trans Royal Soc South Aust 123:1–15

Bourman RP, Murray-Wallace CV, Harvey N (2016) Coastal landscapes of South Australia. University of Adelaide Press, Adelaide, 405 p

Bowler JM (1978) Glacial age aeolian events at high and low latitudes: a Southern hemisphere perspective. In van Zinderen Bakker EM (ed) Antarctic glacial history and world palaeoenvironments. AA Balkema, Rotterdam, 149–172

Bryan B, Harvey N, Belperio AP, Bourman R (2001) Distributed process modeling for regional assessment of coastal vulnerability to sea-level rise. Environmental Monitoring Assessment 6:57–65

Burne RV (1982) Relative fall of Holocene sea level and coastal progradation, northeastern Spencer Gulf, South Australia. BMR J Aust Geol Geophys 7:35–45

Burne RV, Colwell JB (1982) Temperate carbonate sediments of northern Spencer Gulf, South Australia: a high salinity 'foramol' province. Sedimentology 29:223–238

Burton TE (1982) Mangrove development north of Adelaide, 1935–1982, vol 106. Trans Royal Society South Australia, pp 183–189

Butler AJ, Depers AM, McKillop SC, Thomas DP (1977) Distribution and sediments of mangroves forests in South Australia, vol 101. Trans Royal Soc South Aust, pp 35–44

Byrne G, Wynne AA, Thomas RI (1983) Adelaide coast protection strategy. In: 6th Australian conference on coastal and ocean engineering, Brisbane, Institution of Engineers Australia, pp 273–278

Cann JH, Jago JB (2018) Rapidly spreading mangroves at Port Gawler, South Australia: an update. Aust J Earth Sci 65:243–247. https://doi.org/10.1080/08120099.2018.1414076

Chappell JF (1989) Coastal engineering aspects of Wirruna and Sellicks Beach marinas. In: 9th Australasian conference on coastal and ocean engineering, Adelaide, Institution of Engineers Australia, pp 229–234

CPB (1992) Coastline: coastal erosion, flooding and sea level rise standards and protection policy. Coast Protection Board, Department of Environment Heritage, Adelaide, Coastline 26, 7 p

CPB (1997) Coastal vulnerability assessment. In: Coastline, vol 31. SA Coast Protection Board, Adelaide, p 8

CPB (2005) Adelaide's living beaches: a strategy for 2005–2025. Technical report, Coast Protection Board, Dept Environment Heritage, Adelaide, 206 p

CPB (2014) Developing a management strategy for coastal cliff hazards in South Australia. In: Coastline, vol 37. SA Coast Protection Board, Adelaide, 15 p

De Deckker P, Bauld J, Burne RV (1982) Pillie Lake, Eyre Peninsula, South Australia: modern environment and biota, dolomite sedimentation, and Holocene history. Trans R Soc S Aust 106:169–181

Deans JA (1997) Coastal flooding hazard assessment in South Australia. In: 13th Australasian conference on coastal and ocean engineering, Christchurch, pp 501–506

Deans J (1999) Monitoring sand management at Glenelg and West Beach Harbors, Adelaide. In: 14th Australasian conference on coastal and ocean engineering, Perth, Institution of Engineers Australia, 8 p

Deans J, Townsend M (2003) Value of seagrass meadows to the metropolitan Adelaide coast. Gold Coast Australia. Coast and Ports Australasian Conference 2003, Auckland, 8 p

Deans JA, Tucker R, Townsend M (2003) The coast protection board of South Australia 30 years of rebuilding Adelaide's beaches ... and plans for the next 30 years. In: Coast and Ports Australasian Conference 2003, Auckland, 8 p

Fotheringham DG (2000) Extent and conservation status of mangrove and salt marsh communities in South Australia. Coast Marine Section, Department of Environment and Heritage, Adelaide

Fotheringham D, Coleman P (2008) Salt marshes. In: Shepherd SA, Bryars S, Kirkegaard I, Harbison P, Jennings JT (eds) Natural history of Gulf St Vincent. Royal Society of South Australia, Inc, Adelaide, pp 81–94

Fotheringham DG, Quinn J, Virag A (2018) Observations concerning possible sea level rise effects on a monitored saltmarsh near Sandy Point, Gulf St Vincent, South Australia. Coast Management Branch, Department of Environment Heritage, Adelaide, 1999

Fuller MK, Bone Y, Gostin V, von der Bosch CC (1994) Holocene cool-water carbonate and terrigenous sediments from southern Spencer Gulf, South Australia. Aust J Earth Sci 41:353–363

Gostin VA, Hill SM (2014) Spencer Gulf: geological setting and evolution. Natural History of Spencer Gulf. In: Shepherd SA, Madigan SM, Gillanders BM, Murray-Jones S, Wiltshire DJ (eds) Spencer Gulf: geological setting and evolution, Royal Society of South Australia, Inc., Adelaide 2:21–45

Gostin VA, Hails JR, Belperio AP (1984a) The sedimentary framework of northern Spencer Gulf, South Australia. Mar Geol 61:111–138

Gostin VA, Sargent GEG, Hails JR (1984b) Quaternary seismic stratigraphy of northern Spencer Gulf, South Australia. Mar Geol 61:373–389

Gostin VA, Belperio AP, Cann JH (1988) The Holocene non-tropical coastal and shelf carbonate province of southern Australia. Sediment Geol 60:51–70

Guy J (2009) Semaphore park offshore breakwater – rock armouring a sand filled geotextile tube trial breakwater. Coasts and Ports 2009, Wellington, pp 288–294

Hails JR, Gostin VA (1978) Stranded shingle beach ridges, Upper Spencer Gulf, South Australia: evidence for high wave energy dissipation during the Late Pleistocene. Trans Royal Society South Australia 102:169–173

Hails JR, Belperio AP, Gostin JR (1984) Quaternary sea levels, northern Spencer Gulf, Australia. Mar Geol 61:373–389

Harvey N (2006) Holocene coastal evolution: barriers, beach ridges and tidal flats of South Australia. J Coast Res SI 22:90–99

Harvey N, Belperio AP (1994) Implications of climate change for the South Australian coastline. Trans Royal Soc S Aust 118:45–52

Harvey N, Bowman GM (1987) Coastal management implications of a Holocene sediment budget: Le Fevre Peninsula, South Australia. J Shoreline Manage 3:77–93

Harvey N, Barnett EJ, Bourman RP, Belperio AP (1999a) Holocene sea-level change at Port Pirie, South Australia: a contribution to global sea-level rise estimates from tide gauges. J Coastal Res 15:607–615

Harvey N, Belperio AP, Bourman RP, Bryan B (1999b) A GIS-based approach to regional coastal vulnerability assessment using Holocene geological mapping of the northern Spencer Gulf, South Australia. Asia Pac J Environ Develop 6:1–25

Harvey N, Belperio AP, Bourman RP (2001) Late Quaternary sea-levels, climate change and South Australian coastal geology. In Gostin VA (ed), Gondwana to greenhouse. Geol Soc Australia Spec Publ 21:201–213

Harvey N, Belperio AP, Bourman RP, Mitchell W (2002) Geologic, isostatic and anthropogenic signals affecting sea-level records at tide-gauge sites in southern Australia. Global Planetary Change 32:1–11

Hesse PE (2010) The Australian desert dunefields: formation and evolution in an old, flat, dry continent. In: Bishop P, Pillans B (eds) Australian landscapes, vol 346. Geological Society, London, Special Publications, pp 141–164. https://doi.org/10.1144/SP346.90305-8719/10/$15.00#

James PR, Clark IF (2002). Geology. In Davies M, Twidale CR, Tyler MJ (eds), Natural history of Kangaroo Island, 2nd edn. Royal Society of South Australia Inc, Adelaide, pp 1–22

James NP, Bone Y, Hageman SJ, Feary DA, Gostin VA (1997) Cool-water carbonate sedimentation during the terminal quaternary sea-level cycle: Lincoln Shelf, southern Australia. In: James NP, Clarke JAD (eds) Cool-water carbonates. Society for Sedimentary Geology, Tulsa, pp 53–75

James NP, Bone Y, Della Porta G (2015) Pleistocene aeolianites at Cape Spencer, South Australia; record of a vanished inner neritic cool-water carbonate factory. Sedimentology 62(7):2038–2059

May RI, Bourman RP (1984) Coastal lands lumping in Pleistocene sediments at Sellicks Beach. South Australia. Trans Royal S South Aust 108:85–94

Mitchell PW, Lee KJ (1987) Witton Bluff protection strategy. In: 8th Australasian conference on coastal and ocean engineering, Launceston, Institution of Engineers Australia, pp 169–171

Morris BJ (1976) Investigation of heavy mineral sands, Morrison Beach, Kangaroo Island. Mineral Res Rev 145:34–46

Murray-Wallace CV, Belperio AP (1991) The last interglacial shoreline in Australia – a review. Quat Sci Rev 10:441–461

Oppermann A (1999) A biological survey of the South Australian coastal dune and clifftop vegetation. Department of Environment, Heritage Aboriginal Affairs, Adelaide, South Australia. ISBN 1 876562013

Pan T-Y, Murray-Wallace CV, Dosseto A, Bourman RP (2018) The last interglacial (MIS 5e) sea level highstand from a tectonically stable far-field setting, Yorke Peninsula, southern Australia. Mar Geol 398:126

Richardson L, Mathews E, Heap A (2005) Geomorphology and sedimentology of the South Western Planning Area of Australia: review and synthesis of relevant literature in support of regional marine planning. Geoscience Aust Canberra Record 2005//17., 123 p

Riedel P, O'Brien P, Townsend M (2005) The effects of ocean swell on the stability of Adelaide's metropolitan beaches. In: 17th Australasian conference on coastal and ocean engineering, Adelaide, Institution of Engineers Australia, pp 499–510

Short AD (2001) Beaches of the South Australian Coast and Kangaroo Island. Sydney University Press, Sydney, 346 p

Short AD (2006) Australian beach systems – nature and distribution. J Coastal Res 22:11–27

Short AD (2012) Management of the Adelaide metropolitan beaches: 1836–2011. In: Cooper JAG, Pilkey OH (eds) Pitfalls of shoreline stabilization. Coastal Res Library, vol 3. Springer, Dordrecht, pp 15–36

Short AD, Fotheringham DG (1986a) Morphodynamic, hazard and development impact assessment – Kangaroo Island Coast Protection District. Coast Protection Board, Department of Environmental. Planning, Adelaide, 183 p plus appendices and maps

Short AD, Fotheringham DG (1986b) Coastal morphodynamics and Holocene evolution of the Kangaroo Island coast, South Australia. Coastal Studies Unit Tech Report, 86/1, Coastal Studies Unit, University of Sydney, Sydney, 112 p

Short AD, Fotheringham DG, Buckley R (1986a) Morphodynamic hazard and development impact assessment – Eyre Peninsula, Coast Protection District. Coast Protection Board, Department of Environmental Planning, Adelaide, 230 p plus appendices and maps

Short AD, Fotheringham DG, Buckley R (1986b) Coastal morphodynamics and Holocene evolution of the Eyre Peninsula coast, South Australia. Coastal Studies Unit Tech Report, 86/2, Coastal Studies Unit, University of Sydney, Sydney, 178 p

Short AD, Buckley RC, Fotheringham DG (1989) Preliminary investigation of beach ridge progradation on the Eyre Peninsula and Kangaroo Island. Trans R Soc S Aust 113:145–161

Thom BG, Eliot I, Eliot M, Harvey N, Rissik C, Sharples C, Short AD, Woodroffe CD (2018) National sediment compartment framework for Australian coastal management. Ocean Coast Manag 154:103–120

Thomas RI (1982) Seagrass bedforms and seagrass decline in Gulf St Vincent. ANZAAS Congress, Sydney, 9 p

Thomas RI (1983) Seagrass bedforms, their erosion and implications for coastal management of the Adelaide metropolitan shoreline. In: 6th Australian conference on coastal and ocean engineering, Gold Coast, Institution of Engineers Australia, pp 101–105
Townsend M (2005) Semaphore offshore breakwater a trial. In: 17th Australasian conference on coastal and ocean engineering, Adelaide, pp 691–696
Townsend M, Guy J (2017) Adelaide's beaches: trial by storm. Aust Coasts Ports 2017:526–531
Tucker R, Penny SW (1989) Sand replenishment for Adelaide's beaches, past, present and future. In: 9th Australasian conference on coastal and ocean engineering, Adelaide, Institution of Engineers Australia, pp 155–157
Tucker RK, Schmidt N, Deans JA (2013) Adelaide's living beaches – sand transfer infrastructure project. In: 14th Australasian Port Harbour Conference, pp 780–785
Twidale CR, Burnes JA, Twidale N (1977) Shore platforms and sea level changes in the gulfs region of South Australia. Trans R Soc S Aust 101:63–74
Wynne AA (1978) Yorke Coastal Protection District Study, 4th Australian conference on coastal and ocean engineering, Adelaide, Institution of Engineers Australia, pp 98–104
Wynne AA (1980) Yorke Coast Protection District Study Report, Prepared for Coast Protection Board, Department of Environmental Planning, Adelaide
Wynne AA (1989) Sea level rise and coastal planning policy in South Australia. In: 9th Australasian conference on coastal and ocean engineering, Adelaide, Institution of Engineers Australia, pp 302–307

Chapter 28
Western Eyre Peninsula Region

Abstract The western Eyre Peninsula is a 1000 km long south to southwest-facing coast exposed to the full force of the Southern Ocean swell and west through south winds. The climate is Mediterranean in the south grading to semi-arid in the north regions. Most of the coast is blanketed in calcarenite with no drainage reaching the coast. The coast is wave-dominated coast with micro-tides. It consists of long exposed sections with high energy beaches and Pleistocene calcarenite bluffs and cliffs, all usually backed by massive transgressive dune systems including extensive clifftop dunes, together with a series of sheltered bays containing tide-dominated beach systems, some mangroves and seagrass meadows. Sediments have been largely derived from the inner shelf carbonate factory together with seagrass epifauna in the sheltered bays. This chapter describes the peninsula's coastal processes, beaches, barriers, sediment transport and sediment compartments.

Keywords Eyre Peninsula · South Australia · Southern Ocean · Carbonate sediments · Beaches · Barriers · Sediment transport · Sediment compartments

28.1 Introduction

The western Eyre Peninsula is a 1000 km long, exposed wave and wind-battered coast, blanketed by marine sediments at both low and high sea levels and regularly exposed to the high waves and strong westerly winds of the Southern Ocean. It is also an increasingly arid coast, with rainfall decreasing from 400 mm at Port Lincoln, to 380 mm at Streaky Bay, 300 mm at Ceduna and 280 mm at Eucla. The coast extends for 1143 km to the northwest, between Cape Catastrophe at its southern tip to Head of Bight and the start of the Nullarbor Cliffs (Fig. 28.1), with its overall orientation to the southwest facing directly into the prevailing swell and south through westerly winds. It is also a lightly populated coast with a scattered series of small coastal towns and communities at Coffin Bay (600), Elliston (400), Venus Bay (150), Port Kenny (70), Streaky Bay (1600), Haslam (60), Smoky Bay (600), the large Ceduna (3500) and Fowlers Bay (150), with only the small Eucla between it and the next town at Esperance 1600 km to the west. The hinterland is

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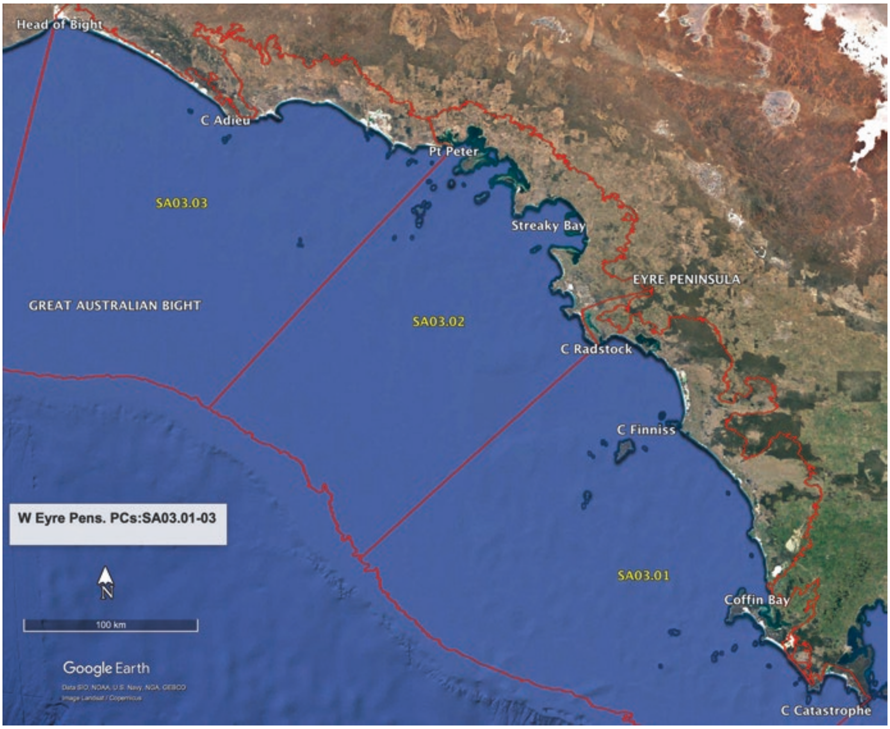


Fig. 28.1 The western Eyre Peninsula region (SA03) and its four PCs extending from Cape Catastrophe to the Head of Bight and the start of the Nullarbor (Bunda) cliffs. (Source: Google Earth)

predominately mallee country taken up for wheat-sheep farming as far west as Cape Adieu. Yalata Aboriginal Land occupies the western 55 km of this region, following which the Nullarbor National Park extends to the WA border. For an overview of the entire peninsula's coastal morphodynamics and Holocene evolution, see Short et al. (1986b); its hazards and impact assessment, Short et al. (1986a); its geology and geomorphology, Bourman et al. (2016); and its natural history, Twidale et al. (1985).

28.2 Geology

The peninsula geology is dominated by the stable Gawler Craton, and all of the coast is underlain by crystalline rocks (granites, gneisses, volcanic rocks and metamorphosed sediments) of the ancient and highly stable craton. These rocks are exposed along parts of the coast between Cape Wiles and Cape Adieu as hard Precambrian crystalline rocks usually blanketed in dune calcarenite.

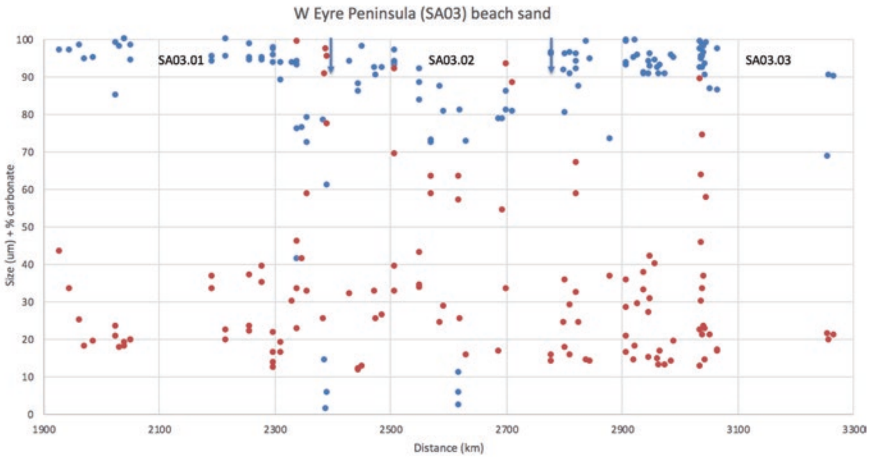
The entire peninsula coast has also been blanketed in a layer of calcareous loess a few metres thick, blown for the exposed seabed during low sea levels and deposited up to 70 km inland blanketing the entire coastal hinterland landscape (Belperio 1995). During each sea level transgression and subsequent stillstand, the wind has blown carbonate-rich sand inland forming 700 km of Holocene transgressive dunes including clifftop dunes, all with a total dune area of ~1000 km^2 (Short et al. 1986b). The successive layers of Pleistocene calcareous dune sand have subsequently been lithified and at the coast eroded to form cliffs, bluffs, platforms, reefs and islands. Today just under half of the coast consists of bedrock and calcarenite bluffs and cliffs, with the cliff averaging ~60 m and reaching as high as 150 m at Whalers Way. Rock platforms and reefs are found at the base of much of the clifline, with the platforms occurring along 440 km of the cliffs and averaging 40 m in width (σ = 33 m), while reefs occur along 350 km of the cliffs with most less than 0.15 km offshore but some extending up to 1 km offshore (Short et al. 1986b). The calcarenite is part of the extensive southern carbonate systems that extends across the entire southern coast and up the WA coast (Brooke 2001; Short 2001). While much of the coast is exposed and either cliffed or backed by transgressive dunes, there are ten partly sheltered bays that vary considerably in size. From the south these are Coffin (150 km^2), Port Douglas (870 km^2), Elliston (2.5 km^2), Venus (80 km^2), Baird (45 km^2), Streaky (780 km^2), Smoky (170 km^2), Decres (40 km^2), Murat (55 km^2), Denial (130 km^2) and Tourville (80 km^2). They all contain lower energy shores and extensive seagrass meadows and varying extent of mangroves.

28.3 Rivers and Creeks

Because of the aridity and predominately porous limestone-calcarenite coast, there are no rivers and only a few usually dry streams along the entire coast, most draining into salt lakes, and no estuaries, other than the inverse Baird Bay. As a consequence, there has been no delivery of terrigenous sediment to the coast throughout the Quaternary. There are however some local hotspots of quartz sand sourced from erosion of quartz-rich adjacent rocks, reefs and headlands, as at Silica Beach (SA 1086, 2390 km) and Point Brown-St Marys Bay (SA 1222, 2630 km) (Fig. 28.2).

28.4 Sediments

Beach sediment throughout the peninsula is predominately moderately well-sorted, fine-medium (0.1–0.4 mm) carbonate-rich (mean = 87%) sand, with the backing dune sand finer, better sorted and slightly richer in carbonate (91%) (Table 28.1; Fig. 28.2). The texture is indicative of the rich shelf source of carbonate material,



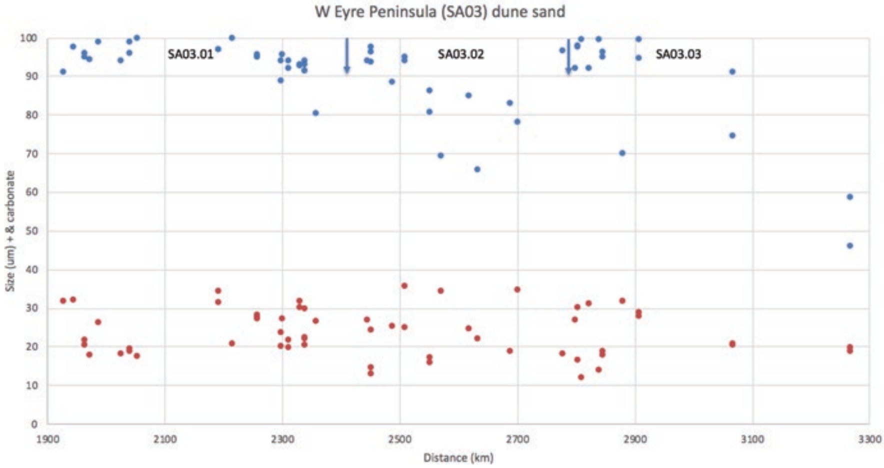


Fig. 28.2 Longshore distribution of western Eyre Peninsula (SA03) beach (upper) and dune (lower) sand characteristics. Carbonate % blue dots, sand size (red, µm). Arrows indicated PC boundaries. Distance is from VIC/SA border

Table 28.1 Western Eyre Peninsula (SA03) beach and dune sand characteristics

	Swash	Dune
n	122	58
Size (mm)	0.34	0.25
σ (mm)	0.23	0.11
Sorting	0.58	0.51
σ *(sorting)*	0.33	0.17
Carbonate (%)	87	91
σ (%)	20	11

delivered to the shore by the persistent moderate to high wave environment (Fig. 16.8), together with seagrass sources in the several large bays (Fig. 16.7).

The source of much of the carbonate material is the 100–200 km wide Great Australian Bight shelf which extends in a 1500 km arc from Cape Jervis-Kangaroo Island across the Bight to Cape Pasley. Richardson et al. (2005) describe it as a broad seaward-sloping shelf with a shallow inshore terrace and extensive middle and outer shelf. It is dominated by the southern swell and storms which maintain a 'shaved' shelf where sediment erosion is greater than sediment accumulation (Fig. 16.9b; James et al. 1994, 1997, 2001). Surface sediments are dominated by cool-water carbonates, with bioclastic detritus of bryozoans, molluscs, sponges, coralline algae, foraminifera and echinoids (Fig. 16.9a). A thin sediment veneer of locally rippled carbonate sand patches is interspersed with outcropping hard substrate. It is classified as the world's largest cool-water carbonate province owing to minimal to zero terrigenous input and seasonal oceanic upwelling occurring on a temperate, latitude-parallel shelf.

James and Bone (2017) investigated the composition of the dune calcarenite at a number of sites throughout this region, between Sleaford Bay and Davenport Creek. They found the sediment is composed of quartz grains, Cenozoic limestone clasts and relict particles, which are overwhelmingly dominated by contemporaneous bio-fragments from offshore. The skeletal grains are, in order of relative abundance, molluscs, benthic foraminifers, coralline algae, bryozoans and echinoids. They also observed a dominance of biofragment-rich sediment in the south and extraclast-rich sediment in the north to west. They found the composition of the calcarenite in this region is very similar to that of the Bonney-Lacapede coast along the southeast of SA (region SA01, Chap. 26). They also assessed the role of the generally high energy surf zone along this coast and its impact on filtering and degrading carbonate skeletal sediments. They divided the particles into three categories: 1) robust – more resistant to fragmentation (molluscs, rotaliid foraminifers, coralline algal rods); 2) intermediate – fragmented but still recognisable (echinoid spines, encrusting corallines); and fragile – easily broken into sand and smaller size pieces (delicate branching bryozoans, miliolid foraminifers, echinoid body plates). Based on this categorisation, they predict that the most abundant skeletons surviving should be molluscs > benthic foraminifers > coralline algal rods; while bryozoans would not be important.

28.5 Coastal Processes

Deepwater waves are generated by the regular passage of midlatitude cyclone (Fig. 16.3) and arrive along the coast as persistently southwest moderate to high swell with a mean H_o between 2.5 and 3 m and $T = 12$ s (Fig. 27.3). Provis and Steedman (1985) recorded wave height across the continental slope and 200 km wide shelf and found while on the slope (1150 m depth) $H_s = 5$ m and $H_{max} = 10$ m, between the slope and 26 m depth wave height was reduced to 25%, while T remained constant.

Closer to shore breaker wave height depends on local gradient, orientation and sheltering by headland, rocks and reefs and can range from the full height (~2 m) to zero in the very sheltered bays. Overall this coast is classified as a high energy, with waves arrive year-round with a slight winter maximum (Figs. 1.12a, 16.4) and little monthly variation (Fig. 1.12b).

Tide is micro throughout the region ranging from 1.1 m at Thistle Island in the south to 1.4 m at Elliston and 1.7 m at Thevenard. As discussed in Sect. 26.7, shelf waves have considerable impact on the actual elevation of sea level causing it to vary regularly by 0.5 m and occasionally more than 1 m, exceeding the tide range at times (Provis and Radok 1979).

Because of the tectonic stability of the Eyre Peninsula coastline, Pleistocene sea levels are usually found 2–4 m above the present shoreline (Murray-Wallace et al. 2016; Pan et al. 2018). Buckley et al. (1987) recorded a Pleistocene platform at 2.5 m at the Merdayerrah Sandpatch, while Murray-Wallace et al. (2016) found elevations of 3.5 m at Lake Newland, 1.9 m at Smoky Bay, 2.7 m at Cape Thevenard and 2.9 m at Tourville Bay and concluded that during the last interglacial (128–116 ka), sea level reached elevations between 2.1 and 4 m, which is also supported by Pan et al. (2018) based on data from the lower Yorke Peninsula. Holocene sea level along the tectonically stable Eyre Peninsula coast reached its present level 7 ka, though there is uncertainty whether it stood 1 m higher between 6 and 4 ka (Bourman et al. 2016), though Murray-Wallace et al. (2016) found that it has not been higher than present at Ceduna.

Landsberg-Bagnold wind vectors for the region range from west (277°) at Port Lincoln, to south (192°) at Elliston, west (287°) at Streaky Bay and Ceduna (251°) and southwest (234°) at Fowlers Bay (Short et al. 1986b). The strong onshore winds have been responsible for the transfer of massive volumes of marine carbonate sediments (loess and sand) to the coast and hinterland.

28.6 Beaches

The western Eyre Peninsula has a total of 638 beaches which occupy 639 km (56%) of the coast. They have a relative short mean length of 1 km owing to the prevalence of calcarenite points, rocks and reefs along the shore precluding the development of many long beaches. While this is a high wave energy coast, there is considerable sheltering by the calcarenite rocks, reefs and points, as well as the major bedrock headlands and within the sheltered bays, resulting in a range of beach types from WD to TM and TD, the latter all occurring in the bays. While the greatest number (278) of beaches are R, these are short in length (mean = 0.4 km) and occupy 19% of the sandy shore, while the 94 longer TBR (1.7 km) dominate occupying 26% of the shore, with the full six WD beach states (R-D) occupying 472 km (74%) of the sandy coast. The remainder is made up of TM R + LTT (3 km, 0.5%) and the TD sand flats (165 km, 25.5%) (Table 28.2). The TM and TD are all located in the eight sheltered bays. All beaches in the region are described in Short (2001).

Table 28.2 Western Eyre Peninsula region (SA03) beach types and states

BS	BS	No.	%	km	% (km)	mean (km)
1	D	12	1.9	59.4	9.3	4.9
2	LBT	5	0.8	5.4	0.9	1.1
3	RBB	20	3.1	81	12.7	4.0
4	TBR	94	14.7	163	25.5	1.7
5	LTT	55	8.6	42.9	6.7	0.8
6	R	278	43.6	120	18.7	0.4
7	R+LTT	7	1.1	3	0.5	0.4
10	B+RSF	22	3.4	38.6	6.0	1.8
11	B+SF	121	19.0	113	17.6	0.9
12	B+TSF	24	3.8	13.5	2.1	0.6
		638	100	638.9	100	1.0

28.7 Barriers

The western Eyre coast has 711 km (67%) of barriers, the excess over the beach length owing to the numerous clifftop dunes whose beaches and sand ramps have been eroded. The carbonate-rich barriers occupy 62% of the shore, the remainder dominated by calcarenite cliffs and slopes. They have a total volume of 20,245 M m^3 (28,457 m^3 M^{-1}) (Table 28.7), both indicative of the abundant shelf sand, high wave energy to deliver it to the coast and strong winds required to transfer it to the massive predominately transgressive dunes, of which 41% are presently unstable. Short et al. (1986b) who investigated the entire Eyre Peninsula coast (including the western Spencer Gulf section) reported that dunes occupy 996 km (60%) of the 1647 km long coast, of which 12.2% (200 km) are foredunes, 29.7% (490 km) are transgressive dunes and 18.6% (307 km) are clifftop dunes.

28.8 Sand Transport

Table 28.3 indicates there has been massive onshore transport from the shelf to the coast and inland. Locally there has also been considerable longshore transport, particularly into the bays and in association with some of the large headlands and points like Point Fowler and islands like Eyre Island. The region contains three PCs (SA:03.01–03) (Fig. 28.1) and ten SCs (Table 28.4). The location and nature of these systems and their sand transport is examined in more detail below.

Table 28.3 Western Eyre Peninsula (SA03) regional and PC barrier dimensions

SA03	SA03.01	SA03.02	SA03.03	SA03
No.	31	26	27	84
Total length (km)	220.5	125.8	220.9	711.4
Mean min width	640	270	620	–
Mean max width	2250	1500	2080	–
Mean height (m)	17	10	10	–
Area (ha)	43,300	9780	35,065	88,145
Unstable (ha)	12,565	3135	20,645	36,345
Total volume (M m^3)	11,216	1253	7776	20,245
Unit volume (m^3 m^{-1})	50,880	9961	35,202	28,457

28.9 PC:SA03.01 Cape Catastrophe-Cape Radstock

PC:SA03.01 commences at the southern tip of the peninsula at Cape Catastrophe and extends generally to the northwest for 477 km to Cape Radstock. For the most part, this is an exposed high energy coast, but which also contains five bays with varying degrees of sheltering, namely, Port Douglas and Coffin, Elliston, Venus and Baird bays. A number of calcarenite-capped bedrock islands are scattered around the coast, including the Whidbey Islands in the south and the larger Waldgrove Group which includes 25 km^2 Flinders Island and the Pearson Isles which lie up to 70 km offshore. As a consequence, the coast has a range of environments from fully exposed high energy beaches to very sheltered tidal flats. Likewise, the barriers range from massive transgressive dunes to regressive beach ridges. The coast is composed of a mix of granite, resilient metasedimentary rocks and gneiss in the south, the gneiss forming headlands along the coast northwards to Venus Bay, and granite outcropping again at Cape Radstock, with most of the bedrock blanketed by dune calcarenite.

The open coast is dominated by longer exposed high energy beaches, with TBR-RBB (45%) averaging 3.1 km in length, followed by the partly sheltered and shorter R and LTT (1 km, 32%), through to the increasingly sheltered bays and beaches (B+RSF-TSF) (23%) (Table 28.5). All 289 beaches occupy 218 km (49%) of the coast, the remainder mainly calcarenite bluffs and cliffs along the open coast. In association with the exposed high energy beaches, this PC has the largest barriers in the region with high total and per metre volumes of 11,216 M m^3 and 50,880 m^3 m^{-1} (Table 28.3), most in the form of massive transgressive dunes including clifftop dunes. More details of the beaches and barriers are provided in the discussion of the SCs below.

28.9.1 SC:SA03.01.01 Cape Catastrophe-Point Whidbey

SC:SA03.01.01 extends along the southwest-facing 141 km long southern shore of the Eyre Peninsula between Cape Catastrophe and Point Whidbey (Fig. 28.3). This is the most southern and exposed section of the peninsula, with the highest waves (Fig. 27.3) and highest energy beaches and some of the largest transgressive barrier

Table 28.4 Western Eyre Peninsula region (SA03) PCs and SCs

PC No.[1]	Name	Boundaries	Beach ID[2]	No.	km[3]	Total km
W Eyre Peninsula						
SA03.01.01		C Catastrophe-Pt Whidbey	SA 804-872	69	1924–2065	141
SA03.01.02		Pt Whidbey-Pt Sir Isaac	SA873-893	21	2065–2090	25
SA03.01.03	Coffin Bay	Pt Sir Isaac-Frenchmans Bluff	SA 894-955	62	2090–2183	93
SA03.01.04		Frenchmans Bluff-C Finniss	SA 956-1046	91	2183–2303	120
SA03.01.05	Anxious Bay	C Finniss-C Radstock	SA 1047-1092	46	2303–2401	98
SA03.01	*Eyre Peninsula*	*C Catastrophe-C Radstock*	*SA 804-1092*	*289*	*1924–2401*	*477*
SA03.02.01		C Radstock-C Bauer	SA 1093-1155	63	2401–2497	96
SA03.02.02	Streaky Bay	C Bauer-Pt Brown	SA 1156-1221	66	2497–2617	120
SA03.02.03		Pt Brown-Pt Peter	SA 1222-1305	84	2617–2770	153
SA03.02	*Eyre Peninsula*	*C Radstock-Pt Peter*	*SA 1093-1305*	*213*	*2401–2770*	*369*
SA03.03.01		Pt Peter- C Adieu	SA 1306-1377	72	2770–2949	179
SA03.03.02		C Adieu-Hd of Bight	SA 1378-1441	64	2949–3067	118
SA03.03	*Eyre Peninsula*	*Pt Peter-Hd of Bight*	*SA 1306-1441*	*136*	*2770–3067*	*297*
		Region sub-total		*638*		*1143*

[1]NCCARF compartment number
[2]ABSAMP beach ID
[3]Clockwise distance from state borders

Table 28.5 PC:SA03.01 beach types and states

BS	BS	No.	%	km	%	Mean (km)	σ (km)
3	RBB	15	5.2	45.9	21.0	3.1	6.6
4	TBR	52	18.0	51.6	23.6	1	1.5
5	LTT	35	12.1	21.1	9.7	0.6	0.8
6	R	133	46.0	48.9	22.4	0.4	0.6
10	B+RSF	3	1.0	6.4	2.9	2.1	–
11	B+TF	45	15.6	42.6	19.5	1	1.6
12	B+TSF	6	2.1	1.9	0.9	0.3	0.2
		289	100.0	218.4	100	0.7	–

systems. The coast consists essentially of five major headlands (Cape Catastrophe-West Point, Cape Tournefort, capes Wiles-Carnot, Point Avoid and Point Whidbey) each consisting of a calcarenite-capped bedrock base, separated by a series of high energy embayments (Jussieu Bay, Sleaford Bay, Gunyah Beach and Avoid Bay). The eastern third is located in Lincoln National Park, the southern capes in the private but publicly accessible Whalers Bay reserve, and the western third in Coffin Bay National Park, with no permanent habitation along the coast, while the adjacent waters are all part of Thorny Passage Marine Park. The combination of headlands, cliffs and beaches has produced a range of WD beaches from R to RBB. The R-LTT beaches are generally located along the rocky section in small sheltered embayments and have an average length of just 0.24 km, while the TBR and RBB occupy the larger exposed bays and longer beaches (mean = 1.8 km), with 15.5 km long rip-dominated Gunyah Beach (SA 838), the highest energy beach in the region.

The exposed location and high wave and wind energy is reflected in the nature, extent and size of the barriers, with the Sleaford Bay, Gunyah Beach and Avoid Bay beaches all backed by massive transgressive dune systems, which extend on average 4 km inland and, in the case of Gunyah Beach (Fig. 28.4d), extend inland for 10 km as active dunes. Extensive predominately stable clifftop dunes extending up to 6 km inland also occur in Jussieu Bay and between Cape Wiles and D'Anville Bay, with one of the few remaining active sand ramps and clifftop dunes located in Jussieu Bay (Fig. 28.4b). The Holocene barriers occupy 99 km (70%) of the coast, the remainder made up of former dunes in the form of sequences of Pleistocene dune calcarenite ranging up to 150 m high (Fig. 28.4a), which is usually cliffed along the coast. The barriers total 9212 M ^{3} (93,198 m^3 m^{-1}), with the Gunyah barrier totaling 4500 M m^3 and a massive 225,000 m^3 m^{-1}, a third of which is unstable, while 25% of all the dunes are unstable (Fig. 28.4c). Another indication of the high wave energy is boulders weighing 100's kg thrown up by the waves onto clifftops as high as 20 m, as at Cape Carnot.

Fig. 28.3 The southern Eyre Peninsula and SC:SA03.01.01. (Source: Google Earth)

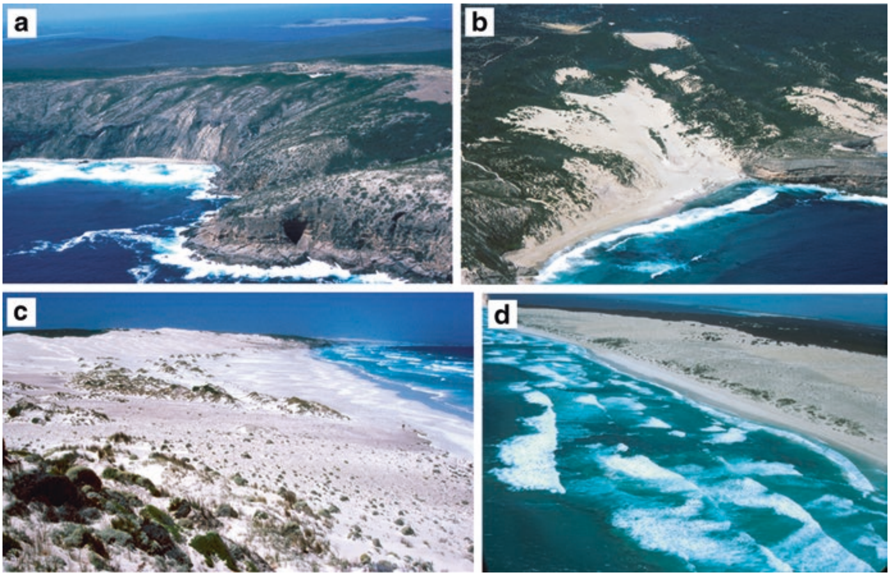


Fig. 28.4 (**a**) 100 m high calcarenite cliffs in Jussieu Bay with beach SA 809 tucked in at the base; (**b**) an active sand ramp and clifftop dune in lee of Cape Tournefort (SA 813); (**c**) Sleaford Bay beach and active dunes (SA 820); and (**d**) Gunyah Beach (SA 838) one of the highest energy on the southern coast with massive rips and dunes. (Photos: AD Short)

As indicated in Table 28.1 and Fig. 28.2, the beach and dune sediments are predominately well-sorted, fine carbonate-rich sand, averaging 96% carbonate, the sand derived from the inner shelf. This is a swash-aligned coast which has received massive volumes of sand transported onshore from the shelf, into the four larger open embayments with no evidence of ongoing longshore transport or inter-embayment transfer.

28.9.2 SC:SA03.01.02 Point Whidbey-Point Sir Isaac

SC:SA03.01.02 is a 25 km long west-facing rocky section of coast between Cape Whidbey and the northern Point Sir Isaac (Fig. 28.5) and contained entirely within Coffin Bay National Park. The coast consists entirely of 20–50 m high calcarenite cliffs and inshore reefs, with lower waves at the shore, resulting in a series of 21 short (mean = 0.48 km) R-LTT beaches along the base of the cliffs and in lee of the reefs. The present beaches are disconnected from the clifftop dunes, following erosion of the former beaches and sand ramps. The cliffs are entirely blanketed by a fringe of largely vegetated clifftop dunes extending up to 1.5 km inland and adding yet another layer to the calcarenite, the Holocene dunes estimated to be on the order of 50 M m^3.

Fig. 28.5 SCs:SA03.01.02–03, Coffin Peninsula and Coffin Bay. (Source: Google Earth)

28.9.3 SC:SA03.01.03 Point Sir Isaac-Frenchman Bluff

SC:SA03.01.03 encompasses the U-shaped north-facing Coffin Bay, together with the sheltered and shallow (2–6 m) Port Douglas; it includes most of the crenulate port shoreline and extends for 93 km from Point Sir Isaac to Frenchman Bluff (Fig. 28.5). All of the southern shores of the bay and port are located within Coffin Bay National Park, with the small town of Coffin Bay located at the eastern park boundary and the only community in the SC. The bay and port are a sink for both Pleistocene and Holocene shelf and seagrass sediments, together with dune overpassing from the southern beaches (Fig. 28.6a). On the western side of the bay, sand moves along the 7 km long southwestern shore (Seven Mile Beach SA 900) with its 3 km wide sand flats and then along the 5 km long Longnose Point (SA 901) (Fig. 28.6b) slowly building the sandy spit eastwards to enclose Port Douglas and contribute sand to both the spit and 10 km^2 flood tide delta that fills the western side of the port. On the eastern side of the port are three spits together with one in the south. Two are lithified Pleistocene spits at Kellidie Bay and the 11 km long Horse Peninsula that encloses the inner Mount Douglas Bay, while the third is the Holocene Farm Beach (SA942-3) which terminates in a Holocene recurved spit at the entrance to the port (Fig. 28.6c), which is also feeding an 8 km^2 delta on the eastern side of the port. A southern spit encloses Yangie Bay at the base of the port. The size and

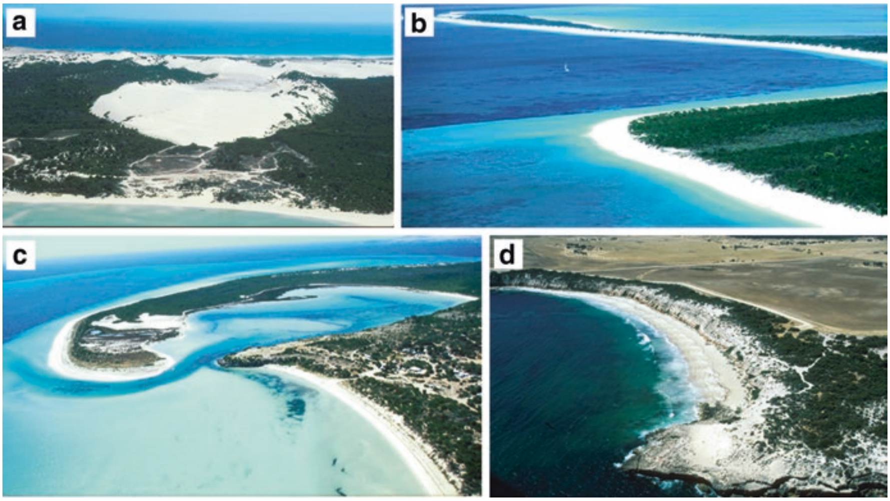


Fig. 28.6 (**a**) A large active parabolic dunes from Sensation Beach (SA 857) overpassing the peninsula and heading towards Port Douglas (SA 916); (**b**) view east from Seven Mile Beach to Point Longshore sand spit (SA 900–901); (**c**) Little Douglas Bay is enclosed by the Farm Beach (SA 942) recurved spit; and (**d**) the reflective Mena Hill Beach (SA 951) typical of this partly sheltered section of coast. (Photos: AD Short)

extent of the Pleistocene spits imply a higher level of wave energy and no Longnose Point together with extensive Pleistocene flood tide deltas, all assisted by the 2 m higher Pleistocene sea level (Harvey et al. 2002). The Holocene sand flats, spits and flood tide deltas cover an area of ~70 km^2, which would equate to a volume of sand on the order of 350 M m^3, all transported by the westerly waves and tides into the southern reaches of the bay and port entrance.

Short et al. (1986b, 1989) investigate the chronology of four beach ridge sites around the bay and port. Based on a date from the rear of very low energy beach ridges at the northern end of Mount Dutton Bay, they found sea level flooded the bay to its present level by 6.3 ka, with the first swale in front of this site dating 4.6 ka, with the elevation of the inner ridges and swales suggesting a slight (0.5 m) but unconfirmed fall in sea level. Bourman et al. (2016) also reported the occurrence of shell beds at the head of Dutton Bay at an elevation of 1 m which may also indicate a subsequent slight fall in sea level. In the southern reaches of the port at Yangie Bay, Short et al. (1989) dated the base of tidal flats at 2.8 ka and 2.1 ka indicating that there was a considerable lag between the flooding of the bay and tidal flats aggradation. At Salt Waterhole inside the port at the base of Point Longnose, there are a series of four beach ridges (backed by Pleistocene ridges) that were likely deposited by refracted ocean swell before Point Longnose commenced its eastward progradation. The ridges dated between 3.9 and 3.2 ka, with the cessation of progradation probably related to the development of the Longnose spit which stopped the constructive ocean swell from reaching this part of the port. Finally, at Morgans Landing on Seven Mile Beach, Short et al. (1989) dated a series of four beach ridges, each part of east-trending spits between 3.7 and 2.5 ka, which are now stable apart from being reworked by easterly migrating sand waves associated with the longshore sand transport. In summary, this set of dates indicate that the bay and port were flooded by the sea level transgression to at least the present level by 6.3 ka, following which there was very slow aggradation of sheltered tidal flats and low energy inner port beaches ridges. By 4 ka, sand was moving eastwards past Morgans Landing depositing the beach ridge-spits, and ocean waves were penetrating Port Douglas in the absence of Point Longnose and depositing the Salt Waterhole ridges. The easterly sand transport filled Morgans Landing by 2.5 ka, and Pont Longnose was building eastwards across the port entrance by 3 ka.

The bay contains 62 beaches occupying 53 km (57%) of the shore, the remainder mainly low (<20 m) calcarenite cliffs and bluffs on the east and western arms of the bay and along the Horse Peninsula. The partly sheltered beaches along the eastern side of the bay between Farm Beach (SA 943) and Frenchman Bluff (SA 956) are all R (Fig. 28.6d), with those along the very sheltered western and southern shore B+SF, while those within the port are TD B + SF and a few B+TSF, indicative of the very low wave energy in this micro-tidal environment.

The bay area contains seven barriers, all low energy regressive systems consisting of either multiple foredune ridges and/or recurved spits, with a series of more than 20 recurves on Point Longnose and 25 ridges at Farm Beach. The barriers have a total volume of 142 M m^3 (8255 m^3 m^{-1}), less than half of what is estimated to be stored in the subaqueous sand flats and tidal deltas. In addition, sand has overpassed the peninsula from western Gunyah, the Avoid Bay beaches and Sensation Beach to reach the southern shore of the bay to feed the easterly longshore transport and adjacent sand flats. The dunes also reach the southern port shore (Fig. 28.6a) where they protrude into the port and are very slowly reworked by local wind waves into the sand flats, the sand then slowly migrating eastwards along the Yangie Bay spit and east of Yangie Bay towards Coffin Bay township.

In summary, the bay and port are a major local sink for both Pleistocene and Holocene sands delivered by dune overpassing from the south (Fig. 28.6a) and wave- and tide-driven longshore sand transport from the north and west (Fig. 28.6b, c), with sand originating predominately from the shelf, but also the possibility of significant local seagrass production. The bay-port is infilling with both tidal and wave deposits, a process which is likely to continue and even be accelerated by rising sea level. Based on the estimated volume of Holocene sand in the bay-port (350 + 142 M m^3), this would represent a deliver on the order of 80,000 m^3 $year^{-1}$ into the bay at a rate of ~6 m^3 m^{-1} $year^{-1}$ across the 13 km wide bay mouth.

28.9.4 SC:SA03.01.04 Frenchman Bluff-Cape Finniss

SC:SA03.01.04 is a gently curving section of coast that trends from Frenchman Bluff for 120 km north-northwest and then northwest to Cape Finniss, with Point Drummond protruding in the centre (Fig. 28.7a). The southern Frenchman Bluff

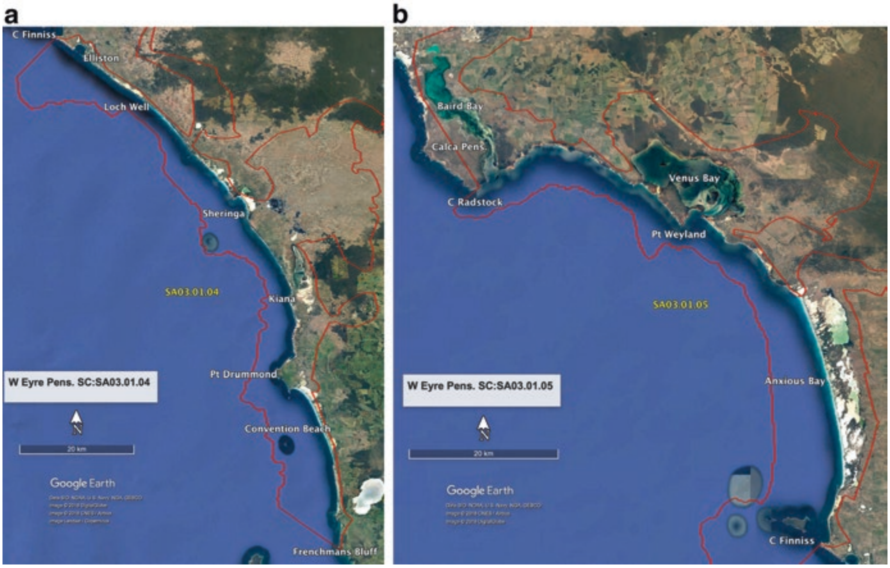


Fig. 28.7 (**a**) SC:SA03.01.04 and (**b**) SC03.02.05. (Source: Google Earth)

is in line with Point Sir Isaac, located 14 km due east, which affords moderate protection from the prevailing southwest swell, with Greenly Beach just north of the bluff usually R (Fig. 28.8a). North from here the degree of protection gradually decreases so that by Convention Beach (Fig. 28.8b), 15 km to the north, the coast is receiving the full force of the southwest waves and TBR-RBB dominate.

While this is an open and reasonably continuous coast, with just three metasedimentary headlands at Frenchman Bluff, Coles Point and the large Point Drummond, it is predominately a calcarenite-dominated coast, with calcarenite bluffs and cliffs rising to between 40 and 100 m, including 35 km of continuous cliffs between Sheringa and Elliston. In addition, there is the slightly sheltered Sheringa Bay and the more protected Waterloo Bay at Elliston, both located in lee of breaches in the line of cliffs. The only development on the coast is the small town of Elliston and the Loch Wells access stairs. Among the cliffs are 91 beaches occupying just 38.7 km (32%) of the shore. While this is an exposed high energy coast, 50 of the beaches are short R occupying 8.7 km and 14 are LTT (9.5 km) as result of sheltering by calcarenite reefs, such as at Hill Bay. There is 20 km of exposed higher energy beaches ranging from TBR (15.5 km) and RBB (5 km) and including the 7 km long Convention-Picnic beaches (SA 973–986) (Fig. 28.8b) and Loch Wells (SA 1032) with its several kilometres of massive beach rips (Fig. 28.8d) spaced ~400 m apart.

This section is completely blanketed to some degree by Pleistocene dune calcarenite, together with six Holocene barrier systems that back the beaches and some of the bluffs, totaling 39 km (33%) in length, with the largest barriers backing Sheringa

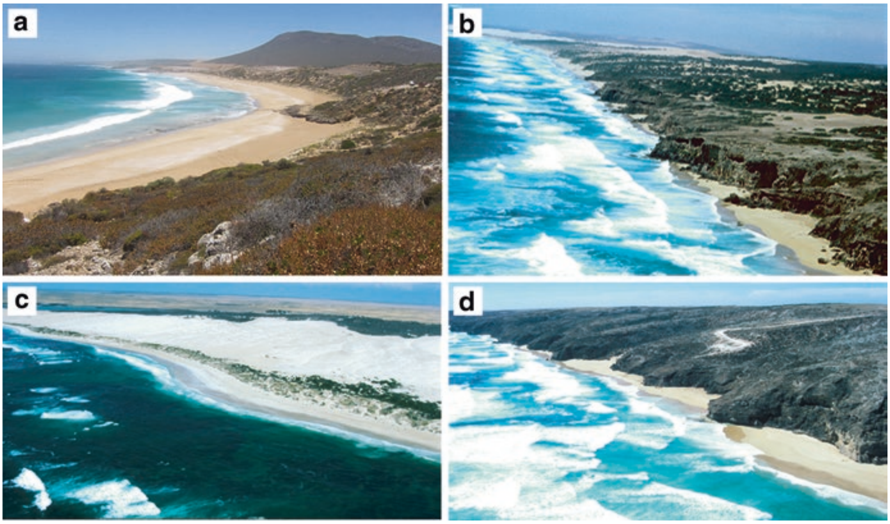


Fig. 28.8 (**a**) Mount Greenly and Greenly Beach (SA 961); (**b**) the calcarenite-dominated southern end of Convention Beach (SA 979); (**c**) the partly reef-sheltered Sheringa beach and active dunes; and (**d**) the rip-dominated Loch Wells Beach (SA 1032). (Photos: AD Short)

(Fig. 28.8c) and Convention-Picnic beaches (Fig. 28.9b). All the barriers consist of transgressive dunes including blowouts, parabolics and dune sheets, with 60% presently unstable. They have a total volume of 706 M m^3 (18,243 m^3 m^{-1}).

The beach and dunes are composed of carbonate-rich (96%), well-sorted, fine to medium sand (Fig. 28.2) indicating a shelf source which was delivered by the energetic wave climate. However, only some of this has been deposited in the barrier systems, while most sand could not be accommodated because of the steep nearshore gradients and line of cliffs, with most of the cliffs receiving no Holocene sand. All transport is expected to the onshore in this swash-aligned shore with no evidence of longshore transport, apart from sand moving into Waterloo Bay.

28.9.5 SC:SA03.01.05 Cape Finniss-Cape Radstock

SC:SA03.01.05 commences at Cape Finniss and trends north before curving west to the prominent 120 m high Cape Radstock, the PC boundary (Fig. 28.7b), a total distance of 98 km. This section can be divided into two parts, the southern third containing the sandy west-facing high energy Anxious Bay and the northern two-thirds which face southwest to south-facing and predominately composed of calcarenite cliffs together with Venus and Baird bays, both inverse estuaries located in valleys lying in lee of 100 m high calcarenite cliffs. Venus Bay has an entrance stand

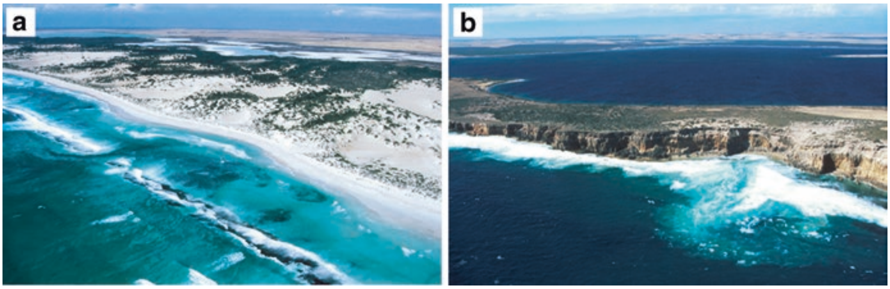


Fig. 28.9 (**a**) Shore parallel beachrock reefs along Anxious Bay beach (SA 1054); (**b**) large rip current at the base of 100 m high calcarenite cliffs just north of Point Weyland with Venus Bay in the background. (Photos: AD Short)

of mangroves, while the high salinities in Baird Bay allow only occasional development of juvenile mangroves which subsequently die-off during periods of higher salinities.

Like most of the west coast, this is a carbonate-rich environment, and most of the beaches >90% carbonate; however the overall average (69%) is diluted by the occurrence of quartz (silica)-rich beaches around Silica Beach (SA 1082-1086), no doubt derived from erosion of the local granite, with Johnson (1978) proposing it was eroded from the now submerged granite outcrops. This section also has slightly coarser (0.5 mm), moderately well-sorted sand. There are 46 beaches occupying 58 km (60%), including the 24 km long Anxious Bay beach. They range from reef-sheltered R (12.5 km) and LTT (5 km) to the exposed TBR (32 km), together with B+SF (9 km) in the entrances to the sheltered Venus and Baird bays. A 2 km long section of Anxious Bay is paralleled by a beachrock reef located 250 m offshore (Fig. 28.9a).

There are six barriers along this section which are dominated by the long and large Anxious Bay system (1060 M m^3, 36,550 m^3 m^{-1}). Five consist of moderate to massive episodic dune transgression extending on average 1–3 km inland; the sixth is a series of three recurved spits at the entrance to Baird Bay. The barriers occupy 46 km (47%) of the shore and total 1156 M m^3 (25,295 m^3 m^{-1}), the same order of magnitude as the adjacent southern SC. In addition, Venus and Baird bays have flood tide deltas with an area of ~15 and ~10 km^2, respectively, which would represent on the order of 125 M m^3 of shelf sand. The remainder of the shore, particularly in the north, consists of long sections of 50–100 m high calcarenite cliffs (Fig. 28.9b), most devoid of Holocene sand. Like the previous SC, this section has received massive volumes of wave-supplied carbonate-rich shelf sands, some of which has been deposited in the barriers and two flood tide deltas, while much could not be accommodated owing to the existing Pleistocene barrier deposits in the form of the high calcarenite cliffs. In Venus Bay construction of the jetty was followed by initial erosion on the western seaward side of the jetty (Short et al. 1986a). Since then the jetty has trapped 1 km^2 of sand on both sides of the 300 m long jetty, though primarily on the inner eastern side, the 150 m wide protrusion now impinging on the ebb tide channel. On the northern shore of the bay, the 260 m long Port Kenny jetty has trapped sand on its western side and extended 140 m out along the jetty, the sand probably transported by westerly wind waves and ebbing tidal currents.

28.9.6 PC Overview

This PC extends along the southwest section of the Eyre Peninsula and is the most southern and exposed of the entire peninsula. The level of exposure is reflected in the Pleistocene and Holocene barrier deposits in the form of massive transgressive dunes that during the Pleistocene have blanketed the entire coast and during the Holocene have delivered another 11,216 M m^3 of sand to the barriers at rates averaging 50,880 m^3 m^{-1}, both the highest in the region, as well as ~500 M m^3 to the Coffin, Venus and Baird bays flood tide deltas. Most of this material would have been delivered during and soon after the PMT and sea level stillstand. Since then many beaches and sand ramps have been eroded, and what remains are remnants of a once larger more continuous beach systems, the remains eroded down to a predominately eroded and cliffed coastline together with a mixture of sheltered beach remnants and a few longer higher energy beaches.

Rising sea level will exacerbate the present situation, with ongoing beach recession which could reactivate many of the stable dunes together with a reactivation of the flood tide deltas which will lead to further loss of marine sand to the bays. The cliffs will experience accelerated erosion as less wave energy is dissipated over the reefs and platforms, thereby increasing physical wave attack on the platforms and cliffs. Shack communities located on low-lying beach ridges around Port Douglas, in Baird Bay and at Yanerby, Streaky Bay (Caravan Park), will also be increasingly exposed to inundation.

28.10 PC:SA03.02 Central Western Eyre Peninsula

PC:SA03.02 occupies the central section of the western Eyre Peninsula extending for 369 km from Point Radstock to Point Peter (Fig. 28.1). In between the coast is dominated by a series of ten bays: the exposed Searcy, Searle and Corvisart and the more sheltered Streaky, Smoky, Decres, Bosanquet, Murat, Denial and Tourville, with the coast having a crenulation ratio of 2.7 indicative of the indented nature of the coast. In addition, there are a series of calcarenite-capped bedrock islands off the coast, eight located in the Nuyts Archipelago including the 40 km^2 St Peter. The sheltering of the coast within the bays and to a lesser extent by the islands lowers wave height along the coast resulting in generally lower energy beach systems. Of the 213 beaches, the majority by number are TD (53%), with 3% TM and 46% WD; however of these only 4% are higher energy TBR, with the bulk (41%) partly sheltered R and LTT. The longer TBR (mean length = 3.1 km) do however make up 13%

Table 28.6 PC:SA03.02 beach types and states

BS	BS	No.	%	km	%	Mean (km)	σ (km)
4	TBR	8	3.8	25.2	13.0	3.1	5
5	LTT	5	2.4	4	2.1	0.8	0.8
6	R	82	38.5	48.8	25.2	0.6	1.3
7	R+LTT	7	3.3	3	1.6	1.5	0.4
10	B+RSF	19	8.9	32.2	16.6	1.7	2.5
11	B+SF	76	35.7	70	36.2	0.9	1.1
12	B+TSF	16	7.5	10.2	5.3	0.6	0.5
		213	100.0	193.4	100	0.9	–

of the beaches by length (Table 28.6). Likewise, in terms of barrier volumes, this PC has a total of 1253 M m^3 which represents 9961 m^3 m^{-1}, both an order of magnitude less than the adjoining PCs (Table 28.3), all indicative of the substantially lower wave energy and consequent lower shelf sand supply, with the sediments in the more sheltered bays derived from the seagrass meadows. This PC contains three SCs, which include the more exposed Searcy-Searle-Corvisart bays, the large sheltered Streaky Bay, and the western bays (Smoky-Tourville).

28.10.1 SC:SA03.02.01 Cape Radstock-Cape Bauer

SC:SA03.02.01 commences at the high calcarenite Cape Radstock and trends essentially northwest to the 80 m high calcarenite Cape Bauer, with the three exposed bays in between (Fig. 28.10) and a total shoreline length of 96 km. Then only development on the coast is the small communities at either end of Searle Bay. The bays are located between prominent calcarenite-capped bedrock (granite) headlands, namely, Point Labatt, Slade Point-Cape Blanche, Point Westall and Cape Bauer. This section faces for the most part directly into the dominant southwest swell and contains 63 beaches which occupy 48 km (50%) of the shore, the remainder calcarenite cliffs and bedrock on the points. The beaches are a mix of eight exposed TBR occupying 25 km (including 15 km long Yanerbie in Sceale Bay), primarily in the centre of the bays, while 55 sheltered R and LTT occupy 19 km, the latter located in lee of the headlands and sheltered by calcarenite and bedrock reefs (Fig. 28.11a, b).

Beach sand along this SC is predominately carbonate-rich (93%), well-sorted fine sand (Fig. 28.2). The SC has five transgressive barrier systems including clifftop dunes, the three largest in the Searcy and Searle bays, together with the Speed Point to Smooth Pool and Corvisart Bay barriers. In all they occupy 44 km (46%) of the coast with a total volume of 868 M m^3 (19,715 m^3 m^{-1}), with per metre volumes equivalent to the adjoining high energy SC to the south. The remainder of the coast is dominated by the high calcarenite cliffs, platforms and reefs located between Cape Radstock and Searle Bay, those surrounding Slade-Blanche points and Point

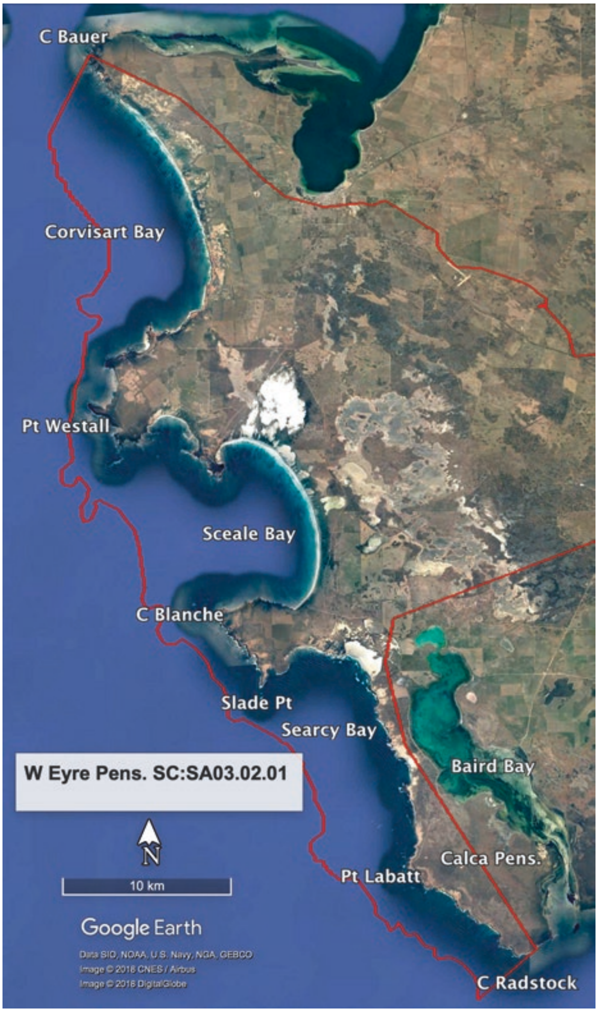


Fig. 28.10 SC:SA03.02.01 contains Searcy, Searle and Corvisart bays. (Source: Google Earth)

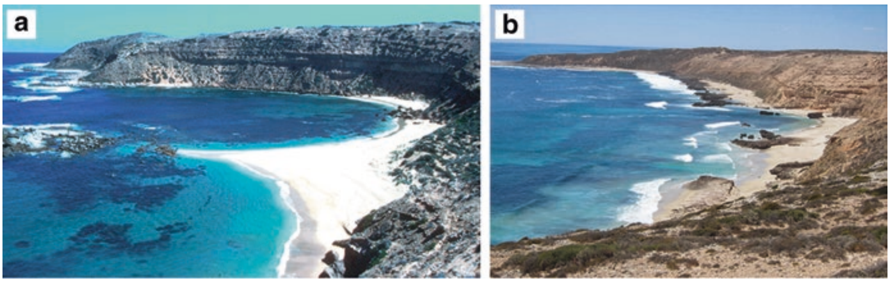


Fig. 28.11 (**a**) A reflective tombolo (SA 1125) located in lee of Slade Point and (**b**) reef and beachrock sheltered beach on Point Westall (SA 1141). (Photos: AD Short)

Table 28.7 Results of OSL dating[a] of clifftop dune sand samples

Location	Sample #	De (Gy)	Dose rate	Over dispersion (%)	Age estimate	Comments
Pt Westall	PW28	19.104 ± 0.565	1.015 ± 0.04	8 ± 3	18,830 ± 1020	very little quartz
Pt Brown	PB25	0.11 ± 0.15	1.0 ± 0.05	18	110 ± 10	very little quartz
Pt Brown	PB24	19.001 ± 0.938	0.899 ± 0.04	16 ± 4	21,127 ± 1430	very little quartz
Pt Vivonne	PV23	1.28 ± 0.01	0.86 ± 0.04	3	1500 ± 100	very little quartz
Cabbots	CB19	1.620 ± 0.198	0.802 ± 0.04	33 ± 9	2020 ± 270	very little quartz

[a]Dating undertaken by TSN Oliver (Australian Defence Force Academy) and T Tamura (Geological Survey of Japan)

Westall, and along much of Corvisart Bay up to Cape Blanche, together with some bedrock on the major points. The clifftop dunes on Point Westall were dated using OSL and returned dates of 18,830 +/1020BP, with a second sample too low in quartz to date. It is assumed the date represents reworking of Pleistocene dunes during the period of stronger drier glacial winds, not the date of original deposition (Table 28.7).

28.10.2 SC:SA03.02.02 Streaky Bay: Cape Bauer-Point Brown

SC:SA03.02.02 encompasses all of Streaky Bay (Fig. 28.12a). The bay has 120 km of shoreline and a 28 km wide entrance providing an embayment ratio of 0.23, which together with the protruding Cape Bauer, Olive Island, the shallow bay floor and substantial bay shoals, combine to substantially lower wave energy around the curving the bay shore. The safe anchorage afforded by Blanche Port within Streaky Bay lead to the establishment of the town of Streaky Bay, with the smaller communities of Perlubie Beach and Haslam located on the eastern shore. The bay sediments are predominately fine, moderately sorted carbonate-rich sand (70–90%), with an outcrop of quartz-rich sand (>90%) around the granitic Point Brown, lowering the SC average to 75% (σ = 29%). The 66 beaches in the bay reflect the dominance of the sandy bay shore occupying 85 km (71%) and the low to very low wave energy, with more exposed R beaches occupying 19 km (16%), while the TD B+RSF, B+TF and B+TSF dominate occupying 65 km (54%) of the bay shore. All the beaches are fringed by subtidal seagrass meadows.

James and Bone (2017) reported that the bay is generally <15 m deep and can be divided into three zones. An outer rocky substrate entrance with sand patches (10–30 m deep); an intermediate seafloor of sand shoals, tidal deltas, spits, and banks with luxuriant seagrass (2–10 m deep) that has two elongate sand bars on the inner part oriented normal to the shoreline; and a series of shallow inboard muddy depressions 7-15 m deep just outside the beaches. While the bay has more than 40 km of

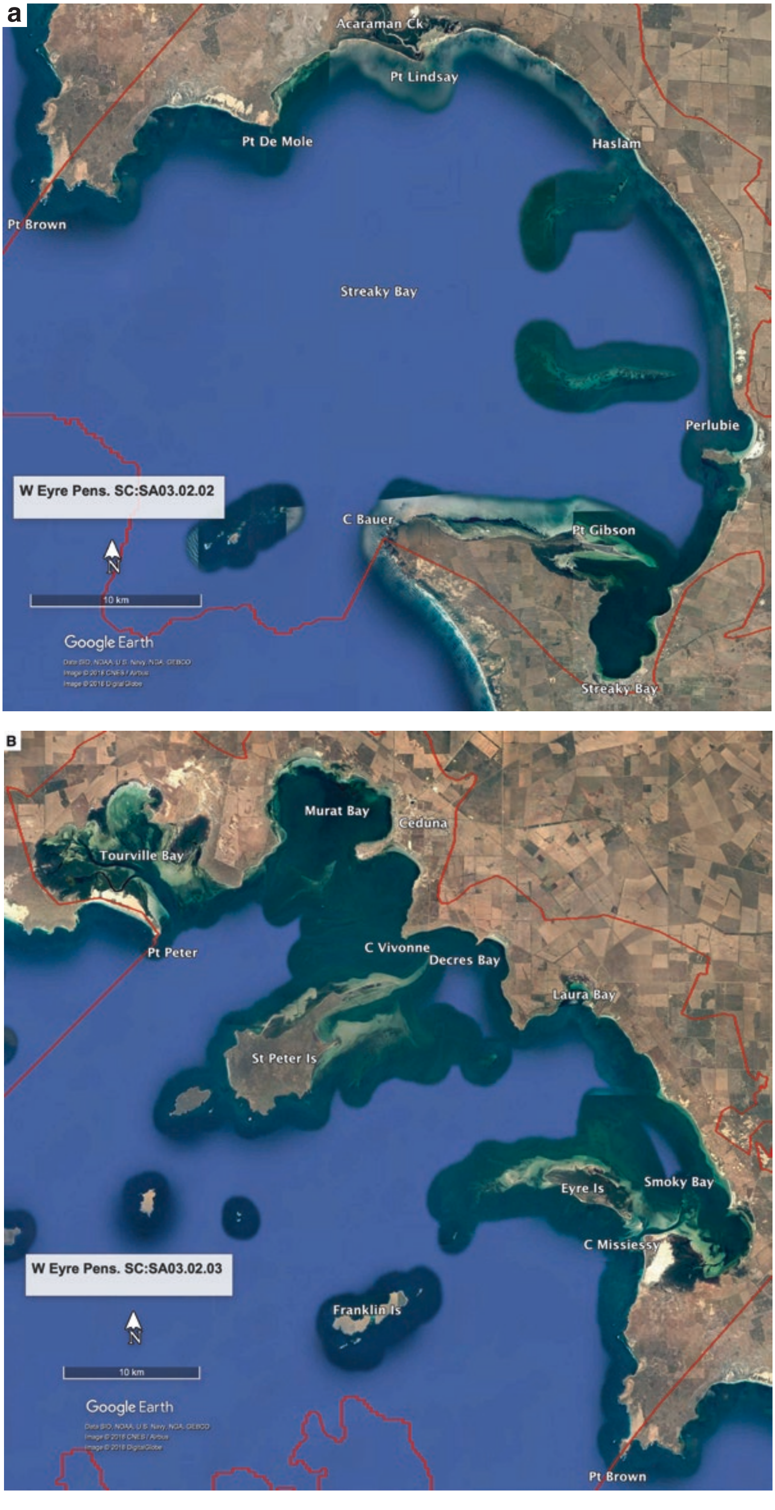


Fig. 28.12 (**a**) Streaky Bay (SC:SA03.02.02) and (**b**) the central bays (SC:SA02.02.03). (Source: Google Earth)

sandy beaches facing west into the prevailing westerly winds and 13 barriers which occupy 64 m (53%) of the bay shore, the barriers are limited in size and extent owing to the low wave energy and consequent low rates of sand supply and more stable foredunes. The barriers are a mix of regressive and transgressive systems. The regressive are generally low beach-foredune ridges (Fig. 28.13a) as along The Spit, Doctors Beach and Crawford Landing in the south and Acraman Creek in the north. Transgressive dunes are located along 30 km of the west-facing central shore between Perlubie Beach and Haslam where they extend less than 1 km inland. Dunes in the more exposed northern Gascoigne Bay extend 1.5 km inland, with 23% of the barriers presently unstable. The Perlubie barrier, which is backed by Pleistocene calcarenite foredune ridges, has a regressive barrier south of Eba Island and a transgressive barrier on the north side of the island, the latter secondary dune transgression over an initial regressive barrier. The innermost Perlubie ridge dated 3.3 ka (Short et al. 1986b, 1989) indicating there was a lag of up to 3 ka between the sea level stillstand and arrival of sand into parts of the bay. The bay barriers have a total volume of 232 M m^3 with a per metre volume of 3778 m^3 m^{-1}, the latter an order of magnitude less than the adjacent open coast.

While the barriers are limited in size, there has been considerable sediment transport into the bay, both along the southern and northern entrances and through the centre of the bay. In the south is the 9 km long east-trending spit, an elongate calcarenite and sand spit that extends to its tip at Point Gibson. The entire core of the spit is Pleistocene calcarenite indicating very similar processes occurring at the last highstand, with Holocene sand moving along the northern shore of the spit to slowly

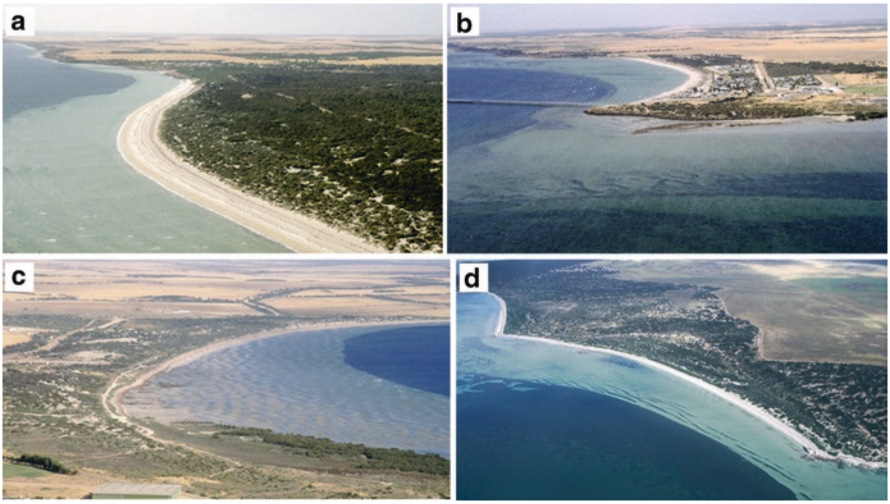


Fig. 28.13 PC:SA03.02 sheltered bay beaches: (**a**) low energy B+SF in Streaky Bay at Haslam (SA 1191); (**b**) Smoky Bay township and long jetty extending out across the sand flats (SA 1234) which has trapped south-moving sand; (**c**) Bosanquet Bay and its ridged sand flats (SA 1272); and (**d**) sand flats and seagrass meadows and 150 m wide regressive barrier in lee of Cape Beaufort (SA 1299). (Photos: AD Short)

extend it further across the entrance to the southern Blanche Port. In the north are the two 5 km long Acraman Creek spits, with the western barrier spit enclosing and blocking a paleao-tidal creek, while the second Point Lindsay spit has deflected the present Acraman Creek 3 km to the east. In addition, there are extensive shore transverse sand shoals lying off the eastern shore of the bay which represent accumulations of marine sand. It is very likely far more sand has been deposited on the bay floor than in the surrounding barrier systems. Short et al. (1986b, 1989) obtained date from the innermost Acraman Creek ridges of 5.9 ka, indicating sea level has reached its present elevation at least by that date.

At Point Collinson on the northern shore of the bay, Short et al. (1986b) found cemented shellrock deposited on top of a stranded rock platform 1 m above sea level. The shells were dated 38 ka and 42 ka indicating they were Pleistocene in age and provide evidence of a ~2 m higher Pleistocene sea level during the last interglacial. Clifftop dunes blanket Point Brown, the northern boundary of the bay. Two cores from the dunes yielded dates of 21,127 ± 1430 year and 110 ± 10 year (Table 28.7), both of which seem to indicate reactivation of prior deposits rather than date of primary deposition.

28.10.3 SC:SA03.02.03 Point Brown-Point Peter

SC:SA03.02.03 extends from Point Brown to Point Peter and includes the series of southwest-facing central Eyre Peninsula bays (Fig. 28.12b) resulting in an indented shoreline with a crenulation ratio of 3.1 for the 153 km of coast. In addition to the bays are the sedimentary Eyre Island and calcarenite-capped, bedrock islands of the Nuyts Archipelago which lie 10’s km offshore and are scattered along the entire SC. The combination of bays, islands and calcarenite reefs results in a low energy shoreline on this otherwise outer high energy coast (Fig. 27.3). Because of the bays and the anchorages they afford, this is the most developed section of the western Eyre Peninsula, with the larger town and port of Ceduna-Thevenard on Murat Bay and smaller communities at Smoky and Denial bays (Fig. 28.13b).

There are a total of 84 beaches spread around the bays with a total length of 61 km (40%), with the remainder of the coast primarily low calcarenite bluffs and cliffs, together with mangroves and tidal flats in lee of Cape Missiessy, in the small Laura Bay in Smoky Bay, on Eyre Island and in Tourville Bay, the latter the westernmost mangroves on the southern Australian coast. Overall the cliffs are considerably lower than the adjacent higher energy sections of coast reaching a maximum elevation of 30 m north from Point Brown but generally <20 m and extensive sections <10 m. The lower elevation is a direct result of the absence of substantial Pleistocene dunes and dune calcarenite. The beaches reflect the low level of wave energy within the bays with B+RSF (Fig. 28.13c), SF and TSF (Fig. 28.13d) occupying 45 km (29%) of the shore, together with a few TM R+LTT (1.5 km, 1%) and some WD R on the outer more exposed sections (10.6 km, 7%). Even along the 16 km long exposed west-facing section between Point Brown and Cape Missiessy, the beaches are all R, owing to continuous calcarenite reefs extending up to 1 km offshore.

There are eight Holocene barrier systems spread along just 20.4 km (13%) of the coast. They range from sheltered beach ridges and recurved spits in Laura Bay, adjacent to Smoky Bay township, and in lee of Murat Bay's Rocky Point; to minor to moderate dune transgression at Cape Missiessy; and clifftop dune extending up to 1 km inland in the exposed St Marys Bay, with 30% of the dunes presently stable. The barriers have a total volume of 154 M m^3 (7537 m^3 m^{-1}), the lower volumes typical of the sheltered sections of the western Eyre Peninsula coast.

However, in addition to the barrier, there are substantial sand deposits on 25 km^2 Eyre Island and its surrounding sand flats, in the 30 km^2 Smoky Bay tidal delta, in the 50 km^2 of tidal flats surrounding St Peter Island and in the 50 km^2 of tidal flats in Tourville Bay, together with the sand flats and shoals in the other sheltered bays. All these represent the order of 200 km^2 of sand deposits which could equate to 1000 M m^3 of marine sand, if so it would be an order of magnitude larger than the barrier sand volume.

Eyre Island (Fig. 28.12b) is a 7 km long, up to 2.5 km wide series of multiple beach ridges and eastward migrating recurved spits moving along two arms, with a mangrove-covered inner core. It appears the western ridges are being eroded, while the eastern continue to accrete, causing the island to slowly migrate eastwards into Smoky Bay. Short et al. (1986b, 1989) dated the westernmost and oldest ridges on the present island, a 600 m wide series of four beach ridges and swales. They found the innermost swale dated 3.8 ka and the outermost 1.8 ka, indicating that a sand platform had to be deposited before the ridges began developing and suggesting most of the island is <3.8 ka, and much probably much younger.

Short et al. (1986b, 1989) also dated the beach ridge sequence in the small, very sheltered Laura Bay located at the top of Smoky Bay. Here the 1.8 km wide sequence of six low shelly ridges and swales has an inner swale date of 4 ka, followed by dates of 3 ka, 2.3 ka and an outer ridge date of 2.3 ka. While the inner dates give an indication of the time of ridge initiation, the outermost may be contaminated by older reworked shells. At Point Vivonne, the low calcarenite bluffs are blanketed with a rim of transgressive dunes, one of which was dated at 1500 ka ± 100 year (Table 28.7) and may represent a reactivation.

There is considerable evidence of landward and longshore transport along this section of coast, with all the bays acting as sediment sinks and separate TCs. In Smoky Bay there are recurved spits in lee of Cape Missiessy and along Eyre Island all moving sand towards the southern end of the bay. The southerly transport is manifested at the Smoky Bay attached breakwater-boat ramp where the beach has built 20 m bayward between 2003 and 2011 and extended its length by 150 m to the south, indicating the breakwater has trapped 4000 m^2 of south-moving sand, which represents a transport rate on the order of ~500 m^3 $year^{-1}$. In the north of the bay, the small Laura Bay is also acting as a closed sediment sink. Offshore St Peter Island has a 14 km long northeast trending spit for a tail that is moving sand towards Decres Bay. Between St Peter Island and Cape Beaufort is a series of large shore transverse tidal sand shoals that are moving sand towards Murat Bay, while to the west, Tourville Bay has a 7 km long spit trending northwest into the bay together with a 6 km long cluster of spits within its northern entrance, with the bay as a whole essentially completely infilled with marine sands. Davenport Creek located in the southern side of the bay in lee of the barrier of the same name also contains the only cheniers found on the Eyre Peninsula coast which dated 2.8 and 2.2 ka and overlie mangrove peat (Short et al. 1986b, 1989).

28.10.4 PC Overview

PC SA03.02 while located along the exposed high energy western Eyre Peninsula coast is considerably sheltered by the crenulated nature of the coast which contains a series of embayments ranging in size, shape and orientation, together with a series of islands lying off the coast and calcarenite reefs fringing long sections of open coast. Overall breaker wave energy is consequently low to very low, particularly within the sheltered sections of the bays. As a consequence, low energy TD beaches account for 58% of the beaches by length, with low energy WD R and LTT accounting for 27% beaches and the high energy TBR beach just 13% (Table 28.6). This is a low energy PC set within a high energy coastal setting. The lower wave energy has resulted in smaller barrier systems and lower calcarenite cliffs, while the bays have acted as a major sediment sink for marine sand as indicated by the extensive spits and shore transverse sand shoals, with possibly an order of magnitude more sand deposited in the bays compared to the barrier systems. Rising sea level will raise levels of wave energy within the bays and increase their tidal prism, thereby providing the capacity to increase sand transport into the bays, while their low gradient tidal flats and adjacent beach ridges, spits and samphire flats will become increasingly inundated, resulting in shoreline erosion and landward migration of the seagrass, mangroves and samphire. The towns of Streaky Bay and Ceduna are located on elevated ground, with the beachfront properties at Smoky Bay the most at risk to rising sea level and shoreline recession.

28.11 PC:SA03.03 Western Eyre Peninsula

PC:SA03.03 is the westernmost of the Eyre Peninsula PCs and trends essentially due west from Point Peter to Head of Bight and the beginning of the Nullarbor Cliffs (Fig. 28.1). The 297 km of shoreline faces predominately south into the prevailing southwest swell (Fig. 27.3) and south through westerly winds, with the dominant wind at Fowlers Bay from the southwest (234°), while tides remain micro (0.7 m at Fowlers Bay and 1 m at Eucla). This is a largely undeveloped coast with only two very small coastal communities at Fowlers Bay and Point Sinclair and farmland extending inland from the lee of the dunes and Penong (220), the only town in the region. The eastern section of the Great Australian Bight Marine Park extends along 70 km of the coast west of Cape Adieu, and the Yalata Aboriginal Land occupies the western 55 km of the coast.

This is also a very exposed coast with a few protective headlands in the eastern SC, while the western has no protective headlands, though in places calcarenite and beachrock reefs afford some protection from waves. The coast has 136 beaches occupying 227 km (76%) of the shore. The beaches are dominated by exposed high energy TBR-RBB-LBT-D (186 km, 82%) (Table 28.8), followed by the sheltered R-LTT (40 km, 17%), with the remainder of the coast made up of calcarenite bluffs and cliffs averaging 40 m in height, most capped with clifftop dunes, which include a series of protruding calcarenite-capped bedrock headlands. The coast contains two SCs which are described below.

28.11.1 SC:SA03.03.01 Point Peter-Cape Adieu

SC:SA03.03.01 commences at Point Peter and trends essentially west-northwest for 179 km to Cape Adieu (Fig. 28.14). In between are a series protruding points at Rocky Point, Point Bell, Point Sinclair and Point Fowler separating longer curving sandy beaches, followed by 40 km of rocky coast and shorter beaches to Cape Adieu. The beaches are relatively uniform in sand being composed of

Table 28.8 PC:SA03.03 beach types and states

BS	BS	No.	%	km	% (km)	Mean (km)	σ (km)
1	D	12	8.8	59.4	26.2	5	6
2	LBT	5	3.7	5.4	2.4	1.1	0.7
3	RBB	5	3.7	35.1	15.5	7	7.4
4	TBR	34	25.0	86.2	38.0	2.5	4.8
5	LTT	15	11.0	17.8	7.8	1.2	1.6
6	R	63	46.3	21.8	9.6	0.4	0.4
11	B+SF	2	1.5	1.38	0.6	0.7	
		136	100	227.08	100	1.7	–

Fig. 28.14 SC:SA03.03.01 Point Peter to Cape Adieu. (Source: Google Earth)

carbonate-rich (94%), well-sorted fine-medium sand. This section contains 72 beaches which occupy 122 km (68%) of the coast, the remainder the large calcarenite-capped bedrock points and extensive calcarenite bluffs and cliffs. The beaches are a mix of longer exposed high energy TBR (60 km, mean length = 2.9 km) and RBB (35 km, 7 km) located in the longer exposed embayments between the major points, which from the east are 12, 19, 12 and 25 km long, and shorter sheltered R (12 km, 0.35 km) and LTT (14 km, 1.4 km) in among the calcarenite rocks, cliffs and reefs in the rockier sections.

The long exposed embayments and high energy beaches have combined to develop a 120 km (67%) long series of 19 major transgressive barriers, consisting of either massive dune transgression (Fig. 28.15a–c) and/or clifftop dunes (Fig. 28.15d), with 62% of the dunes presently active, including all of the 8 km^2 Scott Bay dune, whose inner dunes have overpassed across the base of the 1.5 km wide point to reach Fowlers Bay and have buried parts of the old Fowlers Bay township. The barriers have a total volume of 2762 M m^3 (23,096 m^3 m^{-1}), which together with the high level of instability are all indicative of the exposure to high energy waves and winds, coupled with an abundant supply of shelf sand. At Cabbots beach (SA 1374) a clifftop dune dated 2020 ± 270 year (Table 28.7) which is likely to represent reactivation rather than the time of deposition.

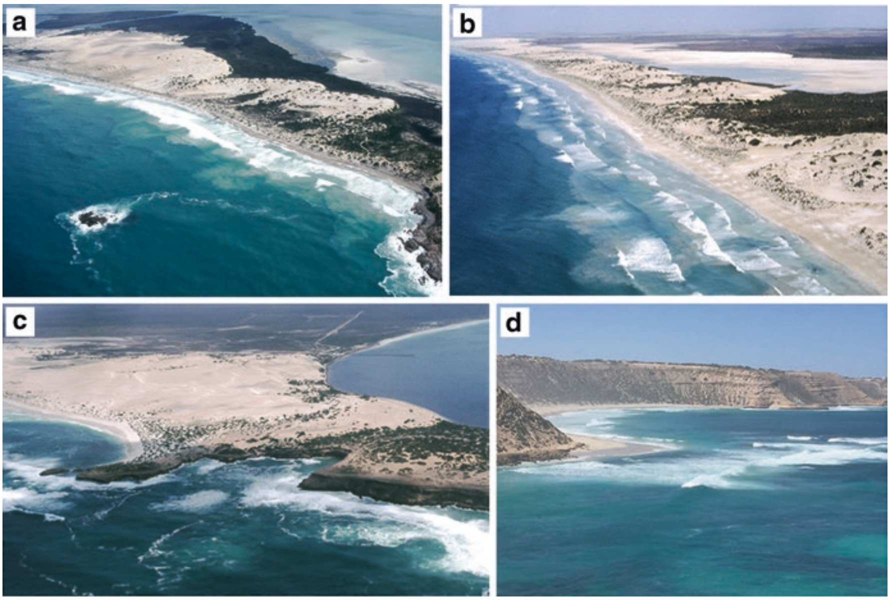


Fig. 28.15 (**a**) Davenport Creek transgressive dunes encroaching on the backing mangroves (SA 1307); (**b**) the Cantaby Sandhill and salt lake west of Point Bell (SA1324); (**c**) Scott Bay (SA 1357) dunes overpassing Point Flower; and (**d**) 60 m high dune-capped calcarenite cliffs and beach in Wandilla Bay (SA1328). (Photos: AD Short)

In addition to the massive onshore transport, there is evidence of longshore transport into Fowlers Bay with a 0.25 km^2 protruding sand spit slowly moving along the northern side of the point in to the bay. In historic times, the spit has migrated past nineteenth century shoreline-based whaling facilities, which are now stranded inland 400 m from the shore.

At Clare Bay Pleistocene beachrock is located up to 2.8–3.2 m above present sea level, with a rock platform cut in the rock 1.4 m MSLW, while the adjacent Holocene platform is located at 0.5 m MSLW. The elevated beachrock and platform suggest a Pleistocene sea level ~1 m above present (Short et al. 1986b) in agreement with the more recent results of Murray-Wallace et al. (2016). At Fowlers Bay Murray-Wallace et al. (2016) investigated a 15 km wide regressive barrier system containing a series of inner Pleistocene barriers up to 30 m high and an outer 20 m high Holocene barrier. They concluded that the now dry inner barrier depressions were flooded by the sea leaving lagoonal facies and indicate the last interglacial sea level reached between +2.2 and 4 m above present.

28.11.2 SC:SA03.03.01 Cape Adieu-Head of Bight

SC:SA03.03.02 continues west of Cape Adieu for 118 km to Head of Bight (Fig. 28.16). There is no development along this section and generally limited 4WD vehicle access to the coast at Yalata beach (SA1414) and the camp sites in the

Fig. 28.16 SC:SA03.03.02 Cape Adieu to Head of Bight. (Source: Google Earth)

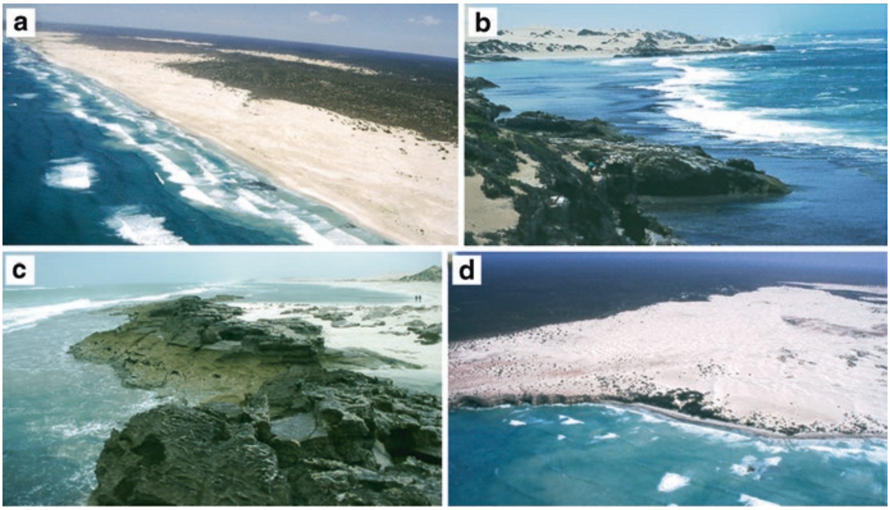


Fig. 28.17 (**a**) High energy beach and dunes of Dog Fence Beach (SA 1411); (**b**) calcarenite platforms at Coombra (SA 1420); (**c**) beachrock reef at Coombra (SA 1427); and (**d**) the massive Yalata dunes at Head of Bight with the start of the Nullarbor Cliffs extending to the left (SA 1441). (Photos: AD Short)

Coombra section (SA1416-1429). The coast trends essentially straight northwest and after a 10 km long rocky section west of the cape contains an almost continuous series of 64 beaches which occupy 105 km (89%) of the shore. It is an exposed high energy coast (Fig. 28.17a) and has the highest energy beaches on the Eyre Peninsula with 12 D beaches spread along 59 km of the coast, followed by 5 LBT (5.5 km), 12 TBR (27 km) and 5 sheltered LTT (4 km) and 29 short R occupying just 10 km, the latter beaches located among the calcarenite bluffs, rocks and reefs, including a 12 km long section of shore-attached beachrock along the Coombra coast (Fig. 28.17b, c).

Six generally long barriers occupy 94 km (80%) of the coast all consisting of massive transgressive dunes extending on average 3 km inland and presently 57% active. They have a total volume of 4938 M m^3 with a high per metre volume of 52,309 $m^3\ m^{-1}$. Half of this sand is contained in the large Yalata barrier (Fig. 27.17d) that extends for 47 km longshore and is 73% unstable. This is a straight exposed coast with essentially no interruptions, which faces directly into the southwest swell and prevailing west through south winds, and with a generally low elevation (<20 m), calcarenite shore has been able to accommodate the beaches, barriers and their dune systems.

28.11.3 PC Overview

PC:SA03.03 is the westernmost, most remote, least developed and one of the highest energy of the regions PCs, with accompanying large transgressive barriers. Combined, the Pleistocene dune calcarenite and Holocene barriers blanket the entire coast, with bedrock only occurring at the base of some of the major headlands. Sea level rise along this coast will lead to an increase in wave energy across the reefs and platforms and an acceleration of retreat of the calcarenite bluffs and the initiation of shoreline retreat and potential reactivation of stable dunes. However this remote section of coast will be largely be left to naturally accommodate there changes.

28.12 Regional Overview

The western Eyre Peninsula contains the longest section of exposed high energy coast in Australia (Figs. 1.12a and 27.3). The 1143 km of shore has been battered by waves and wind and blanketed by carbonate-rich shelf sediment throughout the Quaternary. Shelf loess has blanketed much of the coastal zone during sea level lowstands, while at highstands transgressive dunes have covered the coastal fringe with the dunes subsequently lithified to dune calcarenite and then cliffed and blanketed again during subsequent sea level highstands. The erosion of the calcarenite cliffs produce a wide range of platforms, debris, reefs and islets, as well as beachrock reefs, all of which refract and attenuate the waves resulting in a large number of small sheltered beaches. The higher energy beaches tend to occur on the longer sandy section between the major points and headlands.

This is a rugged exposed coast that has already undergone considerable shoreline retreat as manifested in the erosion of the beaches and sand ramps that supplied the ~300 km of clifftop dunes. The extensive coastal dune systems are presently 41% unstable allowing sand to continue to be lost onshore which will lead to further shoreline retreat. Rising sea level (0.08 mm year^{-1} at Thevenard (Harvey et al. 2002)) will exacerbate the shoreline erosion and may increase dune activity leading to further loss of sand. The rise will also reactivate the many bays increasing wave energy and sand movement into the bays via their recurved spits, flood tide deltas and tidal shoals.

Short et al. (1986a) assessed coastal risk along the Eyre coast and found shacks were at risk to inundation at Shelly Beach (Kellidie Bay), Mount Dutton Bay West, Streaky Bay (Caravan Park), Baird Bay, Yanerby and Smoky Bay; while the old Fowlers Bay township was already partly buried by dune transgression; and shoreline erosion has been experienced at Smoky Bay, Ceduna and Clare Bay, with rock revetments installed at Ceduna and planned for Smoky Bay. While most of the coast is undeveloped, reactivated sand dunes could impinge on backing farmland, and in the sheltered bays, inundation of the sand flats and landward migration of the tide-dependent seagrass, mangroves and samphire flats will occur where space permits.

References

Belperio AP (1995) Coastal and marine sequences. In Chapter 11: Quaternary. In: Drexel JF, Preiss WV (eds) The Geology of South Australia. vol 2, The Phanerozoic. Geological Survey of South Australia Bulletin 54:219–240

Bourman RP, Murray-Wallace CV, Harvey N (2016) Coastal landscapes of South Australia. University of Adelaide Press, Adelaide, 405 p

Brooke B (2001) The distribution of carbonate eolianite. Earth-Sci Rev 55:135–164

Buckley R, Short AD, Fotheringham DG (1987) Late Pleistocene sea-level maxima in the Great Australian Bight. Search 18:86–89

Harvey N, Belperio AP, Bourman RP, Mitchell W (2002) Geologic, isostatic and anthropogenic signals affecting sea-level records at tide-gauge sites in southern Australia. Glob Planet Chang 32:1–11

James NP, Bone Y (2017) Provenance of Holocene calcareous beach-dune sediments, Western Eyre Peninsula, Great Australian Bight, Australia. Sediment Geol 357:83–98. https://doi.org/10.1016/j.sedgeo.2017.06.002

James NP, Boreen TD, Bone Y, Feary DA (1994) Holocene carbonate sedimentation on the west Eucla Shelf, Great Australian Bight: a shaved shelf. Sedimentary Geol 90:161–177

James NP, Bone Y, Hageman SJ, Feary DA, Gostin VA (1997) Cool-water carbonate sedimentation during the terminal Quaternary sea-level cycle: Lincoln Shelf, southern Australia. In: James NP, Clarke JAD (eds) Cool-water carbonates. Soc Sediment Geol, Tulsa, pp 53–75

James NP, Bone Y, Collins LB, Kyser TK (2001) Surficial sediments of the Great Australian Bight: facies dynamics and oceanography on a vast cool-water carbonate shelf. J Sediment Res, Section B: Stratigr Glob Stud 71:549–567

Johnson PD (1978) Baird Bay beach sand, Eyre Peninsula, South Australia. Min Resour Rev South Australia, 149:54–56

Murray-Wallace CV, Belperio AP, Dosseto A, Nicholas WA, Mitchell C, Bourman RP, Eggins SM, Grün R (2016) Last interglacial (MIS 5e) sea-level determined from a tectonically stable, far-field location, Eyre Peninsula, southern Australia. Aust J Earth Sci 63(5):611

Pan T-Y, Murray-Wallace CV, Dosseto A, Bourman RP (2018) The last interglacial (MIS 5e) sea level highstand from a tectonically stable far-field setting, Yorke Peninsula, southern Australia. Mar Geol 398:126–126

Provis DG, Radok R (1979) Sea-level oscillations along the Australian coast. Aust J Marine Freshwater Res 30:295–301

Provis DG, Steedman RK (1985) Wave measurements in the Great Australian Bight. In: 7th Australasian conference on coastal and ocean engineering 2, pp 51–60

Richardson L, Mathews E, Heap A (2005) Geomorphology and sedimentology of the South Western Planning area of Australia: review and synthesis of relevant literature in support of Regional marine planning. Geoscience Australia, Canberra, Record 2005/17, 123 p

Short AD (2001) Beaches of the South Australian coast and Kangaroo Island. Sydney University Press, Sydney, 346 p

Short AD, Fotheringham DG, Buckley R (1986a) Morphodynamic hazard and development impact assessment – Eyre Peninsula, Coast Protection District. Coast Protection Board, Department Env. Planning, Adelaide, 230 p plus appendices and maps

Short AD, Fotheringham DG, Buckley R (1986b) Coastal morphodynamics and Holocene evolution of the Eyre Peninsula coast, South Australia. Coastal Studies Unit Tech. Rept., 86/2, Coastal Studies Unit, University of Sydney, Sydney, 178 p

Short AD, Buckley RC, Fotheringham DG (1989) Preliminary investigation of beach ridge progradation on the Eyre Peninsula and Kangaroo Island, vol 113. Trans Royal Soc South Australia, pp 145–161

Twidale CR, Tyler MJ, Davies M (1985) Natural history of Eyre Peninsula. Adelaide, Royal Society South Australia Inc, Adelaide, 229 p

Chapter 29
Nullarbor Region

Abstract The Nullarbor is a vast Tertiary limestone plain cliffed along its 800 km long southern boundary by the Southern Ocean wave attack. The coastal zone is largely contained in aboriginal land, parks and reserves with very little development and formal access. It faces south to southeast into the Southern Ocean with waves ranging from moderate to high to low where attenuated by inshore reefs, while tides are micro. Beach sediments are carbonate-rich in the east, becoming quartz-rich from Twilight Cove to the west. The coast has two long cliffed sections (Nullarbor and Baxter cliffs) which are bounded by the Roe Plain and the Bilbunya barrier systems, whose beaches range from exposed high energy to low energy sheltered. Barrier systems also range from low energy regressive beach-foredune ridges to some massive areas of dune transgression including extensive clifftop dunes and coastal-glacial dunes extending in places over 100 km inland. It also includes Australia's only star dunes. This chapter describes the coastal processes, beaches, barriers, sediment transport and sediment compartments.

Keywords Nullarbor · Roe Plain · Cliffs · Limestone · Clifftop dunes · Beaches · Barriers · Sediment transport · Sediment compartments

29.1 Introduction

The Nullarbor regionis one of the more remote and certainly the least developed on the Australian coast, with most of this region also located in parks and reserves. In SA the eastern section is located in the Yalata Aboriginal Land, while most of the cliffs are in the Nullarbor National Park. The entire WA section is contained from the east in the 10 km long Eucla National Park, the 466 km long Nuytsland Nature Reserve and 100 km long Cape Arid National Park. Offshore the Great Australian Bight Marine Reserve parallels the coast for 325 km between SA's Cape Adieu and the SA-WA border. The only community on the 844 km of coast is the border stop at Eucla (100). The only other habitation is the Eyre Bird Observatory and a few seasonal fishing shacks at Red Rock and Israelite Bay. There is public access to the coast at Head of Bight and Eucla and 4WD access to Red Rock and Eyre

A. D. Short, *Australian Coastal Systems*, Coastal Research Library 32,
https://doi.org/10.1007/978-3-030-14294-0_29

(ex-telegraph station), from Mandurah and Cocklebiddy, and in the west via Cape Arid National Park to Israelite Bay-Point Malcolm. There are ruins of the telegraph stations at Eucla and Israelite Bay, a sheep station at Noonaera, and at Twilight Cove on old store room built during the overland telegraph construction and Carsile's camp, a rabbit trappers shack, which burnt down in a bushfire in 2017.

29.2 Geology

The coast of the Nullarbor region follows the southern boundary of the Nullarbor Plain a 200,000 km^2 limestone-karst plain, which commences near Head of Bight and trends west and then southwest for 790 km to near Cape Pasley (Fig. 29.1). The continuous boundary consists of two cliff sections (the Nullarbor and Baxter cliffs) and two inland escarpments (Hampton Bluffs and Wylie Escarpment) (Table 29.1). The Nullarbor sediments were deposited in the Eucla Basin (Fig. 1.3) as shallow marine deposits beginning in the Cretaceous. The lower sequences are sandstone and siltstone, while the upper are carbonate deposited between 35 and 20 Ma

Fig. 29.1 The Nullarbor region extends from Head of Bight in SA to Cape Pasley in WA and contains four PCs. (Source: Google Earth)

Table 29.1 Southern boundaries of the Nullarbor Plain

	Name	Location (coastal plain)	Elevation (m)	Length (km)
1	Nullarbor (Bunda) Cliffs	Head of Bight-Wilson Bluff	60–90	210
2	Hampton Bluffs	Wilson Bluff-Twilight Cove (Roe Plain)	80–100	300
3	Baxter Cliffs	Twilight Cove-Pt Culver	100–120	160
4	Wylie Escarpment	Point Culver-lee of Pt Malcolm (Bilbunya barrier)	70–120	120
			Total	790

Fig. 29.2 (**a**) The Nullarbor cliffs just east of Merdayerrah showing the two distinct limestone units, the lower white Wilson Bluff limestone and upper red Toolina and Nullarbor limestone; and (**b**) the Baxter Cliffs at Toolina Cove (WA 18) showing the same stratigraphy. The small beach was used as a landing during construction of the overland telegraph line in the 1870s with material winched to the clifftop. (Photos: AD Short)

(Lowry 1970; Lowry and Jennings 1974). Both units are exposed in the cliffs as the lower white Wilson Bluff limestone and upper red Toolina and Nullarbor limestone (Fig. 29.2). The basin was subsequently uplifted and tilted to form the flat Nullarbor limestone of the Nullarbor Plain which slopes gently to the south. The limestone has since undergone considerable subterranean karst erosion and the formation of blowholes, sinkholes, dolines and networks of caves (Lowry and Jennings 1974). The climate is semi-arid, and owing to the low rainfall (270 mm at Eucla) and either limestone plain or sand dunes, there is no surface drainage in the region. The only non-limestone on the coast is at Red Rock where a low outcrop of red sandstone forms the dune-capped point.

29.3 Sediments

There are two distinct beach sand provinces along the coast. Between Head of Bight and Eyre (280 km, Fig. 29.3), the beaches are rich in carbonate averaging 82% (σ = 17%), a continuation of the carbonate-rich western Eyre Peninsula region (mean 87%, Fig. 28.2). At Eyre (280 km) the carbonate drops to 62%, and by Twilight Cove (307 km), it is down to 1–2%, with the remainder of the coast averaging just 6% (σ = 7%) (Fig. 29.3), with the regional average 50% (σ = 40%) (Table 29.2). The trend indicates a shelf carbonate source in the east and an increasingly terrigenous source to the west, with both provinces composed of fine well-sorted sand. Lowry and Jennings (1974) proposed the quartz sand is derived from the Precambrian granite that dominates the western hinterland and offshore islands that extend west from Point Lorensen (573 km), with carbonate averaging 22% in the adjoining southern WA region (Table 30.2). The quartz has been deposited on

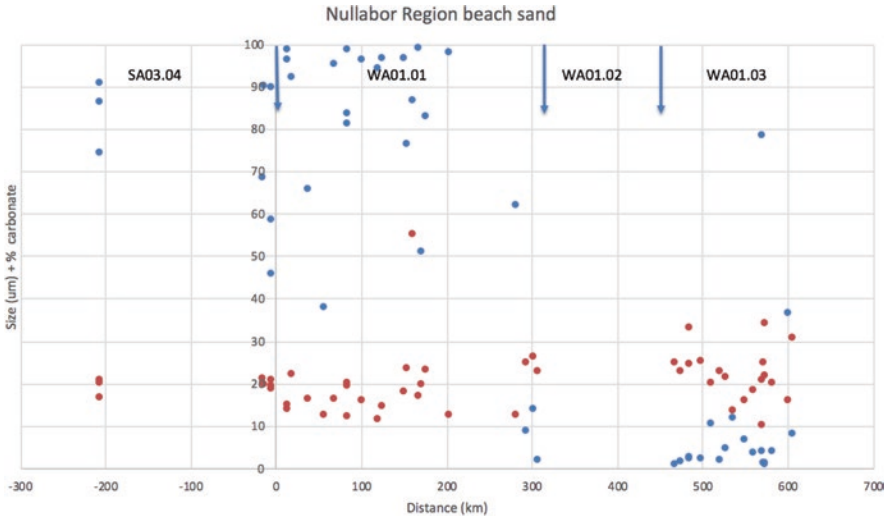


Fig. 29.3 Nullarbor region beach sand size and percent carbonate. Arrows indicated PC boundaries. Distance from SA/WA border. The Nullarbor Cliffs are located between -210 and -30 km and the Baxter Cliffs between 310 and 460 km

Table 29.2 Nullarbor region (SA03.04-WA01.01-03) beach sand characteristics

n	50
Size (mm)	0.21
σ (mm)	0.07
Sorting	0.44
σ (sorting)	0.11
% carbonate	50
σ (%)	40

the shelf at low sea level and reworked and transported by southerly waves during and following the PMT to the northeast along the long Bilbunya beach and the base of the Baxter Cliffs in order to reach Twilight Cove and beyond. The fine often pure white quartz-rich sand (<10% carbonate) extends west as far as Hellfire Bay (830 km) and the sand remain quartz-rich (>50% quartz) all the way to Cape Leeuwin (1817 km, Fig. 30.2). It is only in rounding Cape Leeuwin that the carbonate-rich sand returns.

The source of the carbonate sediments is the western Great Australian Bight, which west of Eucla has sediments which are a mixture of quartz sand, siliceous spicules, bioclastic carbonate particles, carbonate lithocasts, relict grains and dolomite rhombs (James et al. 1994). The sediment averages 1.5 m in thickness with the base of the deeper shelf sediments dating 13–8.8 ka and the basal shallow shelf sediments dating 2.6–1.1 ka. James et al. found the inner shelf (<70 m depth) to be stripped of sediment with any new carbonate material continually transported landward by the high energy wave environment. They applied the term ‘shaved shelf’ to this environment, similar to the Otway shelf described in Sect. 16.5.4 and illustrated in Fig. 16.9b. This implies the inner shelf was stripped of its sediments during the PMT, and subsequent carbonate detritus is transported out of the system.

29.4 Coastal Processes

Tides along the Nullarbor coast are micro and amongst the smallest in Australia decreasing from 1.3 m at Eucla to 1.1 m at Mary Ann Haven. Shelf waves propagate eastwards along the coast with amplitudes on the order of 0.5 m and can reach 1 m (Provis and Radok 1979), the same magnitude as the tide. As a consequence, sea level depends on both the stage of the shelf waves and tides.

The deepwater wave climate is dominated by the persistent moderate to high (2–3 m), long period (12–15 s) southwest swell (Fig. 27.3), together with local onshore sea breeze. The breaker wave climate however varies considerably along this reasonably straight coast. The Nullarbor and Baxter cliffs receive the full force of the deepwater waves. However west from Eucla, the low gradient Roe Plain extends offshore as shallow seagrass-covered calcarenite reefs, which substantially lower waves at the shore by up to 90% and more, with breaker waves usually just a few centimetres high. The waves begin to pick up west from around Eyre and average about 0.5 m at Twilight Cove and resume full height along the Baxter Cliffs to Point Culver and the northern end of Bilbunya beach, where they average ~2 m. Their height then gradually drops southwards along Bilbunya beach, owing to its easterly orientation and increasing sheltering by offshore islands and the southern points, and is <0.5 m at the southern Point Lorensen. It remains <1 m to Point Malcolm and then picks up once around Point Malcolm where the coast faces south into the prevailing southerly swell.

29.5 Beaches

The beach systems along the Nullarbor coast are present along the Roe Plain (WA01.01) and south from Point Culver (WA01.03) and largely absent from most of the Nullarbor and Baxter cliffs. The beaches occupy 484 km (57%) of the entire shore, but 97% of the non-cliffed sections. The type of beaches reflects the variable breaker wave climate and the generally fine sand. Low gradient LTT dominates the long Roe Plain beaches owing to both the low waves and fine sand, the latter precluding the formation of R beaches, with LTT comprising 65% of the beaches by length and R just 3% (Table 29.3). The higher energy beaches (TBR-RBB, 31%) dominate the northern exposed Bilbunya beach and exposed beaches between Point Malcolm and Cape Pasley, while the very low energy TD B+SF (1%) occurs in Israelite Bay. For a full description of all the beaches in this region, see Short (2001, 2005).

Table 29.3 Nullarbor region beach types and states

BS	BS	No.	%	km	% (km)	mean (km)
3	RBB	7	10.6	10.8	2.2	1.5
4	TBR	13	19.7	140.4	29.0	10.8
5	LTT	24	36.4	314.9	65.0	13.1
6	R	16	24.2	12.8	2.6	0.8
11	B+SF	2	3.0	3.5	0.7	1.8
14	R+RF	4	6.1	1.8	0.4	0.5
		66	100.0	484.2	100	7.3

Table 29.4 Nullarbor region barrier dimensions

WA01	SA03.04	WA01.01	WA1.02	WA1.03	Nullarbor
No.	1	6	3	7	16
Total length (km)	8.5	305	59	150	522
Mean min width	200	3500	13000	500	–
Mean max width	1000	48,500	23,000	1900	–
Mean height (m)	20	11	8	10	10
Area (ha)	1900	150,000	49,000	32,560	233,460
Unstable (ha)	1300	10,500	0	5550	17,350
Total volume (M m^3)	380	11,700	4300	325	16,705
Unit volume (m^3 m^{-1})	44,705	38,423	72,880	2170	32,000

29.6 Barriers

There are 16 generally long barrier systems along this region, with a mean length of 33 km that occupy 522 km (59%) of the coast, including extensive clifftop dunes particularly on the Baxter Cliffs but also some on the Nullarbor Cliffs and even very old Pleistocene dunes on the Hampton Bluffs (Lowry and Jennings 1974). The dunes are both long and extensive extending up to 100 km inland. Recent dating indicates that the extensive dunes that originate from the eastern Baxter Cliffs-Twilight Cove are glacial age. South of Point Culver is the 104 km long Bilbunya barrier that ranges from transgressive in the north to regressive in the south. Both of these systems are discussed below.

The barriers have a total volume of 16,705 M m^3 (32,000 m^3 m^{-1}) (Table 29.4). These volumes and rates per meter are comparable to the most exposed section of the western Eyre Peninsula coast and attest to the high volumes of sand transport to this coast, both carbonate in the east and shelf quartz in the west. These barriers will be examined in more detail in the following SCs.

29.7 Sand Transport

Sand transport in this region is predominately onshore; however there must also be considerable longshore transport to supply the quartz-rich sand as far north as Twilight Cove, at least 270 km from its nearest source. Also, the long southeast-facing Bilbunya beach is aligned at an angle to the predominately southwest waves, and sand would be expected to move northwards along this shore, at a rate increasing to the north, and along the base of the Baxter Cliffs. This also will be examined in the following sections.

This region contains the SA Nullarbor Cliffs SC (SA03.04.01) and the three WA PCs: the Roe Plain (WA01.01), Baxter Cliffs (WA01.02) and the Bilbunya-Cape Palsey section (WA01.03) (Table 29.5). The WA PCs, SCs and TCs were initially identified and mapped by Elliot (2011). They are each discussed below.

Table 29.5 Nullarbor region PCs and SCs

Nullarbor coast[a]	Location	Boundaries	Beaches[b]	No. beaches	km[c]	Total km
SA03.04.01	Nullarbor Cliffs	Head of Bight-Wilson Bluff	SA 1442-1454	13	3067–3273	206
WA01.01.01	Roe Plain (E)	Wilson Bluff-Red Rock Pt	WA 1-8	8	0–160	160
WA01.01.02	Roe Plain	Red Rock Pt-Scorpion Bight	WA 9-11	3	160–235	75
WA01.01.03	Roe Plain (W)	Scorpion Bight-Twilight Cove	WA 12-16	5	235–308	73
WA01.0	Roe Plain	Wilson Bluff-Twilight Cove	WA 1-16	29	0–308	308
WA01.02.01	Baxter Cliffs (E)	Twilight Cove-Pt Dover	WA 17	1	308–365	57
WA01.02.02	Baxter Cliffs (W)	Pt Dover-Pt Culver	WA 18	1	365–450	85
WA01.02		Twilight Cove-Pt Culver	WA 17-18	2	308–450	142
WA01.03.01	Bilbunya (N)	Pt Culver-Wattle Camp	WA 19-23	5	450–528	78
WA01.03.02	Bilbunya (S)	Wattle Camp-Pt Lorensen	WA 23-25	2	528–571	43
WA01.03.03		Pt Lorensen-Pt Malcolm	WA 26-30	5	571–605	34
WA01.03.04		Pt Malcolm-C Palsey	WA 31-52	22	605–638	33
WA01.03	SE WA	Pt Culver-C Palsey	WA 19-52	34	450–638	188
		Region total		65		844

[a]NCCARF compartment number
[b]ABSAMP beach ID
[c]Clockwise distance from state borders

29.8 PC/SC:SA03.04.01 Nullarbor Cliffs

PC: SA03.04 contains one SC:SA03.04.01 which includes the entire the Nullarbor (Bunda) Cliffs. It commences at Head of Bight and extends 206 km to the border at Wilson Bluff (Table 29.1; Fig. 29.4). The 60–90 m high vertical cliffs (Fig. 29.2a) run continuously westwards for 183 km until they encounter the sloping calcarenite and then dunes of the Merdayerrah Sandpatch, which partially blanket the cliffs for another 23 km to the border, after which the cliffs trend inland as the Hampton Bluffs.

The vertical cliffs dominate this PC/SC with the only beaches along the 23 km long Merdayerrah Sandpatch. The 13 beaches occupy 15 km (65%) of the Sandpatch, which represents just 7% of the entire SC. The beaches are separated by Pleistocene dune calcarenite that dominates the Sandpatch and along the shore forms bluffs, rock platforms and reefs. There are 11 short (400 m) R beaches all located in the rocky eastern section of the Sandpatch, followed by a longer LTT and finally the main 8.5 km long TBR (Table 29.6) which has a low gradient 500 m wide double-bar surf zone that continues to within 2 km of the border, with vertical cliffs then extending to the border and PC boundary.

The Sandpatch, which was first described by Jennings (1967), is composed of lithified Pleistocene dune ramps, which are blanketed along a 6.5 km long section in lee of the TBR beach (SA 1454) by active and vegetated Holocene sand ramps. The dunes have reached the top of the 90 m high cliffs along a 3 km long section and migrated up to 300 m inland (Fig. 29.5d). This barrier has a volume of 380 M m^3

Fig. 29.4 PC/SC:SA03.04.01: The Nullarbor (Bunda) Cliffs. M8 and 9 and N10-17 are clifftop dune sample sites. (Source: Google Earth)

Table 29.6 SC:SA03.04.01 beach types and states

BS	BS	No.	%	km	%	mean (km)	σ (km)
4	TBR	1	7.7	8.5	56.7	8.5	–
5	LTT	1	7.7	1.8	12.0	1.8	–
6	R	11	84.6	4.7	31.3	0.4	0.2
		13	100	15	100	1.2	–

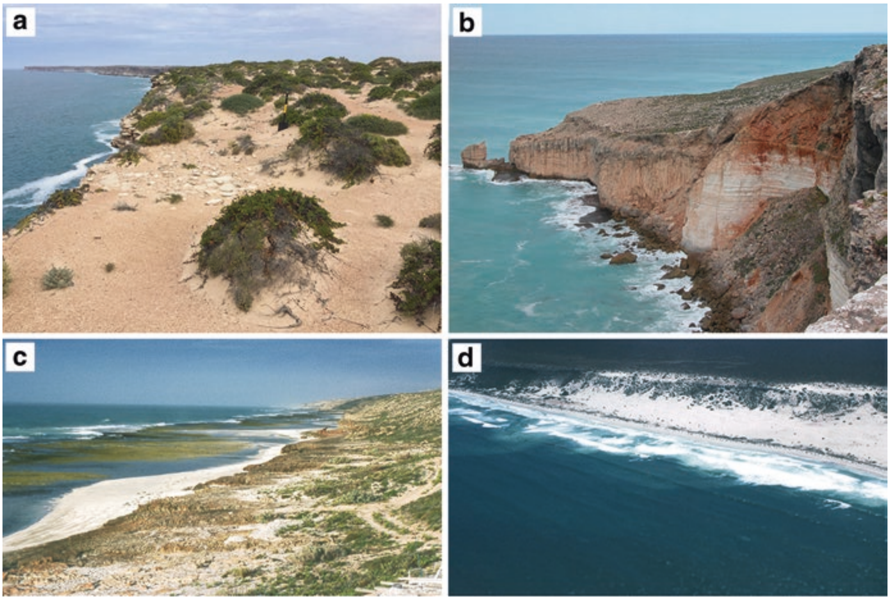


Fig. 29.5 (**a**) Clifftop dunes on the edge of the Nullarbor Cliffs 85 km west of Head of Bight; (**b**) lithified Pleistocene sand ramp (left) overlapping Nullarbor limestone that marks the eastern end of the Merdayerrah Sandpatch; (**c**) Holocene rock platform, beach (SA 1447) and stranded Pleistocene platform at Merdayerrah; and (**d**) the main Merdayerrah beach (SA 1454), sand ramp and clifftop dunes. (Photos: AD Short)

and is presently ~70% unstable (Table 29.3), the instability perhaps caused by rabbits that also destabilised the adjacent WA Eucla dunes. In addition, there are small Holocene clifftop dunes at least 11 locations spread along 120 km of the cliff west from Head of Bight. At Head of Bight, the dunes extend for 2 km west along the cliffs with most clustered between 45 and 120 km west and in some sections extending continuously along the cliffs for up to 6 km (Fig. 29.5a). Most of these dunes lie in lee of a deflated cliff edge and are low (<10 m) hummocky and extend between 50 and 200 m inland. The presence of the Holocene clifftop dunes indicates that there were extensive sand ramps along parts of the cliffs at least until 7.6 ka (sample N17) (Table 29.7), following which they were completely eroded leading the dune remnants on top of the cliffs. These have been reactivated at 3.1 ka (sample N11) and in the last few hundred years (N12-16) (Table 29.7).

The eastern end of the Sandpatch is marked by a 0.3 km offset in the run of the cliffs (Fig. 29.5b), also noted by Jennings (1967). This is a result of the calcarenite being more resistant to erosion than the softer limestone leading to differential erosion and rates of retreat of the adjacent limestone and calcarenite. Assuming the Sandpatch ramp was lithified during a low sea-level period, the subsequent PMT and stillstand has eroded the base of the calcarenite by approximately 750 m leaving 40 m high cliffs, while the 90 m high limestone has retreated the additional 300 m.

Table 29.7 Results of OSL dating[a] of clifftop dune sand samples

Location	Sample #	De (Gy)	Dose rate	Overdispersion (%)	Age estimate	Distance from Head of Bight (km)
Nullarbor	N17	5.05 ± 0.11	0.67 ± 0.03	13	7600 ± 400	6
Nullarbor	N16	0.65 ± 0.11	0.606 ± 0.03	5.7 ± 1.5	1080 ± 60	5
Nullarbor	N15	0.35 ± 0.01	0.19 ± 0.01	66	430 ± 30	66
Nullarbor	N14	0.44 ± .01	0.94 ± 0.04	9	470 ± 20	66
Nullarbor	N13	0.15 ± 0.01	0.93 ± 0.04	94	170 ± 10	50
Nullarbor	N12	0.28 ± 0.01	0.96 ± 0.05	37	290 ± 20	50
Nullarbor	N11	2.27 ± 0.03	0.73 ± 0.03	6	3100 ± 100	86
Merdayerrah	M9	0.58 ± 0.09	0.88 ± 0.04	87	670 ± 110	180
Merdayerrah	M8	no signal	0.847 ± 0.04	N/A	N/A	180
						Distance from SA/ WA border
Madura	K7	10.83 ± 0.53	0.449 ± 0.03	24 ± 3	24120 ± 1840	~200
Madura	K6	8.69 ± 0.16	0.4 ± 0.02	25	21800 ± 1000	~200
Baxter	B5	1.52 ± 0.03	0.38 ± 0.01	37	4000 ± 200	~300
Baxter	B4	1.72 ± 0.10	0.37 ± .01	33	4700 ± 300	~300
Twilight Cove	T3	0.228 ± 0.018	0.449 ± 0.03	36 ± 6	510 ± 50	~300
Twilight Cove	T2	2.26 ± 0.04	0.48 ± 0.02	12	4700 ± 200	~300
Twilight Cove	T1	1.69 ± 0.02	0.49 ± 0.02	8	3500 ± 100	~300

[a]Dating undertaken by TSN Oliver (Australian Defence Force Academy) and T Tamura (Geological Survey of Japan)

Based on Fotheringham (2009) estimates of calcarenite cliff retreat of up to 30 mm year^{-1} in exposed locations, the calcarenite could have retreated 180 m over the past 6 ka. As it has retreated ~300 m, this would imply the cliff has been eroded at pervious sea-level high stands or the erosion rate is greater in this very exposed location. The answer is probably a combination of the two. It would also indicate that the limestone is eroding at a rate >30 mm year^{-1}, similar to James et al. (2006) estimation that the limestone cliffs retreat at a rate of ~30 mm year^{-1}. A veneer of dune sand on the ramp was dated at 670 year ± 110 year (M9 Table 29.7), which appears to indicate a reactivation of the sand rather than the time of primary deposition.

Short et al. (1986) and Buckley et al. (1987) examined a stranded and active rock platform (Fig. 29.5c) cut in the calcarenite along the eastern base of the Sandpatch calcarenite. Potholes in the upper platform contained *Anardarra* shells that dated pre-Holocene and indicate that it is Pleistocene in age. As this platform stands 3–4 m above the lower active platform, it indicates that the last interglacial sea level was also 3–4 m above present in this location, a level which has been confirmed for the Eyre Peninsula by Murray-Wallace et al. (2016) and the Yorke Peninsula by Pan et al. (2018). This would also indicate that like the western Eyre and lower Yorke peninsulas, the Nullarbor is also tectonically stable.

29.8.1 PC Overview

The Nullarbor Cliffs dominate the central Great Australian Bight and have been a formidable barrier to onshore sand transport. Some sand has however made it up onto the top of the cliffs to deposit small areas of clifftop dunes along a 120 km section of the cliffs, with the early to mid-Holocene beaches and ramps that supplied the dunes long since gone. Only in the west at Merdayerrah Sandpatch has Pleistocene calcarenite sand ramps permitted the development of a beach-dune system the latter just reaching the top of the 90 m high cliffs. The cliffs and Sandpatch are exposed to a persistent high wave environment that has caused considerable and ongoing cliff retreat, at rates greater than 30 mm year^{-1}. Rising sea level can be expected to slightly increase the rate.

29.9 PC:WA01.01 The Roe Plain: Wilson Bluff–Twilight Cove

This PC contains the Roe Plain, an uplifted section of sea bed bordered by the Nullarbor and Baxter cliffs, and backed by the Hampton Bluffs, a continuous escarpment of relict sea cliffs which links the two lines of active sea cliffs (Table 29.1). The plain includes a 2–3 m thick Roe calcarenite which was investigated by Lowry (1970) and James et al. (2006). James et al. found that the Nullarbor Limestone was uplifted and tilted seawards in the Late Miocene. This was followed by marine inundation, and erosion of the Nullarbor Cliffs including the Hampton Bluffs during the Pliocene. During this period, they estimate the limestone cliffs retreated 85 km over 3 Ma, which represents an average of ~30 mm year^{-1}, in agreement with Fotheringham (2009) rapid rate of calcarenite retreat. However as discussed in Sect. 29.8, the limestone retreats more rapidly than the calcarenite, so this rate is quite feasible. Minor uplift at the Plio-Pleistocene boundary exposed the Roe calcarenite, which consists of high energy shallow marine deposits, which were subsequently lithified. The inner plain at Mandurah (40 km inland) is 33 m above sea level (Murray-Wallace and Woodroffe 2014). The wide gently sloping plain then it extends seawards of the shoreline as a very low gradient calcarenite seabed. The plain has a 308 km long shoreline, reaches a maximum width of 40 km at Mandurah and has an area of ~6800 km^2. The low gradient nearshore and numerous inshore reefs substantially lower breaker wave height to usually <0.5 m (Fig. 27.3) producing a low energy shoreline for most of the plain. The only bedrock on the entire plain is at Red Rock where the red sandstone forms a low rocky point. The plain contains three SCs SA01.01-01-03 (Fig. 29.6). In this section they will be discussed as one PC.

The plain commences at the SA-WA border extending west from the base of Wilson Bluff, with the active Delisser (Eucla) dunes blanketing the first 14 km of the plain and climbing the Hampton Bluffs along the first 4 km (Fig. 29.7a). Apart

Fig. 29.6 SCs WA01.01.01-03 extend the length of the Roe Plain. T, B and K indicate dune dating sites. (Source: Google Earth)

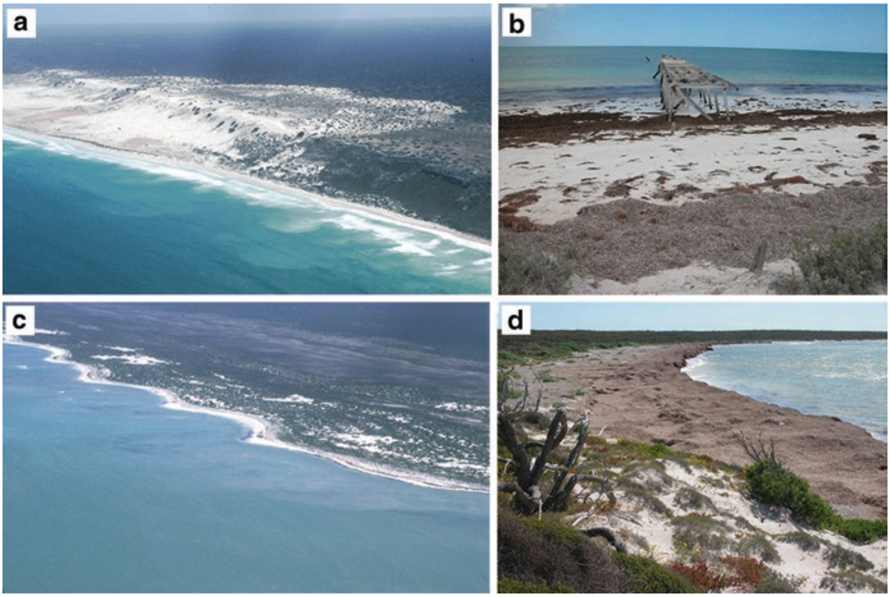


Fig. 29.7 (**a**) The Delisser dunes at Eucla climbing up over the start of the 90 m high Hampton Bluffs (WA 1); (**b**) the old jetty at Eucla (WA 1) with typical low wave conditions, LTT beach and seagrass debris; (**c**) scalloped shoreline (WA 6) along the Roe Plain induced by wave refraction over the shallow calcarenite reefs and typical of this coast; (**d**) a berm of seagrass debris 50 m wide and 1 m high deposited on the beach at Red Rock (WA 8), typical of this, and the Roe Plain beaches. (Photos: AD Short)

from the small Red Rock point, the plain has an entire sandy shoreline, with 16 long beaches occupying the entire coast (Table 29.8). The beaches are uniformly composed of fine white carbonate-rich sand which combines with the low breaker waves (<0.5 m) to maintain LTT beach conditions (Fig. 29.7b), the fine sand precluding the development of R beaches. The low gradient nearshore contains extensive shallow calcarenite reefs and seagrass meadows, with seagrass growing to the shore and blanketing the beaches in thick seagrass berms. The reefs induce both wave attenuation leading to the low breaker waves and wave refraction leading to a highly crenulate shoreline with numerous low sandy forelands (Fig. 29.7c) which separate the beaches. West from Eyre, the nearshore gradually deepens, and wave energy increases slightly; however the beaches remain LTT (Fig. 29.9b), with seagrass growing to within 100 m of the shore and its debris deposited on the beaches as often substantial berms (Fig. 29.7d).

The beaches are backed by near continuous barriers extending the length of the plain. The barriers range from a few regressive foredune ridges to active and stable transgressive dunes which extend on average a few kilometre inland (Fig. 29.7c), with per meter volumes between 10,000 and 50,000 $m^3\ m^{-1}$. In the west however is the massive transgressive systems that originates along a 40 km long section of coast between Kaniaal beach-Twilight Cove and the eastern end of the Baxter Cliffs. This dune system extends to west-northwest across the plain subparalleling the coast for a maximum distance of 105 km, the longest coastal dune system in Australia (Fig. 29.8). The dunes are now stable and well vegetated with mallee (Fig. 29.7c). Dates of 24,120 ± 1840 and 21,800 ± 1000 year (M7-6, Table 29.7) were obtained from this dune system 16 km south of Mandurah and 80 km east-

Table 29.8 Roe Plain (PC:WA01.01) beach types and states

BS	BS	No.	%	Total length (km)	%	Mean length (km)	σ (km)
5	LTT	16	100	308	100	19.2	16.4

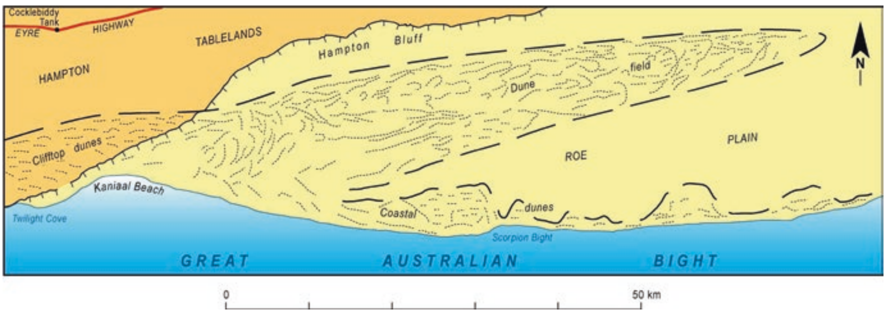


Fig. 29.8 The western Roe Plain showing the coast, Hampton Bluffs and outline of the large 'glacial' dune field that originated between Baxter Cliffs-Twilight Cove and Kaniaal Beach. (Source: Short and Woodroffe 2009). The location of dune dating sites T1, 2, B4, 5 and M6, 7 are indicated in Fig. 29.6

northeast of its coastal origin. This confirms the dunes were active during the drier, windier glacial period when the sea level was lower and more arid conditions and strong westerly winds prevailed (Bowler 1978). Similar dates (26–15 ka) for 'glacial' dunes have been reported from eastern Australia by Thom and Oliver (2018). The dune sands are quartz-rich (>95% quartz) indicating they originated from shelf quartz sources to the west. The sand was probably deposited along the base of and on top of the eastern Baxter Cliffs and the Twilight-Kaniaal beaches during the sea-level highstand and then reworked and transported further inland during the glacial period.

Combined the Roe Plain barriers have a total volume of 11,700 M m^3 with per meter volume of 38,423 m^3 m^{-1}, the latter equivalent to the Nullabor's Merdayerrah Sandpatch dunes. However, 40% of this volume has come from the western 'glacial' age dunes, rather than the coastal Holocene dunes. If the glacial dunes are removed, the Holocene dune volumes are 6700 M m^3 and 29,193 m^3 m^{-1}. While most of the dunes are vegetated and stable, 6% are presently unstable leading to areas of minor to moderate dune transgression (Fig. 29.9a). However, dunes at 68 km that were bare and active in 1996 were largely covered by vegetation in 2010 and almost completely covered in 2018. The Red Rock and Eyre dune fields however remain active.

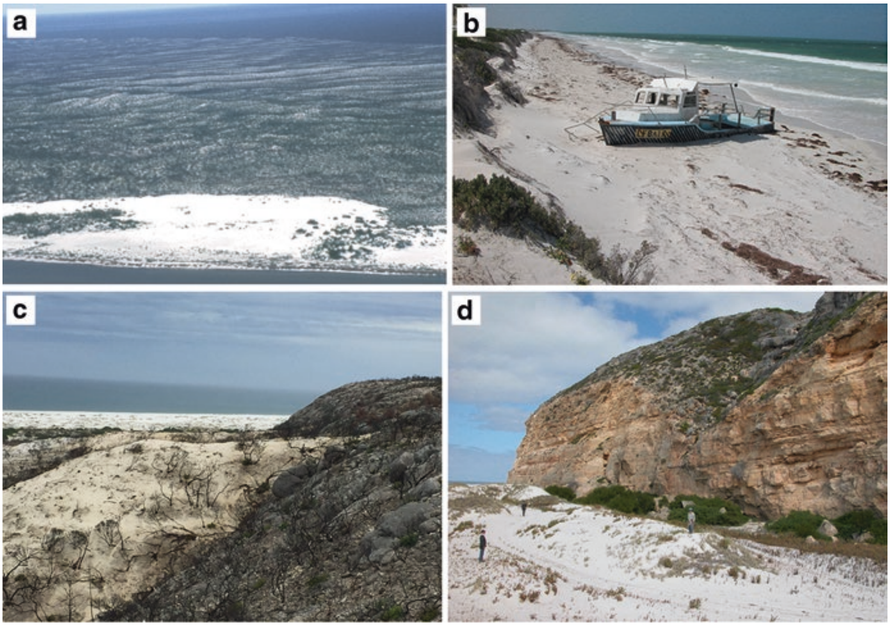


Fig 29.9 (**a**) Active dunes and inner vegetated (with burnt vegetation) 'glacial' dunes that extend 15 km inland, near Eyre (WA 13); (**b**) stranded fishing boat on the beach at Eyre (WA 13) with the moderate waves maintaining a LTT; (**c**) stalled 'yellow' dune sand ramp nearing the crest of the western end of the Hampton Bluffs at Twilight Cove (WA 16) (bushfire had recently burnt the vegetation); and (**d**) the start of the recently prograded dunes at Baxter Cliffs at Twilight Cove, with all the sand in image deposited since 1973 (see Fig 29.10 for location). (Photos: AD Short)

In the western Twilight Cove area, there is evidence of at least four episodes of dune transgression, some of which were noted by Jennings (1967). The location of the dune samples is indicated on Figs. 29.8 and 29.10. The outermost dune system is a 400 m wide foredune system composed of white quartz-rich sand, backed by an older series of white transgressive dunes that may have originated from a stranded shoreline located at the rear of the foredune and extending another 500 m inland. These dunes overlap the base of older climbing yellow dunes (Fig. 29.9c) that date 4700 ± 200 year and 3500 ± 100 year (T2, 1 Table 29.7, Fig. 29.10). The now vegetated yellow dunes built a ramp against the backing 90 m high Hampton Bluffs but did not quite reached the crest of the bluffs. On top of the bluffs dune, samples B4 and B5 located 0.5. 3.2 and 4.1 km north of the bluff edge, respectively, were dated at 4700 ± 300 year, 4000 ± 200 year and 510 ± 50 (B4, 5, T3 Table 29.7). These indicate a period of climbing and clifftop dune activity around this time, with the 510 year date probably due to reactivation. These in turn are backed by the far more extensive 'glacial' dune fields. There four systems suggest the following scenario and are labelled 1–5 in Fig. 29.10:

- 'Glacial' dunes were active ~22–24 ka reworking pre-existing coastal dunes and extending to 100 km inland.
- Following the Holocene sea-level stillstand, the yellow dunes were deposited ~4–5 ka behind a beach located ~0.5 km in from the present shoreline. These dunes have partially climbed the backing bluffs (#4, Fig. 29.10) (Fig. 29.9c).
- At the same time, clifftop dunes (B4, 5) are active on top the bluffs (#5), these dunes originating from ramps located up to 14 km southwest of Twilight Cove. These were reactivated ~0.5 ka (T3 510 ± 50 year ~ 0.5 ka).
- This was followed by deposition of the undated white foredune belt (#3).
- The shoreline then prograded ~500 m seawards, and the present foredune belt was deposited (#2).

Fig. 29.10 Google image of Twilight Cove showing the position of the 1972 shoreline (red line), location of the five dune phases (1–5) discussed in text and location of the two dating sites (T1 and T2) on vegetated dune ramps. Fig. 29.9d was taken at the western end of the red line. (Source: Google Earth)

- Between 1972 and 2018, the shoreline has prograded another 600 m seawards (#1) against the western cliff base (Fig. 29.9d), leaving a wide low sandy back beach capped by several low foredune ridges that in 2018 were slowly being vegetated.

The cause of the longer-term progradation and build up against the western Twilight Cove cliff face indicates that the cove has acted as a sediment sink for quartz-rich sand. The immediate origin of this sand, while undoubtedly from the west, is unknown. One can only assume it is transported to the northeast along the base of the cliffs. Two very small beaches (WA 17 and 18 Toolina Cove) located at the base of the cliffs indicate that sand is present along the cliff base. Bird (1976) quotes Jennings as saying he found a 19thC shipwreck located 200 m inland at Twilight Cove, though the exact location of the shoreline at the time (~1960s) and the wreck are unknown. Likewise, the ruins of a structure no doubt associated with construction of the telegraph line in the 1870s are located to the rear of the foredune belt #2, and one would assume it would have been closer to the shore when built. There have therefore been two periods of substantial and apparently rapid progradation since the deposition of the white foredune belt (#3). First is the ~400 m wide #2 foredunes and flats, the flat areas suggesting progradation was too rapid for foredune development; and the ~600 m wide (~10 m year^{-1}) progradation (#1) since 1972, which could be related to either continued sand supply or shoreline rotation, as the progradation increases from 200 m in the east to 700 m against the cliffs in the west. Whether this progradation is permanent or part of a longer-term (decadal) rotational cycle remains to be seen. The recent progradation represents a substantial amount of sand, roughly ~5 M m^3 of sand delivered at a rate (over 46 years) of ~100,000 m^3 year^{-1} or ~30 m^3 m year^{-1}. This is an interesting section of coast preserving glacial dunes, early to mid-Holocene clifftop dunes and ramps, and late Holocene and contemporary beach-foredune progradation that warrants more detailed investigation.

29.9.1 PC Overview

The Roe Plain is a low gradient carbonate-rich plain bordered to either end by steep cliffed coast. It is sheltered by the low gradient seaward extension of the plain that substantially reduces wave energy at the shore and fringed by continuous low energy beaches and seagrass meadows. For the most part, the beaches are backed by foredunes, in some places a few foredune ridges backed in turn by salt-samphire flats and elsewhere transgressive dunes extending up to several kilometres inland. Rising sea level will deepen the shallow nearshore leading to a gradual increase in wave energy which would be expected to increase onshore sand transport and shoreline erosion, possibly leading to renewed dune activity. The samphire flats would also become increasing inundated which would impact the main shore parallel 4WD route.

29.10 PC:WA01.02 Baxter Cliffs: Twilight Cove–Point Culver

The Baxter Cliffs are a 100–120 m high line of vertical limestone cliffs that extend for 160 km between Twilight Cove to Point Culver and 20 km further west. They are a continuation of the Nullarbor Cliffs and Hampton Bluffs, with the cliffline continuing inland south of Point Culver as the Wylie Escarpment (Table 29.1). The cliffs contain two SCs (WA01.02.01-02) (Fig. 29.11) which will be combined in this discussion. The cliffs are part of the Nuytsland Nature Reserve and uninhabited. The only access is the old overgrown telegraph track between Twilight Cove and Bilbunya, with rough 4WD tracks leading out from Caiguna and east of Balladonia. The only structure on the cliffs is the memorial to John Baxter who lost his life at the site during John Eyre's east-west crossing of the Nullarbor coast in 1841.

There are two small inaccessible beaches located at the base of the cliffs, one 20 km southwest of Twilight Cove (WA 17) and the other Toolina Cove (WA 18) another 90 km further southwest (Fig. 29.2a). The cove is accessible by vehicle, and during the construction of the telegraph line in 1876, the cove was used to unload supplies with a windlass conveying them to the clifftop. This was removed in the early 2000s rendering the cove again inaccessible. The two small beaches are located in amongst the rock debris at the base of the cliffs, and both are dominated by rips (Table 29.9).

Fig. 29.11 PC:WA01.02 extends the length of the Baxter Cliffs and contains SCs:WA01.02.01-02. (Source: Google Earth)

Table 29.9 Baxter Cliff beaches types and states

BS	BS	No.	%	km	%	% (km)	σ (km)
4	TBR	2	100	0.25	100	0.12	0.25

There are three areas of clifftop dunes along the cliff line, the dunes first noted by Jennings (1967). In the east are the dunes discussed above (Sect. 29.9) that extend along the cliffs for 14 km southwest of Twilight Cove; a second smaller area that extends for 10 km along the cliff east of Toolina Cove; and the third a 50 km long section located either side of Point Culver that extends west to the top of Bilbunya beach, where it climbed the Wylie Escarpment, and appears to have at least two phases of dune emplacement. The three systems have areas of 22,000, 2000 and 25,000 ha, respectively, and contain a total of 4300 M m^3 (72,881 m^3 m^{-1}), a massive amount of sand to be found on top of 100 m high cliffs and extending up to 50 km inland. The dunes are vegetated and stable. They have been transported subparallel to the cliffline by southwest wind and appear to show multiple phases of dune activity. There are in fact a range of dune forms including: parabolic, linear/transverse and 'tessellated', the latter form terminating in transgressive dune ridges, which, together with the Bilbunya star dunes, make this a very interesting coast for dune dynamics. Preservation of the transverse dunes is also unusual and would suggest a sudden change in climate (wind and/or rainfall) to preserve their forms. The dunes were active during and following the PMT as indicated by the easternmost Twilight Cove dunes (~5 ka), while the Madura dates indicate dunes were active during the 'glacial' period (~22–24 ka), dunes that would be expected to have originated at the coast during former high stands of the sea. The location and form of the dunes suggest at least two periods of emplacement related to the PMT and possibly the last interglacial highstand, together with 'glacial' and more recent reactivation. Clearly there is much work to be done in this area to understand the source, timing of the emplacement and reworking of these clifftop dunes.

29.11 PC:WA01.03 Point Culver–Cape Palsey

The westernmost Nullarbor PC extends for 188 km between Point Culver and Cape Palsey and contains four SCs (Table 29.5; Fig. 29.12). Most of this PC is located in the Nuytsland Nature Reserve, with Cape Arid National Park commencing at Bellinger Island and occupying the western 15 km of the PC. The entire area is uninhabited apart from some seasonal fishing shacks at Israelite Bay and visiting campers to the reserve and national park. This section of coast trends roughly southwest and for the most part is backed by the 70–120 m high Wylie Escarpment, the western 120 km of the Nullarbor plain cliffline, which finally terminates about 20 km north of Cape Pasley. The coast between Point Lorensen and Cape Pasley is dominated by massive granite that forms rounded sloping points, separated by curving quartz-rich sandy beaches. As the coast trends south, the rainfall increases from ~300 to ~400 mm, while temperatures decrease slightly.

Tides along this section remain micro (~1 m), and the dominant southwest swell approaches the coast at an angle (Fig. 29.13d), refracting around the southern points and islands and producing a longshore gradation in wave height, with height generally increasing to the north/northeast within the embayments. There are a total of 35 beaches which occupy 161 km (86%) of the coast. They range from high energy RBB to very low energy B+SF reflecting the variable breaker wave energy along this section (Table 29.10). There are six barrier systems along this section (Table 29.3), dominated by the 103 km long Bilbunya system. These are discussed in the following SCs.

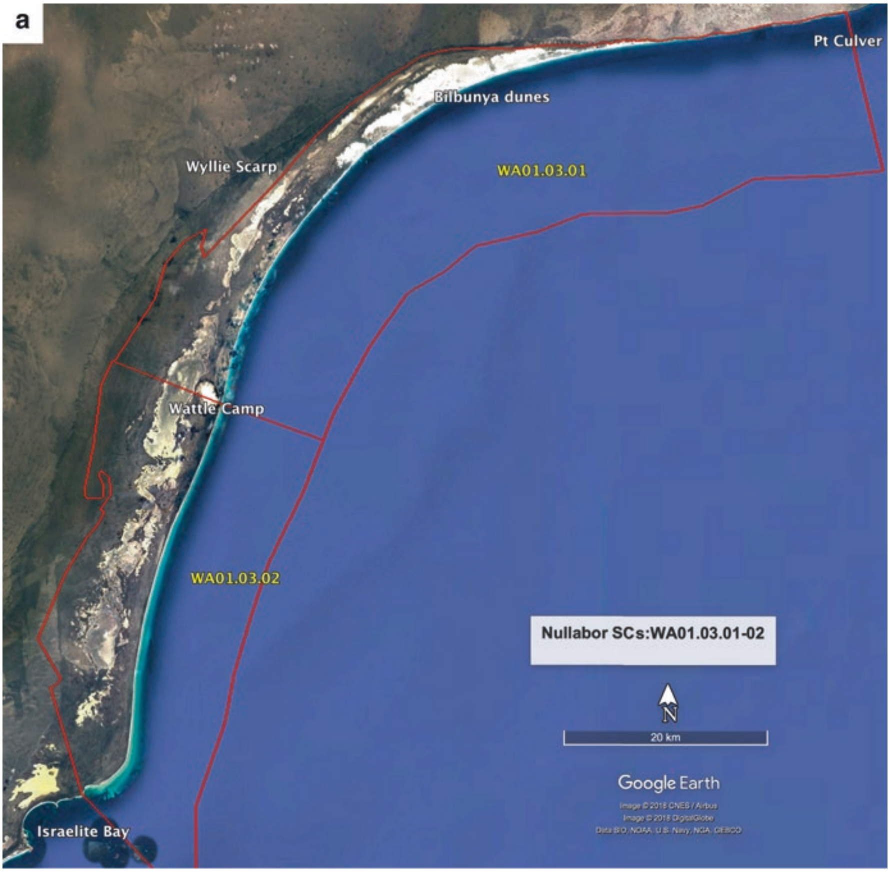


Fig. 29.12 (**a**) SCs WA01.03.01-02; and (**b**) SCs WA01.03.03-04. (Source: Google Earth)

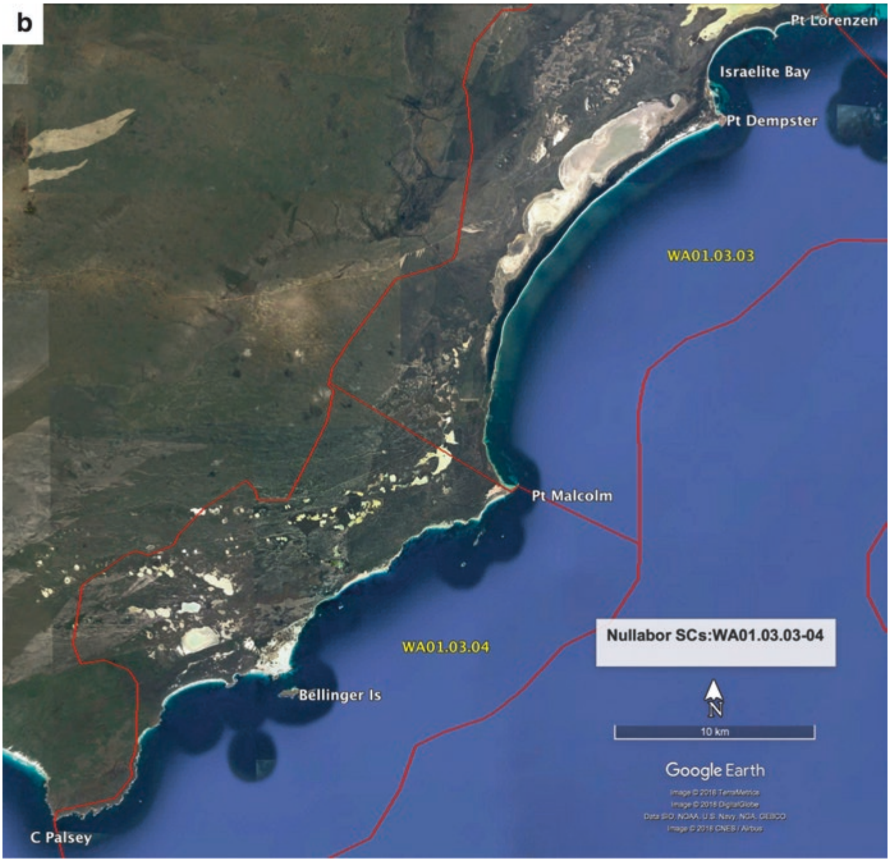


Fig. 29.12 (continued)

Table 29.10 PC:WA01.03 beach types and states

BS	BS	No.	%	Km	%	Mean (km)	σ (km)
3	RBB	7	20.0	10.8	6.7	1.5	1.6
4	TBR	12	34.3	131.9	82.0	11	28.6
5	LTT	5	14.3	4.8	3.0	1.0	0.3
6	R	5	14.3	8.1	5.0	1.6	1.8
11	B+SF	2	5.7	3.5	2.2	1.8	–
14	R+RF	4	11.4	1.8	1.1	0.6	–
		35	100	160.9	100	4.6	–

29.11.1 SCs:WA01.03.01-02 Bilbunya Beach: Point Culver–Point Lorensen

The entire Bilbunya beach and barrier system, as well as the backing Wylie Escarpment, is contained in SCs WA01.03.01-02. The beach commences below the towering Baxter Cliffs and curves to the west then south-southwest for 121 km (Fig. 29.12a). There are seven beaches (WA19-25) along this section which occupy 108 km (89%) of the coast. Table 29.11 provides a summary of their transformation to the south as wave height decreases and in the very south sand fines to 0.1 mm. The beaches commence 10 km west of Point Culver as four discontinuous strips of sand at the base of the cliffs separated by cliff debris (Fig. 29.13a), with a continuous RBB surf zone linking the beaches and actually extending a few kilometres east along the base of the cliffs towards Point Culver. The beaches become continuous

Table 29.11 Bilbunya beach (WA 23) characteristics

Beach length (km)	WA coast (km)	Orientation (deg)	H_b (m)	Sand size (mm)	% $CaCO_3$	Beach slope (deg)	Bar number (1, 2, 3, 4) beach state	Distance to bar crest (m)	Barrier type comments
0–30	465–495	160	1.5-2	0.33	3	5	1- RBB	140	Deflation surface and transgressive dunes, including star dunes
30–40	495–505	140	1.5	0.25	11	4	1-LTT	50	Deflation surface and transgressive dunes
							2-RBB	140	
40–55	505–520	130	1	0.20	2	4	1-R/LTT	50	Vegetated low dunes
							2-Diss	150	Some instability
55–70	520–535	110	0.7	0.23	5	3	1-LTT	35	Vegetated low dunes
							2-LBT	80	Seagrass berm increasing along beach (beachrock at 522 km)
				0.22	12		3-Diss	160	
70–97	535–562	110	0.5	0.14	7	1.5	1-LTT	30	Vegetated low dunes
				0.16			2-Diss	70	Large seagrass berm over beach
				0.19	4		3-Diss	120	
							4-Diss	170	

(continued)

Table 29.11 (continued)

Beach length (km)	WA coast (km)	Orientation (deg)	H_b (m)	Sand size (mm)	% $CaCO_3$	Beach slope (deg)	Bar number (1, 2, 3, 4) beach state	Distance to bar crest (m)	Barrier type comments
98–101	562–565	95	<0.5			1	1-LTT	20	Vegetated low dunes – wash over flats
							2-Diss	50	
							3-Diss	90	Large seagrass berm over beach
							4-Diss	140	
							5-Diss	200	
101–104	565–569	150	<<0.5	0.10	79	1	UD	400	Vegetated washover flats
									Large seagrass berm over beach

Source: Short (2005)

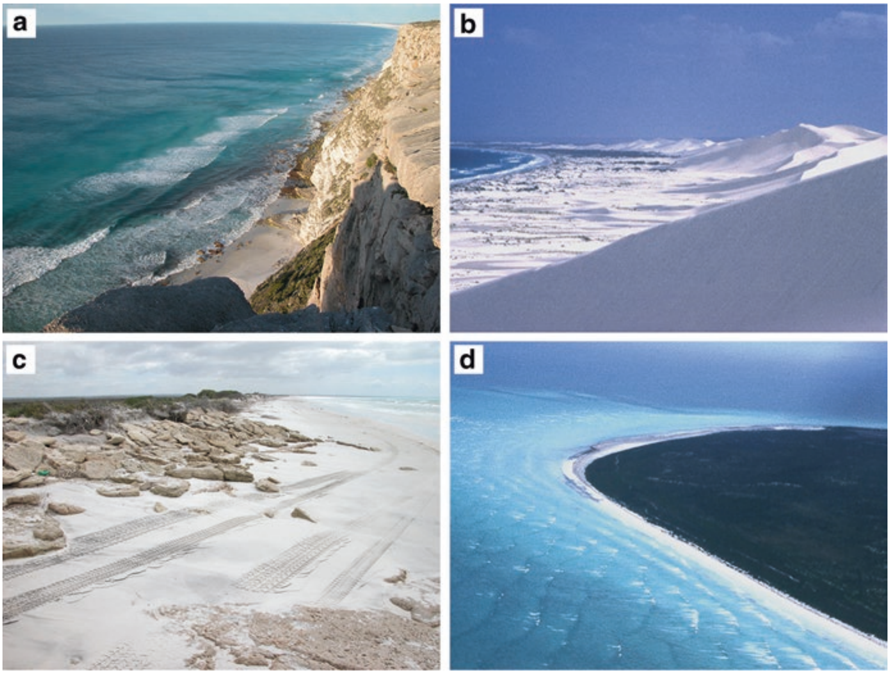


Fig. 29.13 (**a**) The cliff west of Point Culver with pockets of sand at the base (WA 22) and Bilbunya beach in the distance; (**b**) the 125 km high Bilbunya star dunes occupy the northern 20 km of the Bilbunya barrier; (**c**) beachrock slabs on Bilbunya beach at 522 km, also note the low elevation of the barrier and absence of dunes in this section; and (**d**) the 500 m wide ultradissipative multi-bar system at the southern end (560 km) of Bilbunya beach (WA 24). Note the acute angle of wave approach. (Photos: AD Short)

18 km west of the point, with the curving Bilbunya beach extending 104 km down to Point Lorensen, where there are two more small beaches. The cliff-base beaches face south and are RBB (0–30 km Table 29.11). The long Bilbunya beach undergoes a transformation as wave height gradually decreases down the beach from a single bar RBB in the north (0–30 km), to a double (30–55 km), then triple bar (55–70 km) and finally four then five bars in the far south (70–101 km) (Fig. 29.12b), finishing with >400 m wide UD around Point Lorensen (101–104 km). This gradation is in response to a number of factors. First is the change in orientation from south to east which is accompanied by a decrease in wave height, second is the decrease in grain size from medium (0.33 mm) to very fine (0.1 mm) which is accompanied by a decrease in beach-surf zone gradient, and third a possible increase in the dominance of short easterly seas over the low refracted southwest swell. The increasingly low gradient surf zone permits the wave-generated standing waves to imprint themselves on the seabed forming the multiple bars, the bar spacing increasing seawards together with an increase in the overall width of the surf zone (Table 29.11).

Most of the sand is quartz-rich (90–95% quartz) except in the south where the seagrass-covered sand flats supply carbonate sands with the beaches containing 80% carbonate (Fig. 29.3). The increase in carbonate is also accompanied by the appearance of beachrock slabs on the beach (Fig. 29.13c). The southern 50 km of beach is usually covered with 1–2 m thick deposits of seagrass debris up to 50 m wide which blankets the upper beach.

The Bilbunya barrier, like the beach, transforms from higher energy transgressive to low energy regressive. The northern SC:WA01.03.01 commences with 16 massive bare transgressive star dunes rising to a maximum of 125 m along the northern 20 km (Fig. 29.12a) that extend up to 2.5 km inland, followed by a 10 km long section of unstable then stable transgressive dunes that narrow from 2 km to >1 km to the south. South of this is a 20 km long narrow foredune backed by what appears to be former inlets and lagoons, now occupied by salt lakes and samphire, backed by a possibly Pleistocene inner barrier and another salt flat-filled back-barrier depression. SC:WA01.03.02 is a continuous 1–2 km wide low regressive barrier consisting of inner overwash flats, backed by salt lakes-samphire, and ~10 low regressive foredunes. The southern sandy point is composed of a series of low regressive foredunes up to 400 m wide located either side of the low granite rocks of Point Lorensen. The presence of beachrock and lagoonal peats outcropping on the central beach section indicates that this section at least is receding. The retreat could be generated by the increasing rate of longshore transport to the north resulting in a deficiently of sand in the south, which is made up by eroding the beach-barrier.

In all, the entire barrier has volume of 300 M m^3 (2913 m^3 m^{-1}). This relatively low volume is a product of the southeast orientation of much of the barrier with the prevailing southwest winds blowing offshore and precluding the development of transgressive dunes in the south, leaving instead a low regressive barrier. While the star and other transgressive dunes occupy the first 40 km, the rest of the barrier is low (<5 m) and narrow. The star dunes themselves are a very interesting feature, the only such dunes in Australia and the type of dunes that usually occur in bare inland deserts such as the Sahara and Kalahari. They require both bare sand and a range of subdominant wind directions. The nearest wind station at Esperance shows a dominance of southeast wind, together with strong winds also from the south, northeast and north. These may be sufficient to initiate and maintain the dunes. An examination of Google Earth images between 1984 and 2018 shows the dunes are both rotating clockwise as well as slowly migrating northwards.

29.11.2 SC:WA01.03.03 Point Lorensen–Point Malcolm

SC:WA01.03.03 is a southeast-facing section of coast consisting of four granite-controlled embayed beaches that extend for 34 km between Point Lorensen and Point Malcolm. The beaches are generally sheltered by their easterly orientation, their granite headlands and the offshore Easter Group of islands. The SC contains five curving beaches which occupy 32 km (94%) of the shore, the granite points making up the remainder. The northern four beaches are the more sheltered and range from R to LTT to B+SF in the very sheltered Israelite Bay, where seagrass grows to the shore in lee of Point Dempster. The 23 km long Point Dempster-Point Malcolm beach commences as a moderate energy southeast-facing TBR beach (Fig. 29.14a), with the rips extending for about 8 km down the beach. As wave energy decreases to the lee of Point Malcolm, it transforms to a LTT then R and finally a more crenulated B+SF along the southern 8 km. It appears that sand may be bypassing the point and moving into the sand flats and slowly northward up the beach.

This SC contains two small barriers, the semi-circular regressive Israelite Bay system which transforms from high foredune in the north to low beach ridges and north-trending spits in the sheltered south, the latter indicating that sand may be bypassing around the point and into the bay. The longer Dempster-Malcolm systems also transform from minor dune transgression in the north, where it extends 1.3 km inland and overpasses Point Dempster (Fig. 29.14a), to increasing narrow and lower regressive foredune in the centre-south. The combined barriers have a volume of 15 M m^3 (500 m^3 m^{-1}).

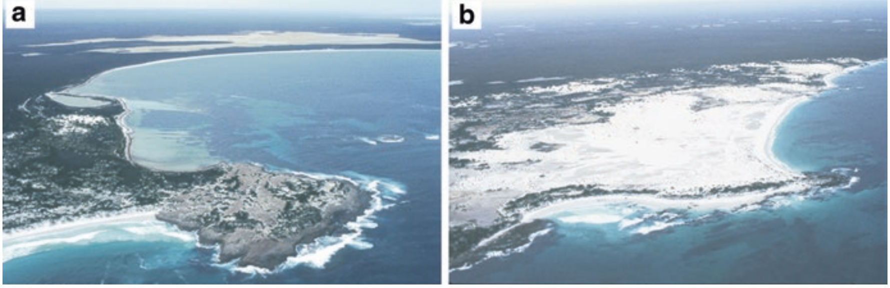


Fig. 29.14 (**a**) Point Dempster and the low energy seagrass filled Israelite bay (WA 29-30) and (**b**) active dunes overpassing a low headland in lee of Bellinger Island (WA 40-42). (Photos: AD Short)

29.11.3 SC:WA01.03.03 Point Malcolm–Cape Pasley

SC:WA01.03.04 commences at the low granite rocks of Point Malcolm and trends southwest for 33 km to the protruding 20 m high Cape Palsey (Fig. 29.12b). In between is a coast dominated by low granite points that border 22 beaches, together with Bellinger Island sitting just 700 m off the centre of the compartment. The generally small beaches occupy 21 km (64%) of the shore, the remainder sloping granite rocks. The beaches are very variable in orientation, degree of embaymentisation and sheltering resulting in a range from 13 exposed RBB and TBR to six sheltered WD R and LTT, together with three R+RF.

All the south-facing beaches are backed by generally vegetated northeast-trending transgressive dunes, apart from those in lee of Bellinger Island which are actively overpassing the low 1–2 km wide point (Fig. 29.14b), with the orientation of the dunes attesting to the dominance of the southwest winds. There are four barrier systems along this section with dunes extending up to 3.5 km inland and occupying 16 km (48%) of the shore. They have a total volume of 11 M m^3 (662 m^3 m^{-1}). The relatively low volumes are a result of the orientation of the coast essentially side-on to the dominate wind which only partially exposes it to onshore aeolian transport.

29.11.4 PC Overview

This is one of the more interesting PCs on the Australian coast enhanced by its remoteness and natural state, but more importantly to the transition along the northern Bilbunya section (SCs:WA01.03.01-2) in orientation, sand size, wave energy and resulting beach state and barrier type, together with the fact it is backed by the former limestone sea cliffs of the Wylie Escarpment. In addition, it contains the only field of large star dunes in Australia and all composed of near pure white quartz sand. The sand has been ultimately derived from the granite-rich hinterland and shelf islands, deposited on the shelf at low sea level and transport onshore during and following the PMT. Given the variable orientation of the curving beach, it is likely to experience an increase in northerly sand transport northwards up the beach, resulting in a deficiency in sand available and beach recession, with considerable evidence of recession along the central-southern section where beachrock and lagoonal peat are exposed on the beach, coupled with the low retreating foredune. The entire system warrants more detailed investigations of its Quaternary history and beach and dune morphodynamics. Rising sea level will aggravate the already receding beaches and also increase inundation of the inter- and back-barrier salt flats. The southern section (SCs:WA01.03.03-4) with its granite headland will be more resilient; however the intervening beaches will be exposed to increasing shoreline retreat leading to possible reactivation of the predominately stable transgressive dunes.

29.12 Regional Overview

The Nullarbor region is both long at 844 km and highly variable in nature owing to the alternation of cliffs and beach barriers, all unified by the continuous southern escarpment of the Nullarbor Plain. This escarpment provides one of the longest continuous uniform cliff-bluff lines in the world at 790 km. Half is exposed sheer vertical cliffs, while half is sheltered by the Roe Plain and the Bilbunya barrier systems, two contrasting systems controlled by their exposure to the southwest waves and winds. There has been considerable sediment accumulation along this coast predominately shelf carbonate in the east and fine terrigenous quartz in the west. The presence of inner Pleistocene dune calcarenite at Merdayerrah, clifftop dunes along the Nullarbor Cliffs, the Roe Plain Holocene barriers, the massive glacial age Twilight Cove dunes, the extensive Baxter Cliff clifftop dunes, and finally the inner and outer Bilbunya barrier systems all attest to the large volumes of sand (Table 29.4) that have been deposited along this coast, with the beaches and sand ramps that supplied the extensive clifftop dunes subsequently eroded. The erosion of the ramps and ongoing recession of Bilbunya beach indicate that the initial abundant shelf supply has been exhausted or much reduced.

Rising sea level will exacerbate the shoreline recession already occurring along parts of Bilbunya beach and in general elsewhere. The rise will also initiate inundation of the back-barrier salt flats that back much of the Roe Plain foredune and the Bilbunya barrier. The deeper nearshore particularly along the Roe Plain will allow higher waves to reach the shore, which will also cause a slight increase in rate of cliff retreat along the Nullarbor and Baxter cliffs. Finally, any change in wave climate will directly impact all the beach systems and their transport systems, while change in wind regime will impact the many unstable dune systems.

References

Bird ECF (1976) Shoreline changes during the past century, 23rd international geographical Congress, Moscow, 54 p

Bowler JM (1978) Glacial age aeolian events at high and low latitudes: a Southern Hemisphere perspective. In van Zinderen Bakker EM (ed) Antartic glacial history and World Paslaeoenvironments. AA Balkema, Rotterdam, pp 149–172

Buckley R, Short AD, Fotheringham DG (1987) Late Pleistocene sea-level maxima in the Great Australian Bight. Search 18:86–89

Eliot I (2011) Coastal compartments of Western Australia: a physical framework for marine and coastal planning. Damara Pty Ltd, Geological Survey WA and Department of Environmental Conservation, Perth, 87 p

Fotheringham DG (2009) Cliff top erosion adjacent Cape Dombey, Robe, South Australia. Coastal Management Branch Technical Report 2009/08, 17 p

James NP, Boreen TD, Bone Y, Feary DA (1994) Holocene carbonate sedimentation on the west Eucla Shelf, Great Australian Bight: a shaved shelf. Sediment Geol 90(3–4):161–177

James NP, Bone Y, Carter RM, Murray-Wallace CV (2006) Origin of the Late Neogene Roe Plains and their calcarenite veneer: implications for sedimentology and tectonics in the Great Australian Bight. Aust J Earth Sci 53:407–419

Jennings JN (1967) Cliff-top dunes. Aust Geogr Stud 5:40–49
Lowry DC (1970) Geology of the Western Australia part of the Eucla Basin, Geological Survey of Western Australia, Bulletin 122, 201 p
Lowry DC, Jennings JN (1974) The Nullabor karst, Australia. Ziets Fur Geomorph. N.F. 18:35–81
Murray-Wallace CV, Woodroffe CD (2014) Quaternary sea-level changes: a global perspective. Cambridge University Press, Cambridge, 484 p
Murray-Wallace CV, Belperio AP, Dosseto A, Nicholas WA, Mitchell C, Bourman RP, Eggins SM, Grün R (2016) Last interglacial (MIS 5e) sea-level determined from a tectonically stable, far-field location, Eyre Peninsula, southern Australia. Aust J Earth Sci 63(5):611
Pan T-Y, Murray-Wallace CV, Dosseto A, Bourman RP (2018) The last interglacial (MIS 5e) sea level highstand from a tectonically stable far-field setting, Yorke Peninsula, southern Australia. Mar Geol 398:126–126
Provis DG, Radok R (1979) Sea-level oscillations along the Australian coast. Aust J Mar Freshw Res 30:295–301
Short AD (2001) Beaches of the South Australian coast and Kangaroo Island. Sydney University Press, Sydney, 433 p
Short AD (2005) Beaches of the Western Australian coast: Eucla to Roebuck Bay. Sydney University Press, Sydney, 433 p
Short AD, Woodroffe CD (2009) The coast of Australia. Cambridge University Press, Melbourne, p 288
Short AD, Fotheringham DG, Buckley RC (1986) Coastal morphodynamics and Holocene evolution of the Eyre Peninsula coast, South Australia. Coastal Studies Unit Tech Rep. 86/2, Coastal Studies Unit, University of Sydney, 178 p
Thom BG, Oliver TSN (2018) Evidence for a change in wind regime during the last glacial maximum from the Sydney region. Aust J Earth Sci. https://doi.org/10.1080/08120099.2019.1522668

Chapter 30
Southern Western Australia Region

Abstract The southern Western Australian coast is the most exposed and highest energy section of the Australian coast with the highest energy beaches and largest barrier systems in Australia. The coast extends for 1180 km between Cape Pasley and Cape Leeuwin, the southwestern tip of the continent. It faces generally south into the Southern Ocean and its persistent moderate to high southerly swell and periodic strong south through west winds. Tides are micro, the lowest in Australia, and the entire coast is wave-dominated. The climate is semi-arid in the east and becomes increasingly humid to the west, and while several small rivers and many streams flow to the coast most terminate in usually closed lagoons, with none delivering sediment to the coast. However, lowstand terrigenous quartz deposits have been combined with shelf carbonate and transported onshore to form the many beaches, tidal deltas and large barriers. This chapter describes the coastal geology and processes, beaches, barriers, sediment transport and sediment compartments.

Keywords South Western Australia · Southern Ocean · Micro-tides · Southerly swell · Beaches · Barriers · Sediment transport · Sediment compartments · Estuaries

30.1 Introduction

The south coast of Western Australia is an exposed south-facing coastline, dominated by its predominately granite and metasedimentary geology. The bedrock forms headlands, points, rocks and reefs which border most of the hundreds of beaches, as well as litter the shelf in the east with hundreds of granite islands particularly in the Recherche Archipelago. It extends 1180 km from Cape Pasley to Cape Leeuwin, the southwestern tip of the continent. It initially trends west from Cape Pasley for 470 km to Red Island and then bulges to the south-trending southwest for 350 km to Bald Head, before turning and trending roughly west for 240 km to Point D'Entrecasteaux, and finally northwest for 120 km to Cape Leeuwin (Fig. 30.1). This is predominately an exposed high energy coast with numerous high energy beaches and a large number of massive transgressive barrier systems.

A. D. Short, *Australian Coastal Systems*, Coastal Research Library 32,
https://doi.org/10.1007/978-3-030-14294-0_30

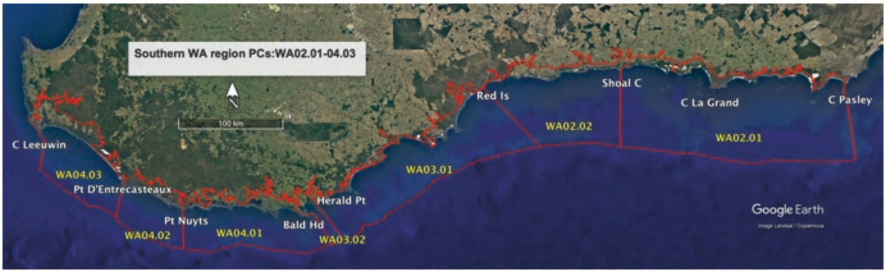


Fig. 30.1 The southern Western Australia region (WA02-04) and its seven PCs (WA02.01-04.03). (Source: Google Earth)

30.2 Geology

The geology is dominated by the southern extent of the large Yilgarn Craton (Fig. 1.2) with its granite and metasedimentary rocks dominating the region in both the east and west, while in between are the sedimentary rocks of the narrow Bremer Basin (Fig. 1.3). The coast can be divided into three geological provinces; beginning is the east with the Esperance coastal plain that narrows towards Esperance with basement gneisses, granites and metasediments forming the prominent capes. Between Mount Barren and Wilson Inlet is a mix of gneiss, siliceous Eocene red beds and quartzite in the Barren province, while the Nornalup province extends a narrow coastal plain from Wilson Inlet to Point D'Entrecasteaux with Eocene sandstones, clays, limestones and lignites.

30.3 Climate

The coast has a warm summer Mediterranean climate (Csb Fig. 1.8) with predominately winter rain and warm drier summers. The climate does however transition to the south and west from semi-arid in the east with rainfall ~400 mm, rising to 620 mm at Esperance, 930 mm at Albany and 960 mm at Cape Leeuwin (Fig. 1.5a, b). At the same time temperatures decrease slightly to the south from a summer mean daily temperature of 20 °C to 18 °C and in winter from 15 °C to 13 °C (Fig. 1.5c, d).

As rainfall increases to the east, the coast becomes more utilised with a series of scattered towns strung along the coast, while the hinterland is dominated by agriculture. Commencing in the east is the large Esperance and its port (10,000), followed by the small Hopetoun (900) and Bremer Bay (240), Cheyne Beach, then the large Albany (38,000), followed by Denmark (2600), Peaceful Bay (360), Walpole (430), Windy Harbour (25) and finally Augusta (1100). Much of the coast is also contained in national parks, with Cape Arid and Le Grand in the east; Stokes near Esperance; then the large Fitzgerald, the smaller Waychinicup, Torndirrup, West Cape Howe and William Bay; and finally the larger Shannon and D'Entrecasteaux parks in the west and the southern tip of Leeuwin-Naturaliste. The parks and reserves occupy about 680 km (58%) of the coast.

30.4 Rivers

This is a more humid coast backed by a rising hinterland which has 88 drainage systems. Most (64) however are small uplands creeks including 20 small rivers, the remainder either tidal creeks or inlets. The 36 larger systems and estuaries and their entrance conditions are listed in Table 30.1. All the rivers have relatively small catchments, and none are delivering bedload to the coast. Agnew et al. (1975) found that the largest, the Blackwood with a catchment of 22,550 km^2, is delivering sand to Hardy Inlet but not the coast. Owing to the low and seasonal rainfall, three are permanently closed, most are closed during the summer months and only four are permanently open. The opening of the inlets is also related to the increase in rainfall from 620 mm at Esperance to 1400 mm at Broke Inlet, with the lower rainfall eastern inlets normally closed, while the more humid western inlets are seasonally open. For a detailed description of all the southwest inlets, see Brearley (2005).

The streams and rivers do deliver quartz eroded from the granite hinterland to the shelf at low sea levels. This sand that has been reworked onshore during and following PMT to build the many quartz-rich beaches and massive dunes along this region.

30.5 Sediments and Shelf

Beach sands along the coast are generally well-sorted fine to medium quartz sand with an average of 22% carbonate (Table 30.2). There is however considerable longshore variation as indicated in Fig. 30.2. While there is an underlying trend of finer quartz-rich sand (0.15–0.4 mm), there are areas of coarser carbonate-rich sand between Cape Le Grand and Whalebone Point (850–1100 km) and a general increase in both west from around Cheyne Beach (1370 km), with the highest carbonate and coarser sand between Augusta and Cape Leeuwin (1810–1820 km).

The South West shelf between Cape Parsley and Cape Naturaliste was investigated by Richardson et al. (2005) who described it as a high energy shelf exposed to the Southern Ocean southwest swell and storms with sediments mobilised down to 100 m. Physically it is narrow and contains nearshore reefs and islands. Surface sediments are dominated by cool-water carbonate shell and coral fragments with local concentrations of bryozoans, foraminifera and algae. A thin sediment blanket of bioclastic carbonate sands occur on the exposed shelf and forms sediment wedges in protected shelf areas.

Table 30.1 South Western Australian river and estuary entrance conditions

River/inlet	Permanently closed	Normally closed	Seasonally open	Permanently open	Type	Catchment (km^2)
Poison		X				
Youndee		X				
Thomas		X				
Alexander		X				
Minglingup		X				
Dailey		X				
Brandy		X				
Gore-Dalyup	X					
Barker		X			2Bi	
Stokes		X			2Bi	5325
Torradup		X			1	105
Oldfield		X			1	
Jerdacuttup	X				2Bi	
Culham	X				2Bi	2500
Hammersley		X			2Bii	800
Dempster		X			2Bii	300
Fitzgerald		X			2Bii	1625
St Mary’s		X			1	115
Gordon Inlet		X			2Bii	3050
Wellstead Estuary		X			2Bii	695
Beaufort		X			2Bii	4775
Eyre			X		1	50
Waychinicup				X	1	185
Moates-Gardner	X					
Taylor Inlet			X		2Bi	
Oyster Harbour				X	1	6370
Torbay			X		2Bi	
Wilson			X		2Biii	2500
Parry			X		2Bi	170
Irwin			X		2Biii	2380
Nornalup-Walpole				X	2Biii	7420
Broke			X		2Biii	840
Gardner			X		1	607
Warren			X		1	4360
Donnelly			X		1	1690
Blackwood-Hardy				X	2Biii	22,550
36	4	18	10	4		

Adapted from Hesp (1984) and Brearley (2005)
Estuarine type: 1 = riverine; 2= barrier estuary: i = small ovoid basin; ii = elongate; iii = large

Table 30.2 Southern WA region (WA02-04) beach sand characteristics

WA02-04	
n	141
size (mm)	0.3
σ (mm)	0.15
sorting	0.44
σ (sorting)	0.14
% carbonate	21.9
σ (%)	20.6

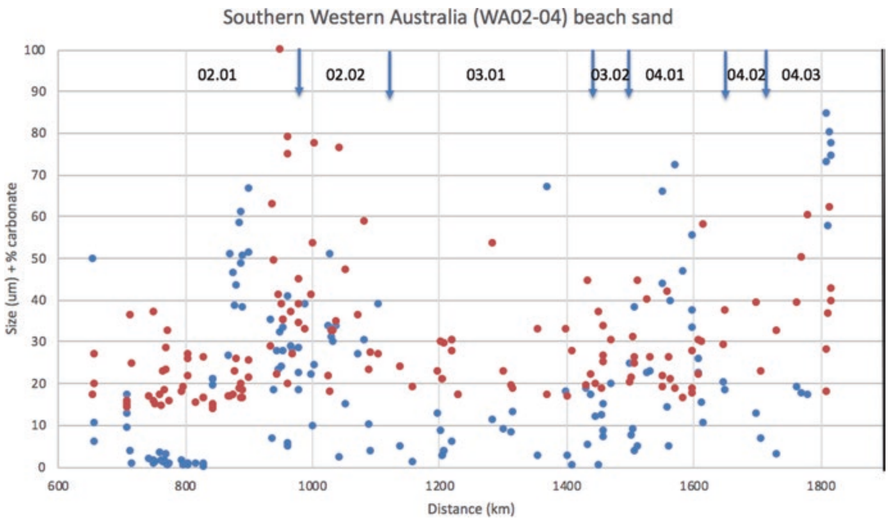


Fig. 30.2 Beach sand size and percent carbonate for the southern WA region and its PCs. Sand size (red, μm), % carbonate (blue). The arrows indicate PC boundaries. Distance is from SA/WA border

The Leeuwin Current flows around Cape Leeuwin, along the south coast and into the Great Australian Bight. It brings warmer tropical waters south and along the south coast with temperature grading from 21 °C in the west to 15 °C in the east. The temperature gradient is reflected in the gradation in benthic fauna from tropical in the west to temperate in the east (Richardson et al. 2005).

30.6 Coastal Processes

The southerly orientation of much of the coast faces it directly into the prevailing southwest wind and swell (Fig. 16.3) exposing it to high energy conditions. Wave energy is high (Fig. 1.12a) with the deepwater waves averaging 2–2.5 m, with periods between 12 and 15 s from the southwest. It is one of the highest energy sections of the Australian coast (Fig. 1.12a) with little monthly variation in height (Figs 1.12b and 16.4). There is however considerable longshore variation in H_b owing wave attenuation and refraction due to the numerous islands, islets, reefs, headlands and embayed beaches resulting in beaches ranging from fully exposed down to a few sheltered TD beaches.

Tides along the entire coast are micro-tidal gradually decreasing from 1.1 m at Mary Ann Haven to 1 m at Albany and 0.8 m at Windy Harbour and Augusta (Fig. 30.3), the latter amongst the lowest tide range in Australia. Winds at Albany are predominately from the west, ranging from northwest though to southwest, with the most transgressive dunes aligned to these directions.

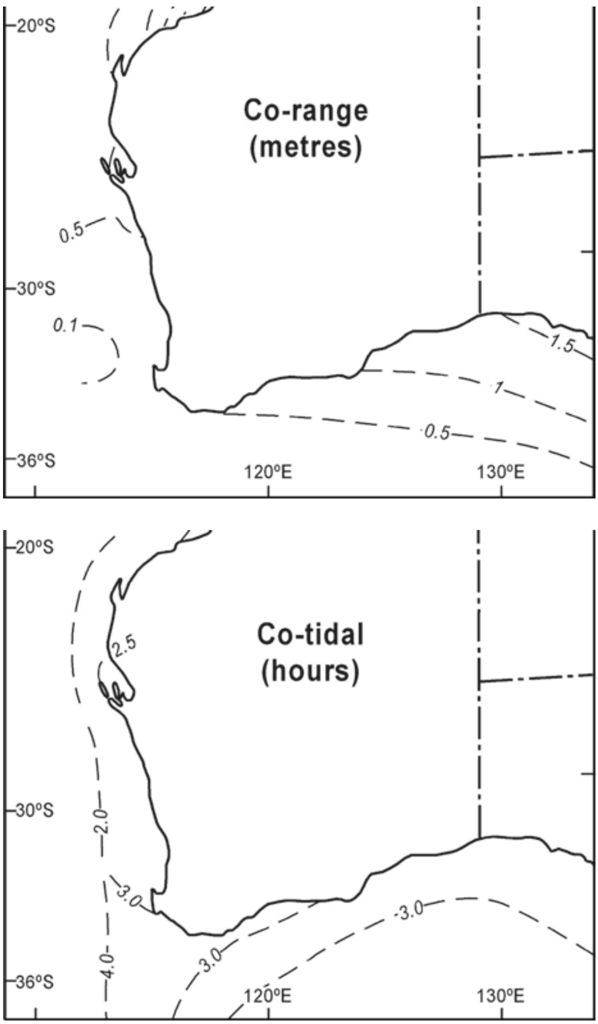


Fig. 30.3 Co-range and co-tidal lines for the southern Western Australia coast. (Source: Short 2005)

Table 30.3 Southern WA beach types and states

BS	BS	No.	%	Total km	% (km)	Mean (km)
3	RBB	78	13.8	123.1	15.9	1.6
4	TBR	170	30.1	431.4	55.8	2.5
5	LTT	120	21.2	122.5	15.8	1.0
6	R	169	29.9	79.2	10.2	0.5
7	R+LTT	1	0.2	2.8	0.4	2.8
11	B+SF	2	0.4	0.1	0.0	0.05
12	B+TSF	1	0.2	0.4	0.1	0.4
14	R+RF	24	4.2	13.8	1.8	0.6
		565	100	773.3	100	1.4

30.7 Beaches

There are 565 beaches along this region which occupy 773 km (66%) of the coast. They average 1.37 km in length, and while predominately WD (98%), there are 3 sheltered TM and TD beaches and 24 fronted by rock flats (Table 30.3). The most dominant beach type is the exposed high energy TBR (56%) and RBB (16%), followed by the sheltered WD LTT (16%) and R (10%). This is the highest energy section of the Australian coast and is an exposed, high energy wave and rip-dominated coast, with the many exposed beaches containing on average 1000 beach rips with the largest average rip spacing in Australia of 380 m (σ = 90 m), together with 524 topographic rips (Short 2006). The highest energy beaches tend to be TBR-RBB rather than D owing to medium to in places coarser sand (0.2–0.4 mm), which precludes the development of the wide low gradient D beaches which require finer sand (0.1–0.2mm). Short (2005) provides a description of all beaches in the southern region.

30.8 Barriers

The energetic and exposed nature of this coast has produced 122 barrier systems that occupy 758 km (64%) of the coast, the remainder composed of the granite and metasedimentary rocks, reefs and headlands. The barriers are predominately composed of transgressive dunes including some climbing clifftop dunes and extend on average between 1.5 and 5 km inland. They have a volume of 41,352 M m^3 with a high per metre volume of 54,554 m^3 m^{-1} and cover an area of 2100 km^2 of which 20% is unstable (Table 30.4).

Table 30.4 Southern WA region and PC barrier dimensions

WA02-04	02.01	02.02	03.01	03.02	04.01	04.02	04.03	WA02-04
No.	43	17	31	5	15	6	5	122
Total length (km)	212	104.5	147.6	12.2	120.5	57.8	103.3	758
Mean min width (m)	1600	400	670	280	1300	1700	1600	–
Mean max width (m)	5200	1500	1550	600	2400	4200	6130	–
Mean height (m)	16	16	16	13	19	18	17	–
Area (ha)	85,268	9802	23,795	604	21,820	18,115	49,790	209,914
Unstable (ha)	24,354	1706	5195	0	490	300	9800	42,845
Total volume (M m^3)	16,991	1914	4517	63	4332	3580	9955	41,352
Unit volume (m^3 m^{-1})	80,243	18,308	30,600	5172	35,950	61,960	96,380	54,554

30.9 Sand Transport

The region has experienced considerable onshore sand transport from the shelf to the coast. The predominance of quartz sands indicate a terrigenous origin with the sand being delivered to the shelf at low sea level and together with shelf carbonate transported shoreward during and subsequent to the PMT. Transport within and between any PCs and SCs will be discussed in the following sections. The south coast region contains seven PCs and 21 SCs (Table 30.5) which are discussed below. Eliot (2011) identified and mapped the PCs and SCs and also identified a further 46 TCs embedded within the SCs.

30.10 PC:WA02.01 Cape Pasley-Shoal Cape

PC:WA02.01 commences at Cape Pasley where the coast turns and trends west for 328 km to Shoal Cape (Fig. 30.1). The westerly trend of the coast is interrupted by the large protruding Cape Arid and Cape Le Grand together with numerous smaller headlands and rocky points, while the 105 islands and 1200 'obstacles to shipping' (i.e. reefs and islets) of the Recherche Archipelago extend more than 50 km offshore and parallel most of this coast. Even with the islands, reefs and headlands, this remains a predominately exposed and high energy coast. The PC contains 134 beaches which occupy 237 km (72%) of the coast, the remainder rocky headlands and shore. The beaches are dominated by 55 longer TBR and RBB (mean = 3.6 km), for the most part well exposed and rip-dominated which occupy 80% of the beaches by length. There are also 75 shorter (0.5–0.8 km) LTT and R, which occupy 19% by length (Table 30.6). The beaches are quartz-rich in the east (60–80% quartz), with carbonate increasing to the west (40–70% carbonate). Accompanying this trend is an increase in grain size from fine to medium to medium to coarse (600–966 km, Fig. 30.2). The nature of the sediments and their regional and local variation in sediment size and composition is indicative of the variable shelf sources – quartz and

Table 30.5 Southern Western Australia region, PCs and SCs

Southeast WA[a]		Boundaries	Beaches[b]	No. beaches	Km[c]	Total km
WA 02.01.01		C Pasley-C Arid	WA 53-73	21	638–683	45
WA 02.01.02		C Arid-Tagon Pt	WA 74-88	15	683–720	37
WA 02.01.03		Tagon Pt-Hammer Hd	WA 89-109	21	720–770	50
WA 02.01.04		Hammer Hd-Mississippi Pt	WA 110-127	18	770–811	41
WA 02.01.05		Mississippi Pt-C Le Grand	WA 128-139	12	811–843	32
WA 02.01.06		C Le Grand-Observation Pt	WA 140-157	18	843–896	53
WA 02.01.07		Observation Pt-Shoal C	WA 158-186	29	896–966	70
WA 02.01		*C Palsey-Shoal C*	*WA 53-186*	*134*	*638–966*	*328*
WA 02.02.01		Shoal C-Mason Bay	WA 187-236	50	966–1046	80
WA 02.02.02		Mason Bay-Hopetoun	WA 237-254	18	1046–1074	28
WA 02.02.03		Hopetoun-Red Is	WA 255-277	23	1074–1116	42
WA 02.02		*Shoal C-Red Is*	*WA 187-277*	*91*	*966–1116*	*150*
WA03.01.01		Red Is-Pt Hood	WA 278-301	24	1116–1176	60
WA03.01.02		Pt Hood-C Knob	WA 302-321	20	1176–1248	72
WA03.01.03		C Knob-Groper Bluff	WA 322-331	10	1248–1292	44
WA03.01.04		Groper Bluff-Bald Is	WA 332-363	32	1292–1376	84
WA03.01.05		Bald Is-C Vancouver	WA 364-378	15	1376–1417	41
WA03.01.06		C Vancouver-Herald Pt	WA 379-387	9	1417–1436	19
WA03.01		*Red Is-Herald Pt*	*WA 278-387*	*110*	*1116–1436*	*320*
WA03.02.01	King George Sound	Herald Pt-Bald Hd	WA 388-411	24	1436–1467	31
WA04.01.01		Bald Hd-Torbay Hd	WA 412-431	20	1467–1517	50
WA04.01.02		Torbay Hd-Wilson Hd	WA 432-444	13	1517–1556	39

(continued)

Table 30.5 (continued)

Southeast WA[a]		Boundaries	Beaches[b]	No. beaches	Km[c]	Total km
WA04.01.03		Wilson Hd-C Faujas	WA 445-471	27	1556–1577	21
WA04.01.04		C Faujas-Pt Irwin	WA 472-496	25	1577–1605	28
WA04.01.05		Pt Irwin-Pt Nuyts	WA 497-522	26	1605–1636	31
WA04.01		*Bald Hd-Pt Nuyts*	*WA 412-522*	*111*	*1467–1636*	*169*
WA04.02.01		Pt Nuyts-West Cliff Pt	WA 523-563	41	1636–1676	40
WA04.02.02		W Cliff Pt-Pt D'Entrecasteaux	WA 564-569	6	1676–1704	28
WA04.02		*Pt Nuyts-* Pt D'Entrecasteaux	*WA 523-569*	*47*	*1636–1704*	*68*
WA04.03.01		Pt D'Entrecasteaux-Black Pt	WA 570-598	29	1704–1770	66
WA04.03.02		Black Pt-C Leeuwin	WA 599-617	19	1770–1818	48
WA04.03		*Pt D'Entrecasteaux-C Leeuwin*	*WA 570-617*	*48*	*1704–1818*	*114*
		Regional total		*565*		*1180*

[a]NCCARF compartment number
[b]ABSAMP beach ID
[c]Clockwise distance from State border

Table 30.6 PC:WA02.01 beach types and states

BS		No.	%	km	%	Mean (km)	σ (km)
3	RBB	2	1.5	2.4	1.0	1.2	–
4	TBR	53	39.6	187.9	79.2	3.6	5.1
5	LTT	33	24.6	26.8	11.3	0.8	0.9
6	R	42	31.3	19.3	8.1	0.5	0.5
14	B+RF	4	3.0	0.7	0.3	0.2	–
		134	100	237.1	100	1.8	–

carbonate – together with the embayed nature of the beaches which precludes longshore transport and sediment exchange and mixing.

The beaches are backed by 43 barrier systems which occupy 212 km (65%) of the coast. They range from a single stable foredune in sheltered bays to minor to moderate to massive dune transgression, the largest in lee of Le Grand Beach extending 35 km inland. On average the barriers are 1.6–5.2 km wide and 38% are unstable. All the dunes trend east to northeast driven by the westerly winds. They have a total volume of 16,991 M m^3 which represents a very high per metre volume of 89,243 $m^3\ m^{-1}$, the second highest for the region (Table 30.4). The high barrier volumes can be attributed to the southwest orientation of four largest high energy beaches into prevailing waves and winds, namely, Yokinup Bay (WA 80-85), around Dunn Rocks (WA 119-124), Le Grand beach (WA 141-148) and between Roses-Barker Inlet (WA 167-178). These will be discussed in the following six SCs WA 02.01.01-06.

30.10.1 SC:WA02.01.01 Cape Pasley-Cape Arid

SC:WA02.01.01 commences at Cape Pasely where the coastal orientation changes abruptly and begins the long westerly trend towards Cape Leeuwin (Fig. 30.4). This SC is located entirely within Cape Arid National Park and is dominated by the boundary granite Cape Pasley and the long Cape Arid, linked by the curving 15 km long south-southwest-facing Sandy Bight beach and its backing massive transgressive dune system orientated to 65°. The dunes extend across the rear of the cape for up to 19 km in places overpassing the cape and reaching the eastern shore (WA 46-49). The dunes are stable apart from a series of foredune blowouts and parabolics extending up to 800 m inland. The barrier has a volume of 1000 M m^3, with a high per metre volume of 71,429 $m^3\ m^{-1}$. A series of eight small barriers are spread along the eastern side of Cape Arid and have a combined volume of just 43 M m^3. Just two small usually closed streams (Poison and Youndee) reach the coast at the western end of the bight.

The 21 beaches along this section occupy 25.4 km (56%) of the shore. They are dominated by the exposed high energy rip-dominated Sandy Bight beach (Fig. 30.5a), with the remaining 20 beaches spread along the 30 km long eastern side Cape Arid where they occupy a series of small embayments averaging 0.5 km in length. They are predominately sheltered with thirteen R, five LTT and just two more exposed TBR. There is just one patch of dune transgression in lee of the southwest-facing Thomas Fishery beach (WA 69) with the dunes overpassing the headland to reach WA 68 (Fig. 30.5b).

Fig. 30.4 SCs:WA02.01.01-03: Cape Pasley to Shoal Cape. (Source: Google Earth)

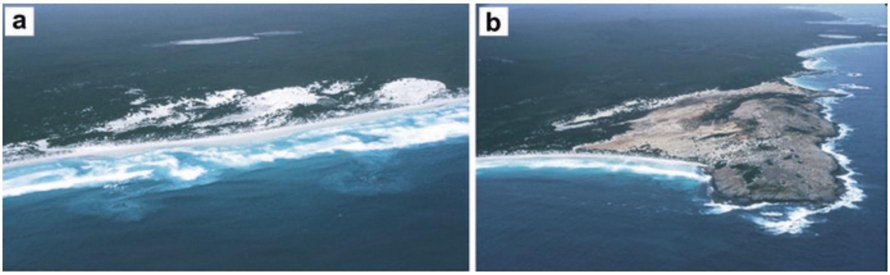


Fig. 30.5 (**a**) Sandy Bight beach (WA 53) with well-developed rips and parabolic dunes; (**b**) headland overpassing near Thomas Fishery Beach (WA 69). (Photos: AD Short)

Sandy Bight has acted as a major sink for wave-delivered shelf sands, with the only leakage being the internal overpassing at Thomas Fishery and the external overpassing across Cape Pasley to the adjoin SC. As the dunes are now predominately stable, contemporary overpass volumes are expected to be low.

30.10.2 SC:WA02.01.02 Cape Arid-Tagon Point

SC:WA02.01.02 encompasses the exposed 20 km wide southwest-facing Yokingup Bay, bordered in the east by Cape Arid and to the west by the elongate Tagon Point (Fig. 30.4), both headlands composed of granite. The entire SC lies within Cape Arid National Park while several kilometres inland from the bay is the most western agricultural land in the south of WA. In between the headlands is 37 km of shoreline which includes 15 beaches occupying 26.5 km (72%) of the shore, the remainder a series of small granite points, together with a cluster of small islands and reefs along the western side of Cape Arid. The beaches are dominated by the 14 km long Yokingup beach (WA 85) and a 15 km long series of 10 small but exposed beaches between the beach and Cape Arid (WA 74-84), together with 3 beaches in lee of Tagon Point including the TBR Tagon beach (WA 88) which is composed of pure quartz sand. The beaches are generally well exposed with most either TBR or RBB including Yokingup, the remainder six rock and reef-sheltered LTT-R averaging just 0.38 km in length. The small usually closed Thomas River is located at the western end of Yokingup beach, adjacent to the vehicle access.

The bay has acted as a major sediment sink dominated by the main Yokingup barrier which consists of massive transgressive dunes extending up to 12 km inland. There is a large 2000 ha unstable area in the centre totalling 29% of the dunes. The barrier has a volume of 1400 M m^3 (77,778 m^3 m^{-1}), both comparable to the adjoining Sandy Bight barrier system. There is no evidence of leakage from the bay, with all the sand trapped within the bay and its dune systems. Three smaller barriers located on either side of the bay total 200 M m^3.

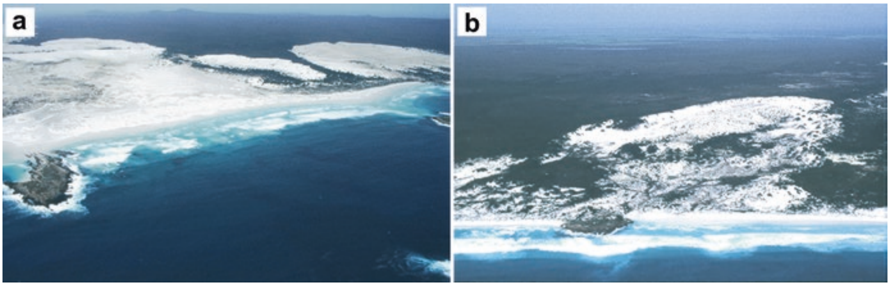


Fig. 30.6 (**a**) Massive active dunes extending 4 km inland at Point Jedacorrudup (WA 84); (**b**) large parabolic dune in Alexander Bay (WA 95). (Photos: AD Short)

30.10.3 SC:WA02.01.03 Tagon Point-Hammer Head

SC:WA02.01.03 is a 50 km long west-trending section of coast containing a series of 21 embayed beaches located between Tagon Head and the anvil-shaped Hammer Head (Fig. 30.4), which is connected to the mainland by a double tombolo. There is access to the coast at Alexander Bay and the Duke of Orleans Bay caravan park, which is the first permanent habitation on the coast since Fowlers Bay (1100 km to the east). The Cape Arid National Park terminates 3 km west of Tagon Point with the rest of the coastal fringe undeveloped, though cleared agricultural land extends to within 1 km of the coast. The beaches occupy 40 km of the coast (80%), with all of them bordered by granite points and rocks, with dozens of islands and reefs of the Recherche Archipelago scattered up to 20 km offshore. The beaches are composed of quartz-rich (97–99% quartz), well-sorted fine sand and average 1.9 km in length, with the longest (6.6 km) and highest energy beach the southwest-facing Alexander bay (WA 96). The beaches generally face south and range from sheltered R (5 km of the beaches) to LTT (11 km) and are dominated by the more exposed TBR-RBB (24 km), while there is one small 50 m long B+SF in the very sheltered seagrass-filled corner of Duke of Orleans Bay. Four usually closed streams reach the coast, namely Blackboy Creek west of Tagon Point, the Alexander River in Alexander Bay and closer to Duke of Orleans Bay the Minglingup and Dailey creeks.

Ten near-continuous barrier systems occupy 35 km (70%) of the shore, all located east of Duke of Orleans Bay. They all contain transgressive dunes ranging from stable to active which extend on average 1.5 km inland, with presently 52% of the 3710 ha of dune unstable (Fig. 30.6a), mainly in lee of Alexander Bay, where they extend 5 km inland (Fig. 30.6b). The barriers have a total volume of 695 M m^3 (19,928 m^3 m^{-1}), both substantially lower than the Sandy Bight and Yokingup systems. This is a reflection of the more southerly, rather than southwestely, orientation of this section of coast.

Fig. 30.7 SCs:WA02.01.04-06 located between Hammer Head and Observation Point. (Source: Google Earth)

30.10.4 SC:WA02.01.04 Hammer Head-Mississippi Point

SC:WA02.01.04 trends west then southwest from Hammer Head for 41 km to Mississippi Point (Fig. 30.7). All but the eastern 5 km is located in Le Grand National Park famous for its sloping granite points, tors and islands and pure white quartz sand beaches. There is 2WD vehicle access to most of the beaches in the east at Wharton Beach (WA 115), accessed via Duke of Orleans Bay, and in the west as far as Rossiter Bay (WA 124) accessed through the national park as well as several beachfront national park camping areas. A series of 18 beaches occupy 30 km (73%) of the shore with sloping granite points and headlands making up the remainder, while offshore are more than 20 small islands of the archipelago. The beaches are composed of fine, well-sorted on near pure white quartz sand (97–99% quartz) (Fig. 30.2). They range from short (mean = 0.19 km) sheltered R east around Hammer Head (Fig. 30.8a) and west around Mississippi Point to more exposed TBR along the central section where they average 3 km in length, the longest located in the centre and adjoining Dunn Rocks and Rossiter Bay (WA 123-124).

There are five barrier systems occupying 30 km of coast (73%), the largest and most active extending east of Dunn Rocks. All consist of transgressive dunes with the Dunn Rocks active dunes extending up to 5 km inland and vegetated dunes to 13 km, with 16% presently unstable. The dunes have a volume of 1825 M m^3, with a per metre volume of 61,242 m^3 m^{-1} comparable to the higher energy Sandy Bight and Yokingup Bay. This SC is a sediment sink for the quartz-rich shelf sand. While there is internal overpassing of Cheyne Point (Fig. 30.8b) and in the past from Wharton Beach to Duke of Orleans Bay, there is no apparent transport around the boundary headlands.

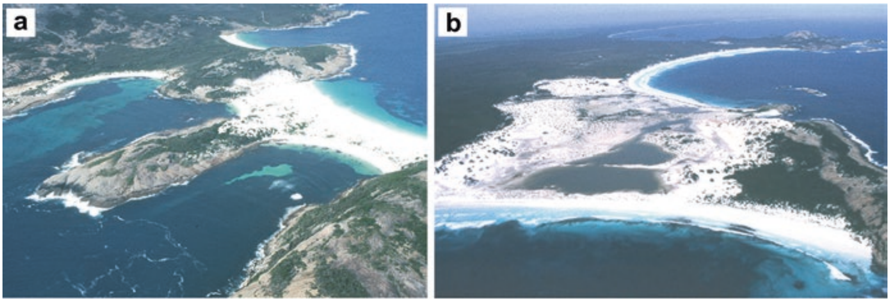


Fig. 30.8 (**a**) Hammer Head (right) is linked to the mainland by two tombolos (WA 109-111); (**b**) headland overpassing at Cheyne Point (WA 117) with Wharton Beach behind (WA 115). (Photos: AD Short)

30.10.5 SC:WA02.01.05 Mississippi Point-Cape Le Grand

SC:WA02.01.05 is a granite-dominated section of steeply sloping headlands and points that extends for 32 km between Mississippi Point and Cape Le Grand, all located within La Grand National Park and is the most spectacular part of the park, with granite tors rising inland including 345 m high Mount Le Grand, while offshore are dozens of granite islands of the archipelago. There are 12 beaches in amongst the rocks totalling just 8 km in length (25% of the coast). The beaches are composed of the purest white quartz sand in Australia (>99% quartz) with Lucky Bay famous for having the whitest beach sand in Australia (see Sect. 34.7 and Table 34.5) and amongst the whitest in the world. The sand is also fine and well-sorted. The beaches are all deeply embayed, and range from eight sheltered R-LTT occupying just 3.7 km to four longer southwest-facing TBR occupying 4.3 km, dominated by the 3.4 km long Lucky Bay.

There are five vegetated barrier systems in the bays dominated by the Lucky Bay barrier which extends inland as now stable transgressive dunes for up to 3 km. The barriers have a volume of 148 M m^3 (20,880 $m^3\ m^{-1}$), 95% contained in the Lucky Bay barrier. The low barrier volume is owing to the rock-dominated shore and generally low energy sheltered bays and beaches, with only Lucky Bay receiving sufficient wave and wind energy to develop a now stable moderate size barrier system. Each of the bays appears to be a closed TC, with no sand exchange between the bays or adjoining SCs.

30.10.6 SC:WA02.01.06 Cape Le Grand-Observation Point

SC:WA02.01.06 is a 30 km wide curving southwest to south-facing embayment located between Cape Le Grand and Observation Point and containing Wylie, Esperance and Twilight bays, as well as the large town and port of Esperance. The boundary headlands and intervening points and slopes are all composed of granite, together with some shore-parallel beachrock reefs west of Esperance. The beach

Fig. 30.9 (**a**) The southern end of the 21 km long Le Grand Beach (WA 141); (**b**) the small Lovers Beach (WA 152), Dempster Head and the Esperance Harbour breakwater and sand trap; (**c**) shore-attached beachrock reefs and strong topographic rip (arrow) at Second Beach (WA153); and (**d**) high energy Quallup Beach and its active dune system (WA 168). (Photos: AD Short)

sand remains fine and well-sorted; however once around Cape le Grand, the amount of carbonate increases to an average of 41% ($\sigma = 14\%$), which has no doubt contributed to the formation of beachrock. The embayment is dominated by its 18 beaches which occupy 51 km (96%) of the shoreline, the remainder steeply dipping granite slopes and points. The beaches are dominated by the 30 km long La Grand-Wylie Beach (Fig. 30.9a), an exposed TBR beach, with other exposed TBR beaches located either side and west of Esperance, totalling 41 km of shoreline, while a cluster of sheltered R-LTT beaches are located in lee of Dempster Head-Esperance Harbour and its 1 km long breakwater (Fig. 30.9b) and total 9 km. The beachrock reefs at Salmon and Fourth beaches (WA 155-156) maintain strong permanent rip currents and hazard surf conditions (Fig. 30.9c).

The embayment consists of five barrier systems dominated by the massive Le Grand-Wylie in the east. This predominately southwest-facing system is backed by some of the most extensive dunes in WA extending up to 27 km inland, with an area of ~400 km^2 and now predominately stable. The dunes leaving the beach are oriented 70° for the first 6 km and then onlap older longwalled parabolic dunes that trend 95°. These inner dunes are likely to be Pleistocene ‘glacial’ age dunes (~20 ka), with the Holocene extending just the first 6 km. The five barrier systems, including the glacial dunes, have a volume of 8230 M m^3 with a per metre rate of a massive 244,946 m^3 m^{-1}, by far the largest volume and dunes in the PC. However, a substantial portion of this volume is likely to be Pleistocene. If this is removed, the volumes reduce to 2630 M m^3 and 78,279 m^3 m^{-1}, the per metre volume comparable to the high energy eastern SCs:WA02.01.01-02. The massive amount of sand in this system would have originated from the shelf and bay floor.

This SC has a closed eastern boundary at Cape Le Grand and leaky eastern boundary in the west at Observation Point with patches of sand extending around the point indicating headland bypassing. This is the most developed and heavily modified SC in the region dominated by Esperance port and its breakwater. In addition, there are a series of seven groynes and three jetties extending for 2.5 km northeast of the port, including a 1 km long seawall, then a small boat harbour with two entrance breakwaters at Brandy Creek 5 km northeast, the usually closed creek being the only drainage into the bay. Based on the impact of these structures, there is considerable evidence for easterly sand transport to and beyond the port. The port has micro-tides (0.7 m) and low waves, with H_s off Brandy Creek 0.65 m (GHD 1999) which would imply lower waves between the creek and the port.

While waves and tides are low, the prevailing southwest swell and westerly wind can drive currents between 0.07 and 0.21 m s^{-1} (GHD 1999) resulting in a predominately easterly longshore sand transport, though this may reverse during summer southeast sea breeze conditions. The easterly transport is manifest with sand accumulating around the port breakwater (Fig. 30.9b) and sedimentation in the port which requires maintenance dredging (Oceania 2013), together with the build-up of sand on the western side of all the groynes and jetties. Tecchiato et al. (2019) investigated the sediment facies and seagrass distribution in Esperance Bay and found the seagrass was a source of carbonate sediment that was being transported onshore to the beach system and longshore to the east. They suggested bedforms around Limpet Rock indicate onshore sediment transport together with sand accumulating both to the east and west of the rock. At the coast, they found evidence of sediment accumulation in the sandbars near Brandy Creek and the substantial accumulation east of Wylie Head inside the 10-m depth contour, all indicating sediment is being transported to the eastern part of Esperance Bay.

The rate of transport should be highest west of the port (1000's m^3 $year^{-1}$) and substantially less within and immediately east of the port possibly on the order of 100's m^3 $year^{-1}$ and then increasing eastward as wave height increases, with Boreham (1991) calculating an easterly rate of 18,000 m^3 $year^{-1}$ at Brandy Creek. He also estimated that the harbour is trapping 25,000 m^3 $year^{-1}$ which has reduced sand available for longshore sand transport probably contributed to recession of the beach and foreshore reserve to east, which is now classified an erosion hotspot (DOT 2016). There has been nourishment of this beach which Paul (1985) estimated would require 25,000 m^3 $year^{-1}$ to stabilise, with an additional seawall planned to combat the ongoing recession (BMT 2016). An intense rainstorm in 2007 transported 150,000 m^3 of fluvial sediment and debris into Brandy Harbour, indicating that episodic terrigenous transport does supply this coast (Jones et al. 2009).

30.10.7 SC:WA02.01.07 Observation Point-Shoal Cape

SC:WA02.01.07 continues west of Esperance for 70 km to Shoal Cape and consists of seven spiralling embayments swash-aligned to the southwest swell and separated by granite headlands and points, together Barker Inlet (Fig. 30.10), the most eastern

Fig. 30.10 SC:WA02.01.07, Observation Point to Cape Shoal. (Source: Google Earth)

lagoon connected to the sea, though it is usually closed. Most of this coast is contained in the Butty Harbour Nature Reserve and Stokes National Park. The coast faces south, with each of the embayments curving round to face southwest into the swell, with most backed by some degree of dune transgression (Fig. 30.9d). There are 29 beaches along this section totalling 56.5 km (81% of the coast) with the rocky sections occupying the remainder. The beaches are well exposed and 17 rip-dominated TBR occupy 52 km of the shore, including 13 km long Roses-Quallup Beach. The remaining nine are small sheltered R-LTT beaches averaging 0.4 km in length and are located in amongst or in lee of the headlands, together with three R+RF on Butty Head. The beaches are composed of well-sorted medium sand with carbonate averaging 28% (σ = 17%) but ranging from 5% to 66%, suggesting a range of local sources and limited longshore transport, with both sand size and carbonate content also increasing to the west (Fig. 30.2: 900–960 km).

Each of the exposed beaches is backed by both Pleistocene and Holocene transgressive dunes which increase in size and instability to the east, the largest system located between Nine Mile (WA 158) and Quallup (WA 169) beaches (Fig. 30.9d) where they rise to over 100 m and extend up to 15 km inland. This 26 km long system contains 4300 M m^3 of sand, with the entire SC containing 6690 M m^3 and a high per metre volume of 114,358 m^3 m^{-1}. In addition, 12% of the 33,450 ha of dunes are presently unstable. This SC has a leaky western boundary with limited dune overpassing of Shoal Cape, together with past overpassing of Butty Head and some of the smaller headlands. It is also possible there is headland bypassing around some of the headlands, particularly as the beaches extend to the eastern tip of most of the headlands. The SC has acted as major sediment sink owing to the number of exposed southwest-facing beaches, with most of the sand deposited in the dune systems. The overall stability of the dunes and the exposure of beachrock along Shelly (WBA 172), Warrenup (174-5), Barker Inlet beach (WA 178), Quagi (WA 180) and Fanny Cove (WA 184) beaches indicate that the initial massive supply of shelf sand to the dunes has slowed or ceased and has been followed by local beach recession.

30.10.8 PC Overview

This is a long and exposed PC containing several massive transgressive dune systems and one of the highest total volume of sand in the regions PCs, averaging 80,243 m^3 m^{-1} (Table 30.4), which is also amongst the highest in Australia (Appendix 34.2). The large onshore sand deposits reflect the abundant shelf source of predominately quartz but also significant carbonate material, which has been transported onshore by the prevailing moderate to high southwest swell and blown inland by the strong south through westerly winds. Much of this coast is contained in national parks and reserves and will be left to fend for itself as climate changes. However, it also contains the large town and major port of Esperance which is already experiencing issues related to the interruption of its easterly longshore sand transport with the foreshore receding, as well as being exposed to inundation during major storm events, particularly those that coincide with high tide and a shelf wave crest. BMT JFA (2015) predicts the entire Esperance-Wylie Head shoreline will be at risk to increasing erosion and inundation as sea level rises, placing property and infrastructure at risk. They propose a range of measures to accommodate this risk including foredune shore protection along the harbour CBD and Castletown areas which are at high to extreme risk and maintenance of the foreshore reserve buffer, and low intensity land use to the east where the coast is at moderate to high risk.

30.11 PC:WA02.02 Shoal Cape to Red Island

PC:WA02.02 commences at Shoal Cape and trends west-southwest for 150 km to Red Island (Fig. 30.1). While this is a south-facing coast, the level of wave exposure is less than the coast to the east owing to the occurrence of beachrock and inshore reefs which substantially lower breaker wave energy along large sections of this PC resulting in a dominance of lower energy beaches with 56% by length R-LTT and 40% TBR-RBB (Table 30.7) accompanied by generally small barrier systems. Most of the coast is undeveloped, with parts located in Stokes National Park, the Lake Shaster and Jerdacuttup River nature reserves and in the west the beginning of the

Table 30.7 PC:WA02.02 beach types and sates

BS		No.	%	Km	%	Mean (km)	σ (km)
3	RBB	11	12.1	6.6	4.9	0.6	0.7
4	TBR	15	16.5	47.0	35.2	3.1	3.8
5	LTT	18	19.8	43.7	32.7	2.4	2
6	R	42	46.2	31.5	23.6	0.8	1
7	R+LTT	1	1.1	2.8	2.1	2.8	–
14	R+RF	4	4.4	2.1	1.6	0.4	–
		91	100	133.7	100	1.5	–

Fig. 30.11 SC:WA02.02.01: Shoal Cape to Mason Bay. (Source: Google Earth)

large Fitzgerald National Park, in all occupying 96 km (64%) of the coast. The historic but small and growing Hopetoun is the only town on the coast. The PC contains three SCs which are discussed below.

30.11.1 SC:WA02.02.01 Shoal Cape-Mason Bay

SC:WA02.02.01 tends essentially due west for 80 km from Shoal Cape to Mason Bay (Fig. 30.11). This is an undeveloped section of coast containing the Stokes and Shaster reserves, with access points to Stokes Inlet, Skippy Rocks, Margaret Cove, Munglinup Beach, Starvation Boat Harbour and Mason Bay, but no development other than some camping areas. It is also moderately sheltered by the beachrock and inshore reefs (Fig. 30.12a–d), with the 50 beaches a mix of reef-sheltered R-LTT occupying 38 km of the shore and more exposed TBR occupying 33 km. Two and in place three shore-parallel beachrock reefs extend for 8 km west from Shoal Cape (WA 187-192) (Fig. 30.12a), either side of Skippy Rocks (WA 194-199), west from Margaret Cove (WA 201-205) and along Munglinup Beach (WA 215-217) (Fig. 30.12c). Further west the reefs tend to be submerged and more scattered with low wave conditions at the shore (Fig. 30.12d). Most of the exposed TBR beaches are located in the east between Shoal Cape and Munglinup, with predominately R-LTT to the west, sheltered by nearshore-inner shelf reefs more than the headlands. The presence of the beachrock and dune calcarenite is a result of the carbonate-enriched beach sand in this PC which has an average of 25% (σ = 12%) carbonate (Fig. 30.2). Three streams, the larger Stokes River and its lagoon and the Torradup and Oldfield rivers, all reach the coast, but all have usually closed entrances (Table 30.1).

There are nine near-continuous barrier systems along this SC occupying 60 km (75%) of the coast. They all consist of now stable Holocene transgressive dunes extending up to 4 km inland overlying and onlapping lithified Pleistocene dunes. They are predominately well vegetated and stable (87%) with a few blowout-parabolics west of Shoal Cape, in Margaret Cove (WA 198) and along Pincer Rock beach (WA 207). The dunes have a total volume of 1384 M m^3 (22,998 m^3 m^{-1}), substantially less than the eastern SCs.

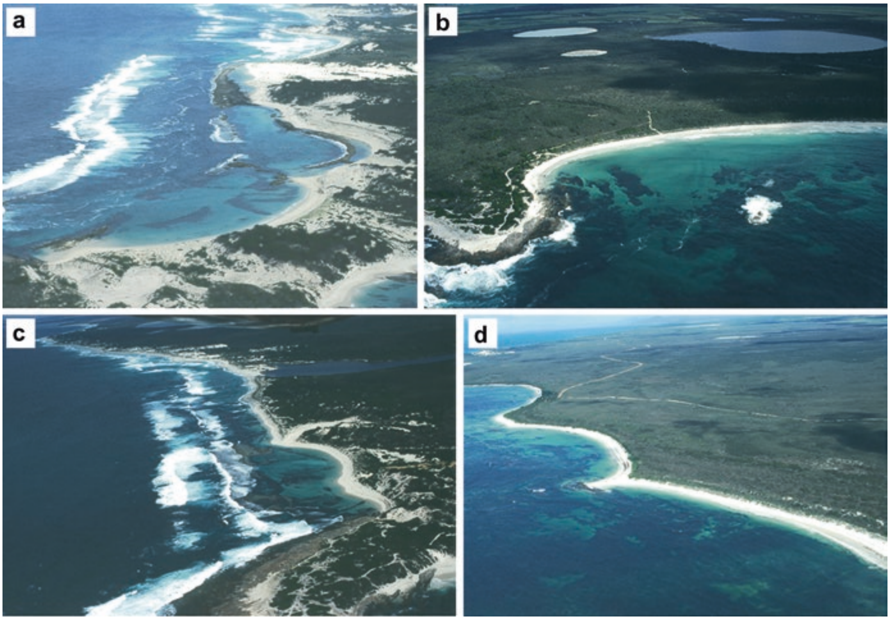


Fig. 30.12 (**a**) Three sets of beachrock reefs at Shoal Cape (WA 187); (**b**) reef-sheltered beaches west of Pincer Rocks (WA 209); (**c**) Munglinup Beach (WA 215) is sheltered in lee of a near-continuous beachrock reef; and (**d**) reef-sheltered beaches and regressive foredunes west of Powell Point (WA 228-29). (Photos: AD Short)

There is potential for easterly longshore sand transport in this SC, with long section of south-facing beaches oblique to the southwest swell and the eastern end of the beaches extending out to the headlands. Rates are expected to be low in the more sheltered west increasing to moderate along the more exposed eastern beaches, with the eastern Shoal Cape also experiencing headland overpassing.

30.11.2 SC:WA02.02.02 Mason Bay-Hopetoun

SC:02.02.02 extends almost straight west from Mason Bay to the protruding Mary Ann Haven at Hopetoun (Fig. 30.13), a distance of 28 km. The Southern Ocean road links Mason Bay and Hopetoun with a few coastal access points along the way, with Hopetoun the only town. The coast is essentially a continuous strip of sand containing 18 beaches that occupy all but 0.5 km of rocky shore in Mason Bay, a total of 27.5 km. The beaches are sheltered by shallow nearshore reefs and shore-attached beachrock reefs extending for 20 km west of Mason Bay (Fig. 30.14a). The reefs lower wave to <1 m along this section resulting in a mix of lower energy R-LTT and some R+rock flats with no higher energy beaches. They also allowed the development of the Hopetoun jetty and port, in an otherwise exposed location (Fig. 30.14b).

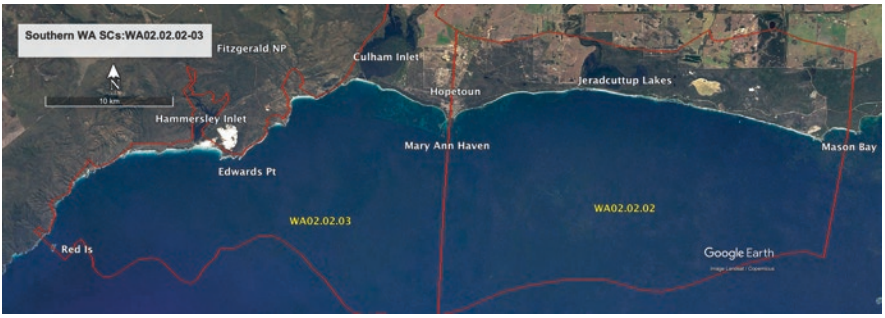


Fig. 30.13 SCs:WA02.02.02-03: Mason Bay-Hopetoun-Red Island. (Source: Google Earth)

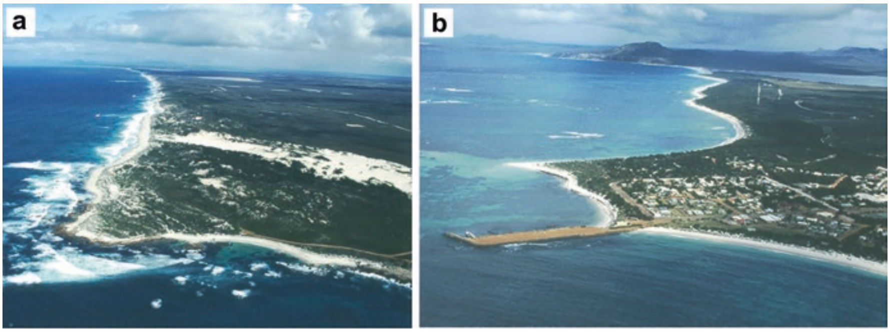


Fig. 30.14 (**a**) A moderate energy, partly reef-sheltered beach extending west of Mason Point (WA 235); (**b**) Hopetoun is located on the Mary Ann Haven cuspate foreland formed in lee of the shallow nearshore reefs (WA 253-5). (Photos: AD Short)

The essentially continuous beaches are backed by a continuous barrier consisting of a 20 m high vegetated foredune(s) extending between 0.2 and 1 m inland that runs the length of the coast. Behind the foredune is a 2–3 km wide backbarrier depression partly occupied by the Jerdacuttup Lakes, feed by the Jerdacuttup River. However, the lakes have no connection to the sea. The barrier system has a relatively low volume of 300 M m^3 (10,000 m^3 m^{-1}). Given the continuous beaches and subdued points, it is likely sand is being transported east along the beaches, all be it at low rates.

30.11.3 SC:WA02.02.03 Hopetoun-Red Island

SC:WA02.02.03 continues east from Hopetoun for 42 km to Red Island, initially trending west-northwest to Culham Inlet and then generally southwest towards the island (Fig. 30.13). This SC has two sections, the reef-sheltered coast between

Hopetoun and Culham Inlet and the more exposed coast to the west. Fitzgerald National Park commences at Culham Inlet, with road access to the park from Hopetoun and then 4WD vehicle access as far west as Quoin Head. The coast has 18 beaches occupying just 19 km (45%) of the shore, the remainder mainly metasedimentary rocks. The beaches reflect the level of wave energy, with a 10 km strip of near-continuous low energy beaches (R-LTT) extending from Mary Ann Haven to Culham Inlet and then a series of embayed rip-dominated TBR located along the rocky coast to the west, including Mylies (WA 261), Hammersley Inlet (WA 264) and Whalebone (WA 266-273) beaches, the latter interrupted with patches of beachrock. Culham Inlet is usually closed to the sea; however in 2016 flooding of the inlet led it to be artificially open for the first time in 15 years. Nearby Hammersley Inlet is also usually closed.

There are seven barrier systems along this section consisting of regressive foredunes along the sheltered beaches, including the cuspate foreland that forms Mary Ann Haven, and transgressive dunes in lee of the more exposed beaches mentioned above, with the largest in lee of Hammersley Inlet climbing over Pleistocene calcarenite to 60 m elevation and extending 3 km inland. The barrier totals 230 M m^3 (16,006 m^3 m^{-1}). These relatively small volumes reflect the combination of the sheltered section of southwest-facing shore, the predominately rocky shore precluding accommodation space, as well as Pleistocene barriers occupying space behind the beaches. Some sand has also been deposited in Culham Inlet which was an open inlet until 3.6 ka (Hodgkin 1997); however as it is usually closed, the amounts are expected to be relatively small. The entire SC appears to be acting as sink with closed boundaries at Red Island and Mary Ann Haven.

30.11.4 PC Overview

Apart from Hopetoun this is an undeveloped PC in a relatively natural state. While much of the coast faces south and some of the beaches southwest towards the prevailing waves and winds, the presence of inshore reefs and long section of beachrock substantially lower waves along the shore resulting in a predominance of lower energy beaches, particularly between Lake Shaster and Culham Inlet. As a consequence, the barriers are small to moderate in size, with the largest dune transgression extending 5 km inland, and dune volumes and per metre volumes are the smallest on the open coast in this region (Table 30.4). There is little at risk along this coast with the growing Hopetoun including the new residential area setback behind foreshore reserves consisting of a band of foredune ridges. The foreshore jetty area is however listed as an erosion hotspot (DOT 2016).

Table 30.8 PC:WA03.01 beach types and states

BS	BS	No.	%	Total (km)	%	Mean (km)	σ (km)
3	RBB	14	12.7	33	20.3	2.4	2.5
4	TBR	41	37.3	98.1	60.2	2.4	4.1
5	LTT	20	18.2	15.2	9.3	0.8	1.1
6	R	31	28.2	7.8	4.8	0.3	0.5
14	R+RF	4	3.6	8.8	5.4	2.2	–
		110	100	162.9	100	1.5	–

30.12 PC:WA03.01 Red Island to Herald Point

PC:WA03.01 is a southeast-trending section of coast extending for 320 km between Red Island and Herald Point (Fig. 30.1). This is a lightly developed coast with the first 30 km located in Fitzgerald National Park and the western tip in Two Peoples Bay Nature Reserve. In between is one small community at Bremer Bay and generally limited public access to the coast. The coast is dominated by a series of major resilient headlands and points all composed of either granite or gneiss, with a series of bays and embayed beaches in between.

Beach sand along this coast tends to be well-sorted, fine-medium and lower in carbonate (mean = 12%, σ = 14%) (Fig. 30.2). Tide are micro (<1 m), and owing to the southeast orientation of much the coast and numerous protruding headlands, points and inshore islands, wave energy is highly variable and generally reduced. The beaches are roughly divided by number between 51 lower energy R-LTT and 55 more exposed TBR-RBB; however by length the longer higher energy beaches dominate occupying 131 km (41%) of the coast (Table 30.8). There are 31 predominately transgressive barrier systems including climbing and clifftop dunes occupying 148 km (46%) of the coast ranging in average width from 0.67 to 1.55 km of which 22% are unstable. They have a total volume of 4517 M m^3, (30,600 m^3 m^{-1}) typical of a moderately exposed higher energy southern coast (Table 30.3). The PC contains six SCs which are discussed below.

30.12.1 SC:WA03.01.01 Red Island-Point Hood

SC:WA03.01.01 is an undeveloped southwest to south-trending 60 km long section of coast between Red Island and Point Hood (Fig. 30.15). The coast is dominated by its series of east-trending headlands. The northern half is located in Fitzgerald National Park, with the only vehicle access to the Point Ann camping area in the park and Gordon Inlet via Bremer Bay; otherwise it is in a natural state. Because of its orientation, the prevailing southwest swell has to refract 90° to reach the coast but still remains high enough to maintain a series of long rip-dominated beaches.

Fig. 30.15 SC:03.02.01: Red Island to Point Hood. (Source: Google Earth)

There are 24 beaches along this section occupying 40 km (67%) of the coast, with 15 higher energy TBR-RBB occupying 36 km of the shore, while nine shorter sheltered R-LTT occupy 4.5 km (Fig. 30.16b).

There are six barrier systems extending along 35 km (58%) of the coast and four usually closed river systems (Dempster, Fitzgerald (Fig. 30.16a), St Mary's and Gardiner (Gordon Inlet) Table 30.1). While the beaches are predominately high energy, the prevailing southwest winds blow off alongshore resulting in relatively small barriers, which are restricted to the more southerly facing shores along the northern end of the longer beaches where they average 150–400 km in width. The dunes are driven by the sub-dominated southeasterly winds with some of the dunes climbing up the backing bedrock reaching 60 m in height. They have a relatively low volume (160 M m^3) and low per metre volume (4622 m^3 m^{-1}). However, 49% are presently unstable, with blowouts and parabolics moving inland and reworking earlier Holocene barriers.

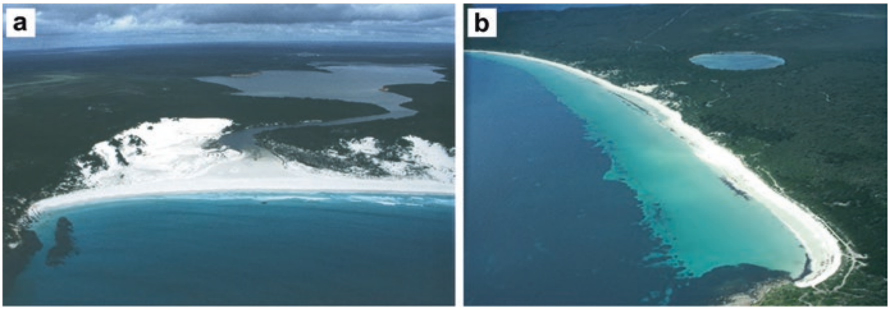


Fig. 30.16 (**a**) Closed mouth of the Fitzgerald Inlet (WA 286); (**b**) sheltered beach in lee of Point Hood (WA 301). (Photos: AD Short)

30.12.2 SC:WA03.01.02 Point Hood-Cape Knob

SC:WA03.01.02 consists of two south-facing embayments, 8 km wide Bremer Bay and 10 km wide Dillon Bay (Fig. 30.17). It extends from Point Hood in the east for 72 km around the bays and headlands to Cape Knob to the southwest. There is limited coastal development at the small Bremer Bay community on the banks of the usually closed Wellstead Estuary, into which flows the Bremer River. South of the town is the golf course and an abalone farm behind the Back Beach foredune (WA 307) and an attached breakwater and boat ramp at Fishery beach (WA 308) built in 1996 (Harrap 1999). An elevated housing development extends for 10 km south of Bremer Bay along the Point Henry headland, while farmland extends to within 1.5 km of Dillon Bay. There is no development in Dillon Bay, part of which is in the national park, apart from 4WD access tracks.

The 2 bays contain 20 beaches occupying 23 km (32%) of the shore, with most of the coast composed of steep rocky slopes rising to over 100 m. The beaches are composed of generally well-sorted fine sand, with ~15% carbonate in Bremer and Dillon beaches and ~5% in the remainder (Fig. 30.2). In amongst and in lee of the rocky headlands are 12 small R-LTT beaches occupying just 5 km of shore. In the central parts of the bays are longer curving more exposed TRR-RBB beaches occupying 18 km including the main 6 km long Bremer Beach (WA 305) and 7 km long Dillon Beach (WA 316) both of which curve to face southwest. As a result both are backed by substantial transgressive dune systems driven by southwest winds and extending up to 3.5 km inland. They have a relatively low total volume of 692 M m^3, owing to the dominance of rocky shore, but a reasonably high per metre volume of 32,704 m^3 m^{-1}. Both dune systems are active and presently 31% unstable. The two bays have acted as sediment sinks, with past overpassing from Foster Beach via Cape Knob, but otherwise no exchange between the bays or the adjoining compartments.

Fig. 30.17 SC:WA03.01.02: Bremer and Dillon bays. (Source: Google Earth)

30.12.3 SC:WA03.01.03 Cape Knob-Groper Bluff

SC:WA03.01.03 is a 30 km long reasonably exposed south-facing embayment which is completely undeveloped apart from 4WD access tracks and a fishing camp at Pallinup Beach (WA 326). The shoreline extends from 44 km between Cape Knob and the protruding Groper Bluff, in addition to two central headlands that break the bay into three beach systems, Foster, Reef and Wary, with the usually closed Beaufort Inlet at the western end of Wary Bay (Fig. 30.18). There are a total of ten beaches around the bay, consisting of three longer systems together with a series of small sheltered beaches in lee of Groper Bluff. The beaches total 31.5 km in length (72% of coast) and range from exposed rip-dominated TBR along the three main beaches switching to R as wave energy drops in lee of the bluff. Reef Beach, which has 30% carbonate, is named after the shore-parallel beachrock reef which occupies the surf zone generating prominent shoreline crenulations, with amplitudes of 200 m, owing to wave refraction and attenuation over the reefs. In addition, Reef Beach has four central reef-controlled rips spaced 1 km apart, while the adjoining Foster Beach has 20 beach rips spaced 320 m apart. The beachrock is no doubt associated with the carbonate-enriched Reef Beach (WA 323) sediments (30% carbonate) with carbonate decreasing westward to 10% at Pallinup Beach.

The bay contains three large overlapping barriers systems associated with each of the main beaches. All three are massive largely vegetated transgressive dune

Fig. 30.18 SC:WA03.01.0: Foster-Reef and Wary bays. (Source: Google Earth)

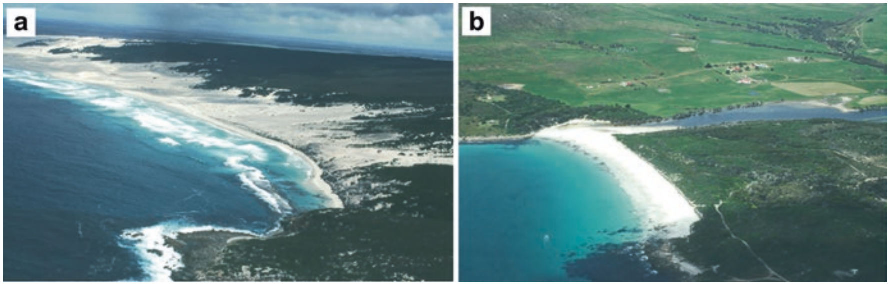


Fig. 30.19 (**a**) The eastern end of Reef Beach (WA 323) with a beachrock reef extending from the point and climbing transgressive dunes; (**b**) the sheltered Eyre River mouth at Cheyne Inlet and beach (WA 346) located in lee of Cape Richie. (Photos: AD Short)

systems extending between 6 and 9 km inland, with the eastern two (Foster and Reef) containing 2320 ha (15%) of active dunes. The Foster and Reef dunes climb to over 220 m over a basement of Pleistocene dune calcarenite and granite (Fig. 30.19a), while the Wary Bay dunes reach 80 m. The three systems have a total volume of 3100 M m^3 which represents a high per metre volume of 107,266 m^3 m^{-1}. The entire embayment appears to be a closed system, though there is evidence of dunes overpassing Cape Knob to Dillon Bay in the past and the present active dune reaching with 400 m of overpassing.

30.12.4 SC:WA03.01.04 Groper Bluff-Bald Island

SC:WA03.01.04 is an 84 km long southwest-trending section of coast dominated by Cheyne Bay in the north and the 22 km long Hassell Beach in the south (Fig. 30.20), with a total of 32 generally small beaches (~1 km length) occupying 52 km (62%)

Fig. 30.20 SC:WA03.01.04: Groper Bluff to Bald Island. (Source: Google Earth)

of the shore, the remainder the bedrock boundaries and central rocky section composed of resilient metasediments. There is little development on the coast other than access points, a few fishing shacks at Boat Harbour (WA 339) and the small community at Cheyne Beach (WA 362) (Fig. 30.21c). While most of this community is set well back from the shore, there are four older houses located on the beach foredune and exposed to erosion and now protected by a makeshift seawall. Development is now prohibited on the foreshore (City of Albany 2015). Much of the hinterland is agricultural land. The only significant drainage in the area is the Eyre River in lee of Cape Riche (Fig. 30.19b), which opens seasonally, the most easterly opening river on the south coast (Table 30.1). The beaches are composed of generally low carbonate (<10%) well-sorted fine sand, though at the southern end of Hassell Beach, it increases to 66% (1370 km, Fig. 30.2). While the beaches generally face east, with just the northern end of the longer beaches swinging round to face south, they receive sufficient wave energy for 19 beaches and 38 km of coast to be dominated by TBR, the remainder mainly sheltered R-LTT in lee of Cape Richie, together with some R+RF.

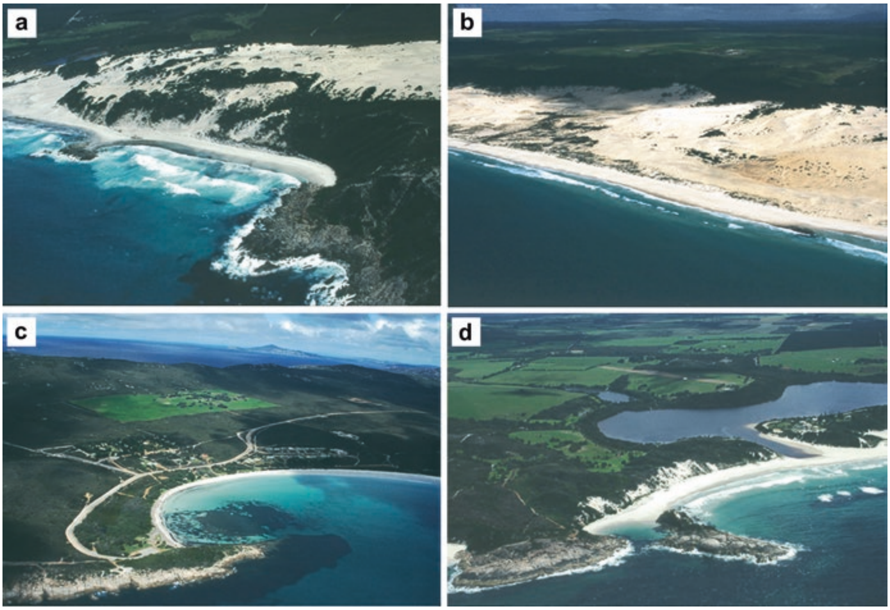


Fig. 30.21 (**a**) Climbing dunes at Cordinup Beach (WA 356); (**d**) active dunes along the northern end of Hassel Beach (WA 362); (**c**) the sheltered Cheyne Beach and its small community at the southern end of Hassel Beach (WA 362); and (**d**) the blocked mouth of Nanarup Inlet (WA 383-4). (Photos: AD Short)

There are 12 barrier systems occupying 50 km (60%) of the shore, which average between 150 and 450 m in width. They range from stable foredunes to generally vegetated Holocene and Pleistocene climbing and clifftop dunes. There are however some active dunes at Cordinup (Fig. 30.21a) and along Hassell Beach (Fig. 30.21b) where they extend up to 2 km. The barriers have a total volume of 487 M m^3, which represent relatively low 9778 M^3 m^{-1}, an order of magnitude less than the adjoining eastern SC. This is owing to the orientation of the coast away from the prevailing waves and winds.

30.12.5 SC:WA03.01.05 Bald Island-Cape Vancouver

SC:WA03.01.05 trends west from Bald Island-Mermaid Point to North Point and then turns and trends south to the protruding Cape Vancouver (Fig. 30.22). Most of the 41 km of coast is located within the Bald Island, Waychinicup, Mount Many Peaks and Two Peoples Bay nature reserves, with no development on the coast apart from several access points. It is also a predominately rocky granite coast, with 15 small beaches occupying just 10 km (25%) of the coast. The beaches range from TBR along the longer south-facing section of Mermaid Point, southeast-facing

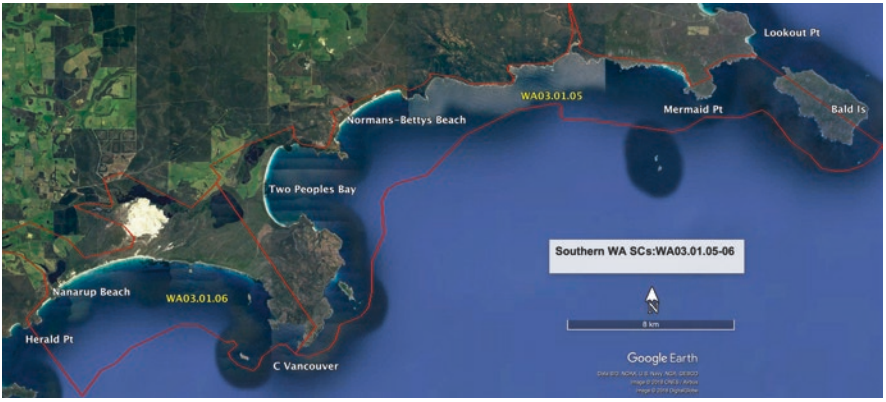


Fig. 30.22 SCs:WA03.01.05-06: Bald Island top Herald Point. (Source: Google Earth)

Norman Beach and the northern half of Two Peoples Bay to shorter LTT-R in small rocky embayments and in lee of North Point and Cape Vancouver. The only drainage on this section of coast is the bedrock-controlled Waychinicup River, which is one of the few permanently open rivers on the coast (Table 30.1), owing to its exit through a narrow drowned bedrock valley.

There are just two barrier systems on this coast at Normans Beach and Two Peoples Bay both containing past moderate dune transgression up to 1 km inland, but now largely stable, the latter blocking the Moates-Gardner lakes from reaching the sea. They have a total volume of 27.5 M m^3 and a per metre volume of just 3427 $m^3\ m^{-1}$. The absence of barriers is a product of the dominance of steep rocky shore on the south-facing shores and southeast to east orientation of the main beaches.

30.12.6 SC:WA03.01.06 Cape Vancouver-Herald Point

SA:WA03.01.06 is a relatively small 19 km long south-facing embayment located between Cape Vancouver and Herald Point (Fig. 30.22) that is partly sheltered by Michaelmas and Breaksea islands. The seasonally open Taylor Inlet is located at the eastern end of the main Nanarup Beach (Fig. 30.21d). There is no development on the coast other than access to Nanarup Beach, with the eastern portion located in Two Peoples Bay Nature Reserve and the western section in Oyster Harbour Gull Rock Nature Reserve. There are nine beaches composed of a mix of fine to medium sand with carbonate ranging from 0.2% to 20%. Nanarup Beach (WA 382) is the longest (5 km) and most exposed with rip-dominated TBR-RBB, with the cluster of beaches to the west sheltered by Herald Point and the islands and either R or LTT.

There is just one Holocene barrier system in lee of Nanarup Beach consisting of stable longwalled parabolic dunes trending northeast, including an inland 300 ha area of bare sand arranged as transverse dunes. The dunes extend up to 4 km inland and form the southern boundary of Moates and Gardner lakes. The barrier has a volume of 50 M m^3 (10,000 m^3 m^{-1}). To the east is a well-vegetated 3.5 km wide Pleistocene dune field that overpasses in lee of Cape Vancouver and reached Two Peoples Bay, though there is no overpassing at present. The bay has acted as a closed Holocene sand trap, with no evidence of leakage to adjoining compartments.

30.12.7 PC Overview

This is a 320 m long generally southeast-facing moderate energy section of coast dominated by a series of major headland that has divided the coast into numerous TCs with little evidence of sediment exchange apart from some dune overpassing. The coast is dominated by national parks and nature reserves with coastal development limited to the Hopetoun, Bremer Bay and Cheyne Beach. The only property at immediate risk is at Cheyne Beach. Changing climate will lead to areas of beach recession and possible reactivation of the numerous largely stable dune fields and the inlet flood tide deltas when open.

30.13 PC/SC:WA03.02.01 King George Sound

King George Sound (Fig. 30.23) is the largest embayment on the south coast, and the safe anchorage it provides is the reason for the siting of the south coast's largest city and port – Albany. It was established in 1826 and is the oldest European settlement in WA. The 8 km wide sound is a reasonably sheltered environment, facing due east, with the narrow Flinders Peninsula stopping southerly swell together with protection from the Michaelmas and Breaksea entrance islands. The sound, excluding Princess Royal Harbour, has 31 km of shoreline of which 17 km consist of 24 generally small sheltered beaches (Table 30.9), the remainder generally steeply sloping granite. The most exposed beach is the northern Gull Rocks Beach (WA 391) which has a series of beach and beachrock reef-induced rips, while the remainder are R to LTT (Fig. 30.24a, b), with one B+SF on the northern estuarine side of Emu Point, which has been dredged for the small boat harbour. The main Middleton Beach which has a H_s = 0.65 m (T = 12 s) is LTT, switching to TBR during higher wave conditions. A surfing reef has been proposed for the beach to the north of the surf club (Royal Haskoning DHV 2015; City of Albany 2016).

The entire sound has acted as a sediment trap and includes one small transgressive and four regressive barriers. The transgressive dune is located in lee of the more exposed Gull Rock Beach and consists of northeast-oriented vegetated dunes extending up to 1 km inland, together with one active blowout. The neighbouring Ledge Point barrier has enclosed and blocked Gull Rock Lake from the sound, while the 4.5 km long Middleton Beach has 12 regressive foredune ridges, and the regressive

Fig. 30.23 PC/SC:WA03.02.01: King George Sound. (Source: Google Earth)

Table 30.9 PC:WA03.02 beach types and states

BS	BS	No.	%	Total (km)	%	Mean (km)	σ (km)
4	TBR	1	4.2	1.8	10.3	1.8	–
5	LTT	2	8.3	4.6	26.4	2.4	–
6	R	19	79.2	10.5	60.3	0.6	0.7
12	B+TSF	1	4.2	0.4	2.3	0.4	–
14	R+RF	1	4.2	0.1	0.6	0.1	–
		24	100	17.4	100	0.7	–

Barker and Frenchman Bay-Goode Beach (Fig. 30.24a) barriers tie Possession Point and Quarantine Hill, respectively, to the mainland. The barriers occupy 12 km (39%) of the shore and have a volume of just 63 M m^3 and a low per metre volume of 5172 m^3 m^{-1}, typical of a low to moderate energy open coast environment.

The sound beach sand is generally well-sorted fine sand with carbonate ranging from 0.2% to 18%, the variability indicative of the lack of interchange between the TCs. There is evidence of northerly transport along the Middleton barrier which widens from 0.4 km in the south to 1 km in the north at Emu Point and in doing so partially blocks the entrance to the permanently open Oyster Bay. The bay has a

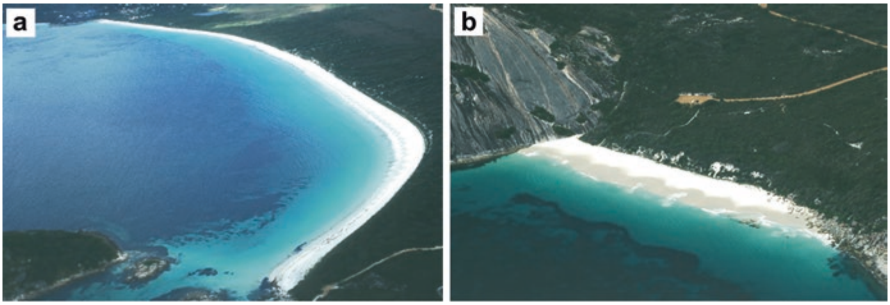


Fig. 30.24 (**a**) Goode Beach (WA 404) is sheltered by the long Flinders Peninsula and its easterly orientation; (**b**) the small reflective beach at the base of the steep sloping granite of 80 m high Isthmus Hill (WA 410). (Photos: AD Short)

dynamic and deep of 160 m wide entrance and well-developed flood and ebb tide delta, the latter of which has generated oscillation in the sandy western shore, resulting in this being classified a coastal hotspot (DOT 2016). This has led to the construction of sea walls and attached breakwaters along an 800 m long section of the shore and the development of an 'adaption and protection strategy' for the point, which will include an assessment of the existing structures, trial sand bag groynes, beach nourishment and monitoring of the shoreline and coastal processes (City of Albany 2017) as well as the implementation of dune retention and foreshore setbacks (City of Albany 2010).

30.13.1 PC Overview

King George Sound and Albany city have a generally high relief foreshore and hinterland apart from the beach systems, and some of the shores of Princess Royal and Oyster harbours. Of the beach systems, only Emu Point is presently at risk owing to recreational development on a dynamic entrance, a risk that is being managed and monitored. The remaining beaches are undeveloped and in a relatively natural state. The most extensively developed lowlands are around the western and southern shore of Princess Royal Harbour, and these are the most at risk to rising sea-level-induced inundation.

30.14 PC:WA04.01 Bald Head to Point Nuyts

PC:WA04.01 trends essentially due west for 169 km from Bald Head, the southern head of King George Sound, to Point Nuyts, where the coast turns and trends northwest (Fig. 30.1). Most of the coast is dominated by the massive vegetated transgressive dunes, with the only development along the coast the wind farm on the crest of the Sandpatch dunes, the small community at Peaceful Bay and the backing agricultural land. The town of Denmark is located on the shores of Wilson Inlet and Walpole on Nornalup Inlet. Most of the coast is located in the Torndirrup, West Cape Howe, William and Walpole Nornalup national parks and the Quarram Nature Reserve (122 km, 73%), together with Walpole and Nornalup Marine Park occupying the entire Nornalup Inlet. Much of the coast is exposed to the full force of the southwest waves and winds, while tides remain micro (1 m). There are five main drainage systems along this section, each flowing into inlets that owing to the higher winter rainfall (900–1000 mm) are seasonally open (Torbay, Wilson, Parry and Irwin), with the western Nornalup-Walpole permanently open, one of two such inlets on the south coast (Table 30.1).

The coast consists of a series of curving south-facing embayments each aligned to the southwest waves and winds and each backed by massive Pleistocene dune calcarenite overlain by Holocene longwalled parabolics, with beachrock reefs paralleling the shore. The calcarenite and beachrock are due in large part to the increase in carbonate content from 15% in the east to 30–40% in the west. The bedrock geology is dominated by steep granite slopes which form all the major headland and points. There are a total of 111 predominately exposed high energy beaches occupying 81 km (48%) of the coast (Table 30.10), the remainder a mix of scarped Pleistocene dune calcarenite, beachrock reefs and the granite headlands. The PC contains five SCs which are discussed below.

30.14.1 SC:WA04.01.01 Bald Head-Torbay Head

SC:WA04.01.01 commences at Bald Head and extends for 50 km west to Torbay Head, at 35.13°S, the southernmost tip of Western Australia (Fig. 30.25). The generally south-facing coast consists of two granite rocky sections between Bald Head and Family Rocks in the east (Fig. 30.26a) and from Migo Island to Torbay Head in the west, linked by the curving Sandpatch Beach (WA 412) and southeast-facing Port Hughes to Port Harding beaches (423-8). In all 20 beaches occupy 21 km (42%) of the shore the remainder both granite and along Sandpatch dune calcarenite

Table 30.10 PC:WA04.01 beach types and states

BS	BS	No.	%	Total (km)	%	Mean (km)	σ (km)
3	RBB	13	11.7	19.3	23.8	1.5	2.6
4	TBR	42	37.8	38.7	47.7	0.9	1.6
5	LTT	27	24.3	16.7	20.6	0.6	1.1
6	R	25	22.5	6.2	7.6	0.3	0.3
11	B+SF	2	1.8	0.1	0.1	0.05	–
14	R+RF	2	1.8	0.2	0.3	0.1	–
		111	100	81.2	100	0.7	–

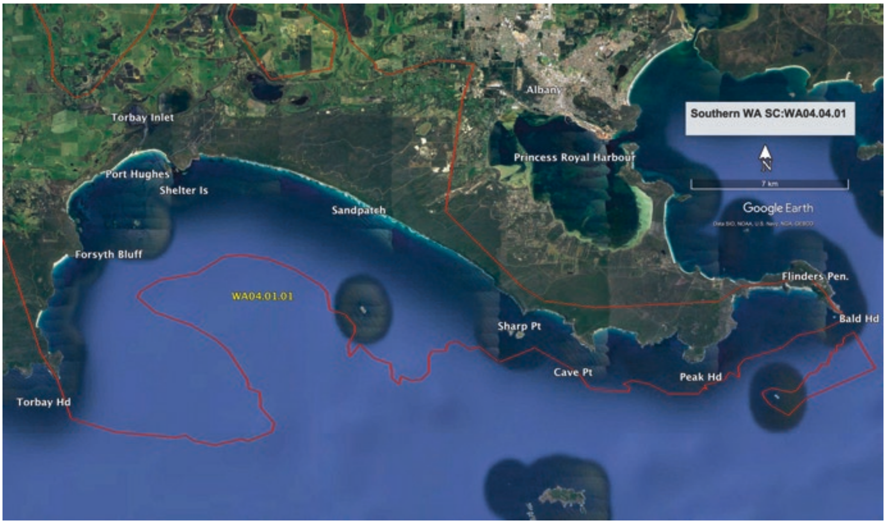


Fig. 30.25 PC/SC:WA03.02.01: King George Sound. (Source: Google Earth)

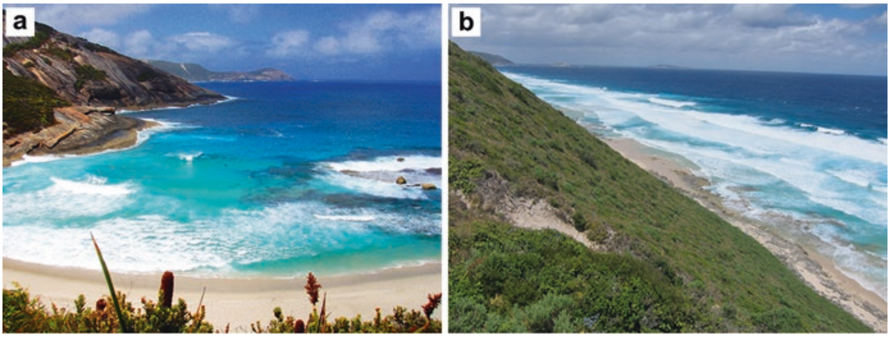


Fig. 30.26 (**a**) The small embayed Salmon Pools Beach (WA 414) fringed by steep granite slopes granite and boulders; (**b**) view from the 100 m high Sandpatch barrier to its high energy surf zone and beachrock strewn beach (WA 421). (Photos: AD Short)

and beachrock. The beach sand is generally well-sorted fine sand ranging in carbonate from 3% to 38% (mean = 15%, σ = 12%), the latter suggesting a range of TCs within this SC. The beaches range from very exposed TBR particularly along Sandpatch (Fig. 30.26b) and along the Port Hughes-Port Harding coast (WA 422-435), while the remaining beaches are sheltered either by headland and reefs and in lee of Torbay Head by their easterly orientation.

The coast is backed by five barrier systems that occupy 36 km (72%) of the coast. They are dominated by the 20 km long Sandpatch barrier consisting of massive climbing Holocene dunes onlapping several episodes of Pleistocene dune calcarenite. At Sandpatch they rise steeply to over 180 m and extend up to 6 km inland reaching Princess Royal Harbour, where they form a series of protruding sandy points and sand flats, with one dune-supplied flat extending 1 km into the harbour. Similar smaller barrier systems extend east to Bald Head where the dunes have climbed to the crest of the 200 m high granite isthmus. The barriers have a total volume of 1442 M m^3 and a large per metre volume of 40,055 m^3 m^{-1}, 80% located in the Sandpatch barrier. The Holocene barriers were likely initiated during the PMT, stabilising soon after the stillstand as sand supplied diminished. They are now all stable and well vegetated. The entire Sandpatch embayment has acted as a major sink for shelf sand, most deposited as another layer of massive dune sand. In the Port Hughes area, northerly sand transport has partially infilled and blocked Torbay Inlet, which now only opens following winter rains.

30.14.2 SC:WA04.01.02 Torbay Head-Wilson Head

SC:04.01.02 trends northwest for 39 km between Torbay and Wilson heads and consists of two exposed southwest-facing embayments, separated by the central Knapp Head, with the seasonally open Wilson Inlet located in lee of Wilson Head (Fig. 30.27). The only development on the coast is Denmark's Ocean Beach Surf

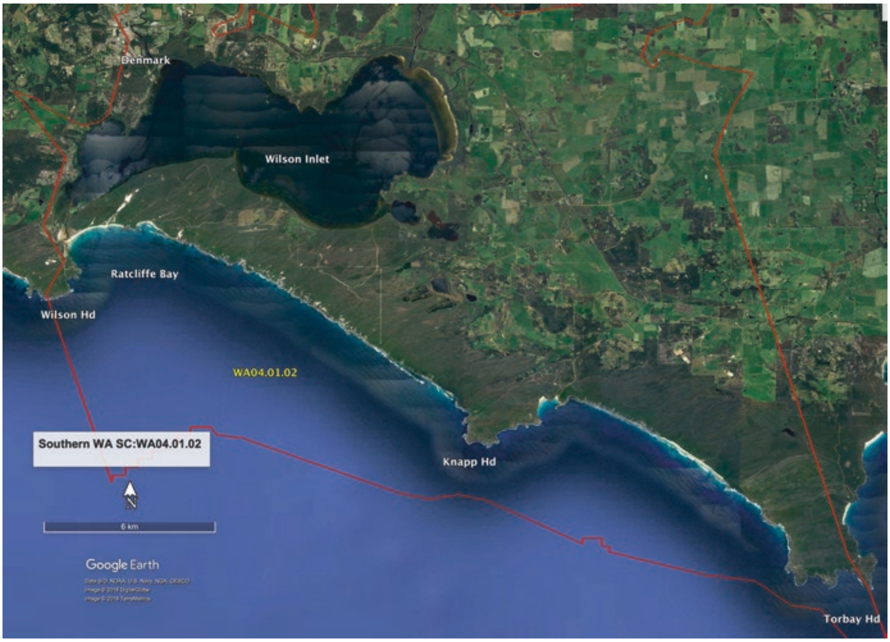


Fig. 30.27 SC:WA04.01.02: Torbay Head to Wilson Head. (Source: Google Earth)

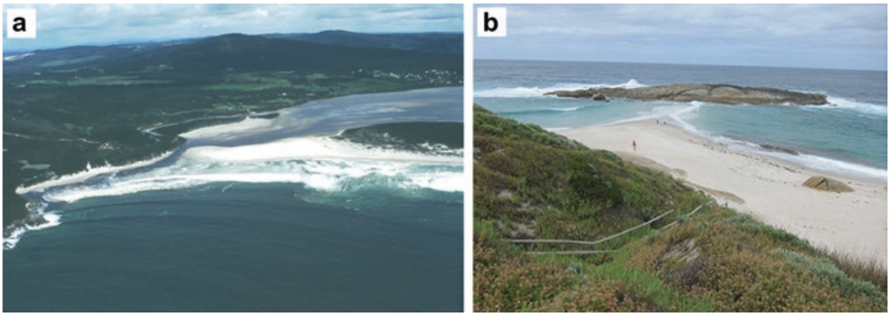


Fig. 30.28 (**a**) The open mouth of Wilson Inlet at Ocean Beach (WA 443-4); (**b**) a small tombolo in lee of a low granite reef at Lights Beach (WA 452). (Photos: AD Short)

Club, also located in lee of Wilson Head (Fig. 30.28a). Wilson Inlet has an area of 48 km^2 and average depth of just 2 m. The inlet opens during the wetter winter season, and when open the inlet often shifts to the east, driven by the southwest waves and tidal currents. The nature dynamics and ecology of the inlet are described by Brearley (2005).

This is a depleted coast with 29 km of continuous barrier fronted by just 7.6 km of beaches, the remainder of the shore exposed beachrock reef and granite headlands. The beaches which average just 0.6 km are either separated either by the beachrock reefs or cliffed dune calcarenite along the two main beaches (WA 433 and 437-443) or located between granite headlands. The exposed beaches are RBB-TBR and include attached beachrock reefs which generate numerous topographic rips, while the Lowland beaches (WA 435-6) in lee of Knapp Head and Ocean Beach (WA 444) (Fig. 30.28a) in lee of Wilson Head are LTT-TBR. The beaches are composed of well-sorted fine sand with carbonate averaging 39% (σ = 17%), the higher carbonate contributing to the formation of the dune calcarenite and beachrock.

The entire coast between Wilson Head and Wilson Inlet is blanketed with Pleistocene dune calcarenite covered by well-vegetated Holocene longwalled parabolic dunes. The dunes extend on average 3 km inland, reaching and blocking Wilson Inlet, and reach heights of up to 240 m. There remains just one active parabolic near Wilson Inlet. The two bays have acted as a single sediment sink, with most sand deposited in the dunes, together with loses into Wilson Inlet. There does not appear to be any headland bypassing; however there has been past headland overpassing over Torbay Head to Shelly Beach (WA 430) and over Knapp Head to the Lowland beaches. The barrier has a total volume of 1000 M m^3 and per metre volume of 34,483 m^3 m^{-1}, both large and very similar to the adjoining eastern SC.

30.14.3 SC:WA04.01.03 Wilson Head-Cape Faujas

SC:WA04.01.03 is a relatively small 21 km long SC consisting of two south-facing embayments located between Wilson Head and Cape Faujas with the extensive Edward Point in the centre and its cluster of granite reefs and boulders (Fig. 30.29). The seasonally open Parry Inlet (Fig. 30.30a) is located in lee of the cape, and the only development on the coast is a few shacks on the slopes behind Parry Beach (WA 466). The bays contain 27 generally small beaches (mean length = 0.5 km) totalling 14 km (67%), including 5.7 km long Mazzoletti (WA 464). The beaches range from very exposed TBR-RBB to beachrock and granite boulder sheltered R-LTT (Fig. 30.28b) and two B+SF (WA 460-1) located in deep narrow granite embayments. The boulder-sheltered beaches include the famous Smooth Pool, Green Pool and Elephant Rocks, which attract a steady stream of swimmers and visitors. Like the adjoining SCs, the beaches are remnants of larger more continuous systems that have been eroded down to smaller stable pockets of sand. The beaches are composed of well-sorted, fine to medium sand with carbonate averaging 33% ($\sigma = 26\%$) and ranging from 5% to 72% (Fig. 30.2).

Fig. 30.29 SCs:WA04.01.03-04: Wilson Head to Point Irwin. (Source: Google Earth)

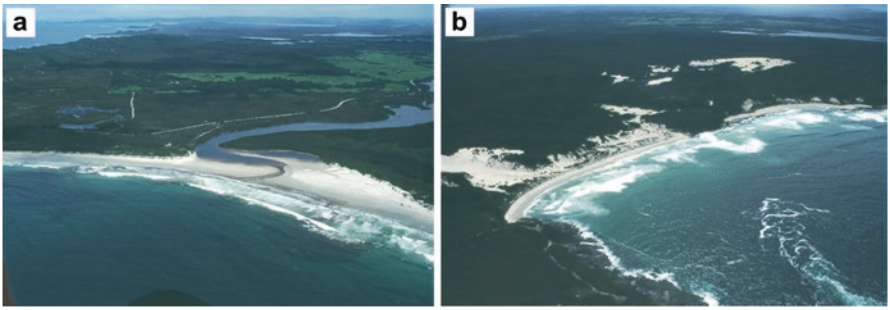


Fig. 30.30 (**a**) Small open mouth of the Parry Inlet (WA 464-5); (**b**) high energy Owingup Beach and its backing stable and active dunes (WA 486). (Photos: AD Short)

There is a continuous barrier system between the Wilson Head and Parry Inlet, consisting of massive Holocene parabolic dunes, deposited over Pleistocene dune calcarenite, the dunes extending up to 3 km inland and reaching 100 m on Wilson Head and Tower Hill, and in the past overpassing Wilson Head to reach Ocean Beach. All the dunes are now well vegetated and stable, apart from a patch on Tower Hill. The dunes have a volume of 420 M m^3 and per metre volume of 30,000 m^3 m^{-1}, comparable to the adjoining exposed SCs. The relatively high carbonate has contributed to the lithification of the Pleistocene dunes and formation of beachrock reefs. Apart for the past headland overpassing from the west (Cape Faujas) and to the east (Wilson Head), this appears to be a closed SC.

30.14.4 SC:WA04.01.04 Cape Faujas-Point Irwin

SC:WA04.01.04 continues west of Cape Faujas for 28 km to Point Irwin, with three open south-facing embayments in between and Irwin Inlet located towards the western end. The only development on the coast is the small community at Peaceful Bay (WA 492) (Figs. 30.29 and 30.31a) with the rest of the coast located in the national parks. The beach sand along this SC remains fine and well-sorted with carbonate increasing to 43% (σ = 8%). There are 25 small beaches totalling 17.6 km in length with a mean length of 0.7 km, the longest 4.8 km long Quarram beach (WA 490). They are predominately very exposed TBR-RBB with both beach and rock-/reef-induced rips (Fig. 30.30b), together with a few sheltered R-LTT in lee of reefs in the central embayment and in the sheltered east-facing Peaceful Bay Beach (WA 492-6).

The entire coast between Cape Faujas and Peaceful Bay is backed by large barrier systems. To the east of Irwin Inlet mouth, the barriers consist of Pleistocene dune calcarenite and beachrock reefs overlain by Holocene longwalled parabolic dunes extending up to 5 km inland at Quarram beach, with a transgressive and then

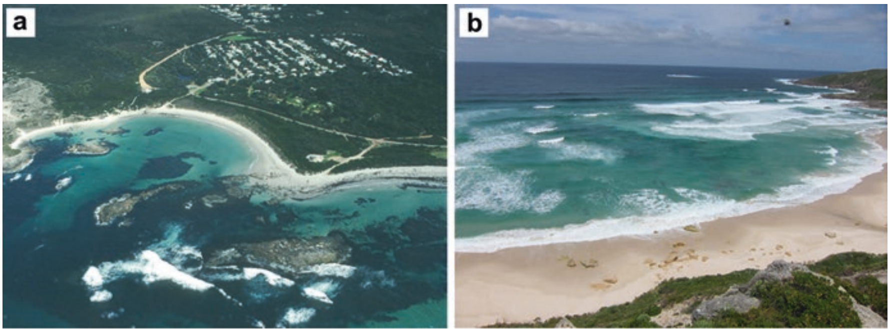


Fig. 30.31 (**a**) The sheltered Peaceful Bay (WA 491-2) and its small community; (**b**) large beach rip at Conspicuous Beach (WA 512). (Photos: AD Short)

regressive barrier to the west of Irwin Inlet mouth. In all the barriers occupy 20.5 km (73%) of the coast and have a volume of 720 M m^3 (35,122 m^3 m^{-1}) both comparable to the adjoining SCs. Like the adjoining compartment, this SC has acted as a sediment sink for the shelf sand, the sand deposited in the dune systems and into Irwin Inlet, with past headland overpassing at both ends.

30.14.5 SC:WA04.01.05 Point Irwin-Point Nuyts

SA:WA04.01.05 continues west with similar sediment and morphological characteristics of the SCs to the east in that it contains a series of small south-facing embayed backed by massive transgressive dunes all bordered by prominent granite headlands and reefs. The SC commences at Point Irwin and trends west for 31 km to Point Nuyts (Fig. 30.32) and lies entirely within Walpole-Nornalup National Park, with no coastal development. It has one longer central Bellanger Beach (WA 516) embayment, with several smaller beaches to the east and two to the west, together with rocky shore. The seasonally open Nornalup-Walpole Inlet enters the sea at the western end of the 10 km long Bellanger Beach. The nature, history, chemistry and ecology of the inlet are described by Brearley (2005). There are a total of 26 beaches occupying 20 km (65%) of the shore. The beaches are predominately exposed high energy TBR-RBB (Fig. 30.21b), with just a few small R and LTT tucked in small sheltered embayments amongst the granite.

The beaches are composed of well to moderately well-sorted, fine to medium sand with carbonate decreasing to a mean of 18% (σ = 6%) (Fig. 30.2). To the east of the inlet, the beaches are backed by two continuous barriers that extend for 21 km. They are composed of Pleistocene dune calcarenite overlain with now well-vegetated Holocene longwalled parabolic dunes extending up to 4 km inland and climbing to 70 m, with three minor areas of dune instability. To the west of the inlet

Fig. 30.32 SC:WA04.01.05: Point Irwin to Point Nuyts. (Source: Google Earth)

is a predominately rock shore which contains the 1.7 km long exposed southwest-facing Circus Beach (WA 520). In lee of this exposed beach are now vegetated climbing transgressive dunes which reached an elevation of 100 m and have previously overpassed Rocky Head to reach the mouth of the inlet. The two barriers have a total volume of 750 M m^3 deposited at a per metre volume of 35,714 m^3 m^{-1}. This is another closed sediment sink, apart from the past headland bypassing internally at Circus Beach and at either boundary.

30.14.6 PC Overview

This is a very exposed PC with predominately high energy TBR-RBB beaches backed by massive Pleistocene dune calcarenite and Holocene longwalled parabolics, all now largely stable and well vegetated. The fives SCs have remarkable uniform per metre volume of between 30,000 and 40,000 m^3 m^{-1}, with a mean rate of 35,950 m^3 m^{-1} (Table 30.4). Because of the rugged, energetic and dune-covered natural of the coast most of it is located in national parks and reserves with only one small community at the sheltered Peaceful Bay. As a result, there is no property or infrastructure at risk from erosion. There are however five inlets or barrier estuaries which are prone to flooding and inundation and which will be impacted by rising sea level as tidal prims and tide elevations increase within each. However, the ongoing decrease in south coast rainfall (Bureau of Meteorology) will also impact the inlets as they become less likely to open during the winter months. Either way the greatest impact of sea-level rise will be seen in the inlets, the lagoons and their low gradient shorelines, while the coast will be left to fend for itself. Any reactivation of the dune systems could however adversely impact on the backing agricultural land.

30.15 PC:WA04.02 Point Nuyts to Point D'Entrecasteaux

At Point Nuyts the coast turns and trends west-northwest for 68 km to Point D'Entrecasteaux, as a relatively straight exposed high energy southwest-facing shore (Fig. 30.1). The entire coast is backed by massive dune transgression apart from the central seasonally closed Broke Inlet. The only development on the coast is the small but growing Windy Harbour community and 4WD access tracks. Most of the coast is located in the D'Entrecasteaux National Park which extends from the border with Walpole-Nornalup National Park to Point D'Entrecasteaux and beyond; as a consequence all of the coast apart from Windy Harbour is located in national parks. The entire coast is well exposed to the prevailing southwest swell and winds, with tides micro (~1 m). Rainfall increases slightly to 1070 mm at Windy Harbour, with a pronounced winter maximum. There are 47 beaches along this coast occupying 45 km (66%); the beaches are mix of higher energy exposed TBR-RBB (65% by length) and sheltered R-LTT (32%) (Table 30.11). The PC contains two SCs which are discussed below.

Table 30.11 PC:WA04.02 beach types and states

BS	BS	No.	%	Total (km)	%	Mean (km)	σ (km)
3	RBB	13	27.7	8.7	19.2	0.7	0.6
4	TBR	11	23.4	20.9	46.1	1.9	4.5
5	LTT	14	29.8	13.9	30.7	1.0	1.4
6	R	3	6.4	0.7	1.6	0.3	–
14	R+RF	6	12.8	1.1	2.4	0.2	0.1
		47	100	45.3	100	1.0	–

Fig. 30.33 SC:WA04.02.01 Point Nuyts to West Cliff Point. (Source: Google Earth)

30.15.1 SC:WA04.02.01 Point Nuyts-West Cliff Point

SC:WA04.02.01 is a relatively straight section of coast trending northwest from Point Nuyts to West Cliff Point, with an offset at Cliffy Head and the large Broke Inlet (48 km^2) reaching the sea via a 3 km long narrow sandy channel though the dunes in lee of the Broke Reefs (Fig. 30.33). The entire coast is located in Walpole-Nornalup and D'Entrecasteaux national parks, with no development, other than access roads and tracks and camping areas. This is a very exposed 40 km long section of coast dominated by massive Pleistocene dune calcarenite which is scarped along much of the coast (Fig. 30.34a), with a capping of massive Holocene long-walled parabolic dunes and a few remaining high energy sandy beaches which are composed of well-sorted fine to medium sand with ~20% carbonate. There are 47

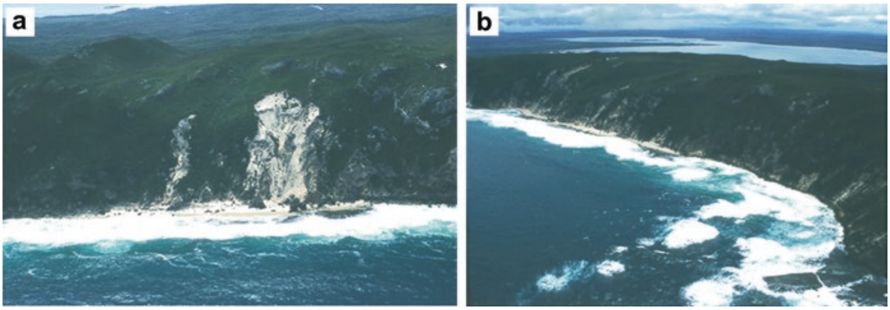


Fig. 30.34 (**a**) Scarped 150 m high calcarenite cliffs west of Cliffy Head (WA 541); (**b**) part of the 150 m high calcarenite barrier that blocks Broke Inlet (rear) from the sea (WA 543). (Photos: AD Short)

generally short beaches along this section occupying 19 km (48%); they average just 0.46 km in length, and none are longer than 2 km, with numerous calcarenite and beachrock rocks and reefs separating many of the beaches (Fig. 30.34b). They are predominately high energy TBR-RBB (14 km), including Hush Hush and Mandalay beaches (WA 524 and 533) together with 4 km of sheltered R-LTT and seven small beaches fronted by rock flats.

There are four near-continuous barrier systems along the coast occupying 32 km (78%) of the coast. They all consists of massive climbing Holocene long-walled parabolics extending up to 7 km inland and overlying layers of Pleistocene dune calcarenite, rising to heights of 200 m east of Broke Inlet (Fig. 30.34b) and up to 100 m west of the inlet. Much of the calcarenite is cliffed and fronted by rocks and reefs, in addition to sections of beachrock reefs. The dunes alignment shifts to a more westerly orientation and are aligned to west-southwest. The dunes have a volume of 3460 M m^3 and a high per metre volume of 73,617 m^3 m^{-1}, reflecting the exposed high energy nature of this compartment. The dunes are all stable and well vegetated apart from one parabolic on the north side of Broke Inlet. There is evidence of past overpassing of Point Nuyts and Cliffy Head, both of which are now well vegetated. Brearley (2005) also reports that Broke Inlet was open to the sea until about 4 ka when it began to become seasonally closed. This could have been due to the encroachment of the dunes into the inlet channel at this time.

30.15.2 SC:WA04.02.02 West Cliff Point-Point D'Entrecasteaux

SC:WA04.02.02 continues northwest from West Cliff Point for 28 km gradually curving round to trend west at Windy Harbour terminating at Point D'Entrecasteaux (Fig 30.35). All of the coast is contained in the D'Entrecasteaux National Park apart

Fig. 30.35 SC:WA04.02.02 West Cliff Point to Point D'Entrecasteaux. (Source: Google Earth)

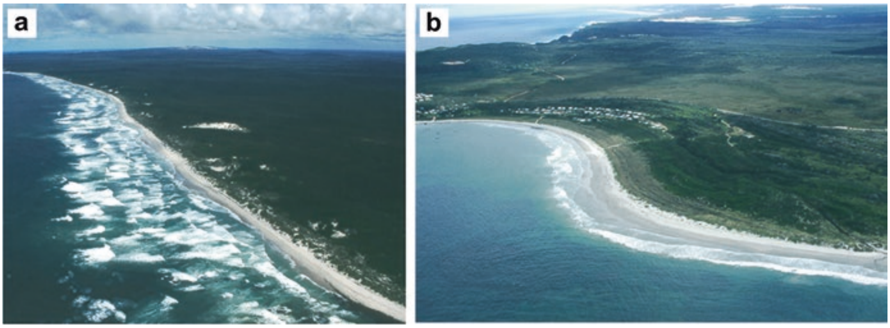


Fig. 30.36 (**a**) The high energy Coodamurrup Beach extending west of Cliff Point (WA 564); (**b**) the sheltered Windy Harbour and its regressive foredune ridges and LTT beach (WA568). (Photos: AD Short)

from the small Windy Harbour community (Fig. 30.36b). This is an exposed south-facing coast which is however afforded shelter towards its western end by a series of nearshore reefs and Sandy and Flat islands. The coast consists of six near-continuous beaches which occupy 26.5 km (95%) of the shore. The 16 km long Coodamurrup Beach (WA 564) is exposed and rip-dominated TBR (Fig. 30.36a), including some reef-generated rips, while west of the small seasonally open Gardner River mouth, the beaches become reef-sheltered LTT as waves drop to <1 m and the sand is fine sand.

There are three near-continuous barrier systems occupying 26 km (92%) of the coast. To the east they are continuation of the massive longwalled parabolics overlying the Pleistocene dune calacenenite. The dunes decrease in size to the west, as wave height decreases, from 6 km in width and height of 50 m at West Cliff Point to 500 m wide and 20 m high at Gardner River. To the west of Gardner River, the barrier consists of a narrow inner transgressive unit, fronted by a series of 20 m high regressive foredunes averaging 200–300 m in width and widening to 500 m at

Windy Harbour, with the community built on the dune ridges (Fig. 30.36b). While the houses are set back from the shore, part is eroding resulting in it being classified a coastal hotspot (DOT 2016).The shoreline west of the river mouth also becomes increasingly crenulated owing to wave refraction over the nearshore reefs and islands. The barriers have a low volume of 122 M m^3 (12,398 m^3 m^{-1}) reflecting both the short length of the SC and the decreasing wave energy and barrier size towards Point D'Entrecasteaux. There is no evidence of longshore transport or transport around the SC boundaries, though there appears to have been limited past overpassing of Point D'Entrecasteaux as far as Windy Harbour.

30.15.3 PC Overview

This is a very exposed high energy section of coast which throughout the Quaternary has been exposed at each highstand to the addition of successive layers of dune transgression now accumulated as dune calcarenite up to 200 m high. The Holocene PMT and stillstand has added another layer of carbonate-enriched sand (~20%) which has assisted the lithification of the dunes and beaches. Most of this sand would have been deposited during and immediately following the PMT, as many of the beaches that supplied the dunes and their ramp have been eroded and the dunes are 98% stable (Table 30.4). The entire PC has a barrier volume of 3580 M m^3 with a relatively high per metre volume of 61,960 m^3 m^{-1}, a reflection of the high waves and wind energy combined with the shelf supply of quartz and carbonate sand. Most of this coast is reserved in national parks with just the small Windy Harbour the only settlement, which has a substantial setback behind the foredune, with the foredune recognised as needing to be maintained and protected (Shire of Manjimup 2007).

Rising sea level will impact the large Broke lagoon and increase inundation of its low-lying shoreline, some of which is developed. Windy Harbour while sited relatively high is backed by backbarrier wetlands which will become increasing prone to inundation and flooding.

30.16 PC:WA04.02 Point D'Entrecasteaux to Cape Leeuwin

This PC is the most exposed and highest energy in the south coast region. It extends for 114 km between Point D'Entrecasteaux and Cape Leeuwin (Fig. 30.1), the cape the southwestern tip of the Australian continent, and also the western boundary of the southern WA coast region. Most of the coast faces southwest directly into the southwest winds and waves, curving round in the northern Flinders Bay to face south and finally east. Most of the southern half is located in D'Entrecasteaux National Park, while in the north is the permanently open mouth of the River at Hardy Inlet, part of which lies adjacent to Scott National Park, with the town of

Table 30.12 PC:WA04.03 beach types and states

BS	BS	No.	%	Total (km)	%	Mean (km)	σ (km)
3	RBB	25	52.1	53.1	55.5	2.1	4.1
4	TBR	7	14.6	37	38.7	5.3	10
5	LTT	6	12.5	1.6	1.7	0.3	0.3
6	R	7	14.6	3.2	3.3	0.5	0.3
14	R+RF	3	6.3	0.8	0.8	0.3	–
		48	100	95.7	100	2.0	–

Augusta on its western shore and the protruding Cape Leeuwin which is located in Leeuwin-Naturaliste National Park.

The high wave energy is indicted by the 48 near-continuous beach systems which occupy 96 km (84%) of the coast and are dominated by the high energy TBR-RBB which occupy 79% of the coast (Table 30.12). Likewise, the barriers are extensive occupying 103 km (90%) of the coast with a total volume of 9955 M m^3 and the highest per metre volume on the south coast of 96,380 m^3 m^{-1} (Table 30.4). The PC contains two SCs which are described below.

30.16.1 SC:WA04.03.01 Point D'Entrecasteaux-Black Point

SC:WA04.03.01 is a relatively straight 66 km long southwest-facing section of coast located between Point D'Entrecasteaux and Black Head and dominated by the 36 km long Malimup-Warren-Yeaarup beach (WA 581-3), the beach crossed in the centre by the seasonally open Warren River mouth (Fig. 30.37). The river has to cut through 600 m of low sand dunes to reach the coast where its small river mouth can be deflected up to 2 km along the beach (Brearley 2005). Twenty kilometres further north is the seasonally open mouth of the Donnelly River (Fig. 30.38a). Most of this coast is located within the D'Entrecasteaux National Park, with the remainder marked for inclusion. There is no development apart from 4WD access tracks and camping on Black Point and some river shacks near the mouth of the Donnelly River, whose nature and entrance are described by Brearley (2005). The coast contains 29 beaches occupying 52 km (79%) of the shore, with all the beaches exposed high energy TBR-RBB (Fig. 30.38b), together with a few around Black Head fronted by rock flats (Table 30.12). This is the longest high energy section of coast on the southern WA coast, with the rip currents on the long central beach spaced every 500 m along the 36 km of beach, the largest rips and rip spacing in Australia (Short and Brander 1999). Besides the long central beach, the shorter beaches are located at the base of the calcarenite cliffs that extends for 10 km northwest from Point D'Entrecasteaux, including Salmon and Doggerup beaches (WA 570 and 575), and between the Donnelly River mouth and Black Point, where bluffs and then 80 m high cliffs of dune calcarenite separate the beaches.

Fig. 30.37 PC/SCs: WA04.03.01-02: Point D'Entrecasteaux to Cape Leewuin. (Source: Google Earth)

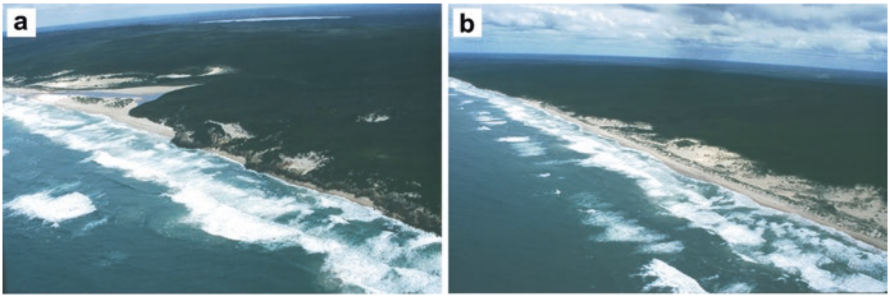


Fig. 30.38 (**a**) The mouth of the Donnelly River together with calcarenite bluffs separating the small but high energy beaches (WA 585-7); (**b**) part of the exposed high energy Jasper Beach (WA 593). (Photos: AD Short)

This long high energy section is backed by some of the largest dune systems on the south coast. Three near-continuous barrier systems occupy 62 km (94%) of the coast and consist of massive longwalled parabolics extending up to 15 km inland near Black Point and to elevation of between 100 and 240 m, as well as several areas of clifftop dunes. The Holocene dunes overly massive layers of Pleistocene dune calcarenite that is exposed along parts of the shore and forms the high cliffs to the west Point D'Entrecasteaux and to the east of Black Point. The transgressive dunes are then fronted by a regressive coastal plain up to 800 m wide extending for 27 km roughly either side of the Warren River. This plain lacks foredune ridges and represents an enigma on this otherwise dune transgressive coast. It remains to be investigated. While most of the dunes are well vegetated and stable, there are areas of inland dune instability. The barriers have a large total volume of 8375 M m^3 and the largest per metre volume on the south coast of 135,876 m^3 m^{-1}.

30.16.2 SC:WA04.03.02 Black Point-Cape Leeuwin

SC:WA04.03.02 commences at 80 m high Black Point, a basalt base covered in Pleistocene dune calcarenite, and trends northwest and then west for 48 km to Cape Leeuwin (Fig. 30.37). The D'Entrecasteaux National Park terminates just west of the point, with the Scott National Park extending to within 2 km of the coast, while the Leeuwin-Naturalist National Park extends along the final 5 km of the coast to Cape Leeuwin. The town of Augusta is located along the western shores of Hardy Inlet and Flinders Bay. The Blackwood River is the largest on the south coast with a catchment of 22,550 km^2 and is one of the few permanently open. The nature of the Blackwood River and Harley Inlet (Fig. 30.39b) and its dynamic and shifting entrance are described by Brearley (2005). Tides at Augusta are 0.8 m, while waves on the open coast remain moderate to high (2–3 m) from the southwest, and winds are predominately westerly.

There are 19 near-continuous beaches along this coast occupying 44 km (92%) of the shore. The first 40 km is exposed and dominated by TBR-RBB, with rip spacing remaining at the large 500 m (Fig. 30.39a). Shore-parallel beachrock reefs are found along sections of the coast, especially west from White Point. They form reef-induced rips at many locations with wave refraction around the reefs also forming the protruding White and Ledge points. As the coast begins to become sheltered in lee of Cape Leeuwin, it curves more to the west and then south, wave energy

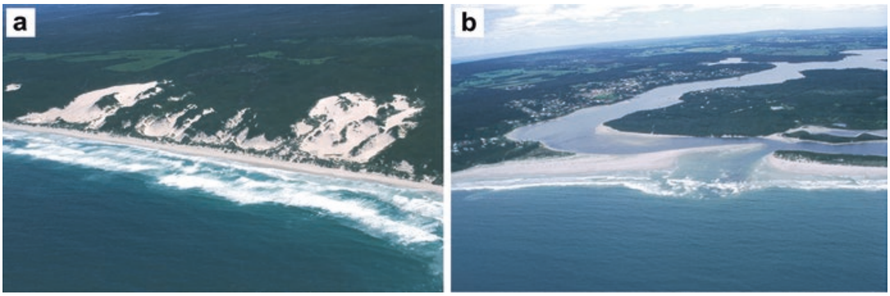


Fig. 30.39 (**a**) A series of blowout-parabolic dunes east of White Point (WA 603) and its 250 m wide rip-dominated surf zone; (**b**) the open mouth of Hardy Inlet at Augusta (WA 605). (Photos: AD Short)

drops and a series of small sheltered R-LTT beaches prevail along the east-facing Augusta coast.

There are two barrier systems along this coast, the long and large transgressive systems extending 40 km from Black Point to Hardy Inlet and the small sheltered regressive system on Duke Point on the western side of the inlet. The larger system consists of massive Pleistocene and Holocene dune transgression, with episodes of Holocene longwalled parabolics extending up to 15 km inland and reaching over 100 m in height at either end and 240 m between Black Head and Black Point. This system has a volume of 1580 M m^3 (39,500 m^3 m^{-1}), its per metre volume typical of the south coast, while the smaller regressive system is just 0.5 M m^3 in volume.

30.16.3 PC Overview

This is a reasonably long and continuous section of coast interrupted by a few prominent headlands and usually closed river mouths. All but the western end of the coast is backed by massive Pleistocene dune calcarenite, including extensive beachrock reef, and climbing Holocene longwalled parabolic dunes typical of a high energy exposed shoreline. Most of the coast is located in national parks with the only area of potential risk around the developed shore of Hardy Inlet-Augusta, which will be exposed to rising sea level.

30.17 Regional Overview

The southern WA coast is a long (1180 km) coast largely exposed to the full force of the high energy Southern Ocean waves and winds. Massive volumes of terrigenous and carbonate sand have been transported from the shelf by the southwest waves and landward by the southwest to west winds. The sand is predominately shelf quartz with carbonate enrichment averaging 22% ($\sigma = 21\%$). There appears to be little longshore sand transport, apart from several cases of headland overpassing owing to the oblique nature of the winds. As a consequence, 758 km (64%) of the coast is backed by usually massive Pleistocene and Holocene transgressive dunes extending usually a few kilometres inland and reaching tens of metres in height. The barriers total 41,352 M m^3 in volume which represents a large 48,140 m^3 m^{-1}, both the largest regional volume and per metre volume on the Australian coast (Table 34.4).

Because of the exposed nature of the coast, most development has been located away from the open coast on estuaries or sheltered locations, such as Esperance and Albany; with the result there are only a very few small locations where property and/or infrastructure is presently at risk, as at Esperance, Cheyne Beach and Emu Point, with DOT (2016) also listing Hopetoun, Bremer Bay and Windy Harbour as being at potential future risk. WAPC (2009) found that the sandy beaches between

Walpole and Augusta appear to be relatively stable and that the major threat to the coastal zone was wind erosion and wind-blown sand from the extensive southwest-oriented coastal dune systems. They also found that the present 38 m coastal setback should be reviewed in light of predicted sea-level rise. The main areas at risk are located around the estuarine shorelines where some development has occurred as at Emu Point, Princess Royal Harbour, Wilson Inlet (Denmark), Nornalup Inlet (Walpole), Broke Inlet and Augusta. These areas will be the most exposed to sea-level rise resulting in increased inundation and flooding.

References

Agnew HJ, Billings J, Imberger J (1975) Sediment transport processes in the Blackwood River estuary, Western Australia. In: 2nd Australian conference on coastal and ocean engineering, Gold Coast, Institution of Engineers Australia, pp 113–119

BMT JFA (2015) Esperance coastal hazard and vulnerability assessment. Prepared for the Shire of Esperance. Prepared for the Shire of Esperance

BMT (2016) Esperance coastal; hazard adaption strategy: Final report. BMT JFA Consultants, Shire of Esperance, 174 p

Boreham P (1991) Sand bypassing at Bandy Creek boat harbour, Esperance using an offshore breakwater. In: 10th Australasian conference on coastal and ocean engineering, Auckland, pp 553–558

Brearley A (2005) Ernest Hodgkin's Swanland: estuaries and coastal lagoons of south-western Australia. University of Western Australia Press, Perth, 550 p

City of Albany (2010) Middleton Beach, Council Management Plan, City of Albany, 38 p

City of Albany (2015) Cheyne Beach, Planning and Development, City of Albany, 10 p

City of Albany (2016) City of Albany artificial surf reef feasibility survey, City of Albany, 20 p

City of Albany (2017) 2017/18 Emu Point to Middleton beach coastal adaption and protection strategy. City of Albany, brochure, 1 p

DOT (2016) Coastal management hotspots in WA. Dept Transport, Perth. https://www.nccarf.edu.au/settlements-infrastructure/sites/www.nccarf.edu.au.settlements-infrastructure/files/Tim_Stead.pdf

Eliot I (2011) Coastal compartments of Western Australia: a physical framework for marine and coastal planning. Damara Pty Ltd, Geol. Survey WA/Department of Environment and conservation, Perth, 87 p

GHD (1999) Esperance foreshore coastal protection works. Prepared for Shire of Esperance by Gutteridge Haskins & Davey Pty Ltd, Report No 14533, Perth, Western Australia

Harrap B (1999) The design and construction of Bremer Bay Boat Harbour, Western Australia. In: 14th Australasian conference on coastal and ocean engineering, Perth, Institution of Engineers Australia, 8 p

Hesp PA (1984) Aspects of the geomorphology of south Western Australian estuaries. In: Hodgkin EP (ed) Estuarine environments of the Southern Hemisphere. Department of Conservative and Environment Bulletin, vol 161, pp 81–83

Hodgkin EP (1997) History and management of Culham Inlet, a coastal salt lake in south-western Australia. J Royal Soc W Aust 80:239–247

Jones R. Bicknell C, Ilich K (2009) The reinstatement of Brandy Creek boat harbour, Esperance. Coast and Ports 2009, Wellington NZ, Institution of Engineers Australia, pp 65–72

Oceania (2013) Port of Esperance maintenance dredging: Environmental impact assessment. Oceania Consulting Pty Ltd., Wembley, 68 p plus appendices

Paul MJ (1985) Beach erosion, Esperance, Western Australia. In: 7th Australasian conference on coastal and ocean engineering, NZ, vol 2, pp 543–552

Richardson L, Mathews E, Heap A (2005) Geomorphology and sedimentology of the South Western planning area of Australia: review and synthesis of relevant literature in support of Regional marine planning. Geoscience Australia, Canberra, Record 2005/17, 123 p

Royal Haskoning DHV (2015) Albany artificial surfing reef feasibility study. City of Albany, 11 p

Shire of Manjimup (2007) Windy harbour management plan. Shire of Manjimup, 72 p

Short AD (2005) Beaches of the Western Australian Coast: Eucla to Roebuck Bay. Sydney University Press, Sydney, 433 p

Short AD (2006) Australian beach systems – nature and distribution. J Coast Res 22:11–27

Short AD, Brander R (1999) Regional variation in rip density. J Coast Res 15:813–822

Tecchiato S, Buosi C, Ibba SA, Del Deo C, Parnum T, O'Leary N, De Muro S (2019) Geomorphological and sedimentological surrogates for the understanding of seagrass distribution within a temperate nearshore setting (Esperance Western Australia). Geo-Mar Lett 39:249–264. https://doi.org/10.1007/s00367-019-00571-5

WAPC (2009) Augusta-Walpole coastal strategy. Western Australia Planning Commission, Perth, 157 p

Chapter 31
Southwest Division

Abstract The southwest Western Australian division extends for 2575 km from Cape Leeuwin north to Exmouth Gulf. In doing so it straddles the Perth and Carnarvon basins and shifts from temperate humid in the south to the hot arid in the north. The entire coast is exposed to the persistent moderate to high southwest swell, with micro-tides until Exmouth Gulf. Breaker wave height, however, varies considerably owing to inshore limestone platform and shore parallel calcarenite reefs. The Leeuwin Current delivers warm tropical water down the coast maintaining the world's most poleward fringing coral reefs and atolls. Several rivers and numerous streams reach the coast most terminating in usually closed estuaries. Coastal sediments are predominately shelf-derived carbonates together with seagrass sourced carbonate banks in sheltered areas including Shark Bay. This chapter describes the divisions, geology, climate and coastal processes and reviews the estuaries, beaches, barriers and sediment compartments.

Keywords Southwest Western Australia · Shark Bay · Exmouth Gulf · Geology · Climate · Wave climate · Estuaries · Beaches · Barriers · Sediment compartments

31.1 Introduction

The southwest division encompasses the entire southern half of the western WA coast, all 2575 km from Cape Leeuwin at the southwestern tip to Giralia in Exmouth Gulf (Fig. 31.1). At Cape Leeuwin the coast undergoes a major change in orientation from south to west and a change in oceans, with the entire division facing west into the Indian Ocean. This is a long more continuous sedimentary coastline, lacking the dominance of bedrock that occurs to the east and north, with the only major interruption at Shark Bay, itself a product of coast barrier building and sedimentation since the Tertiary. The coast trends almost due north and spans 13° of latitude from 34.4° to 21.7°S; in doing so it also transitions from the temperate humid Mediterranean climate in the south to the hot arid desert climate in the north. It is also a carbonate-rich coast with the proportion of carbonate reaching 90% immediately north of the cape and averaging 69% for the entire division. The

A. D. Short, *Australian Coastal Systems*, Coastal Research Library 32,
https://doi.org/10.1007/978-3-030-14294-0_31

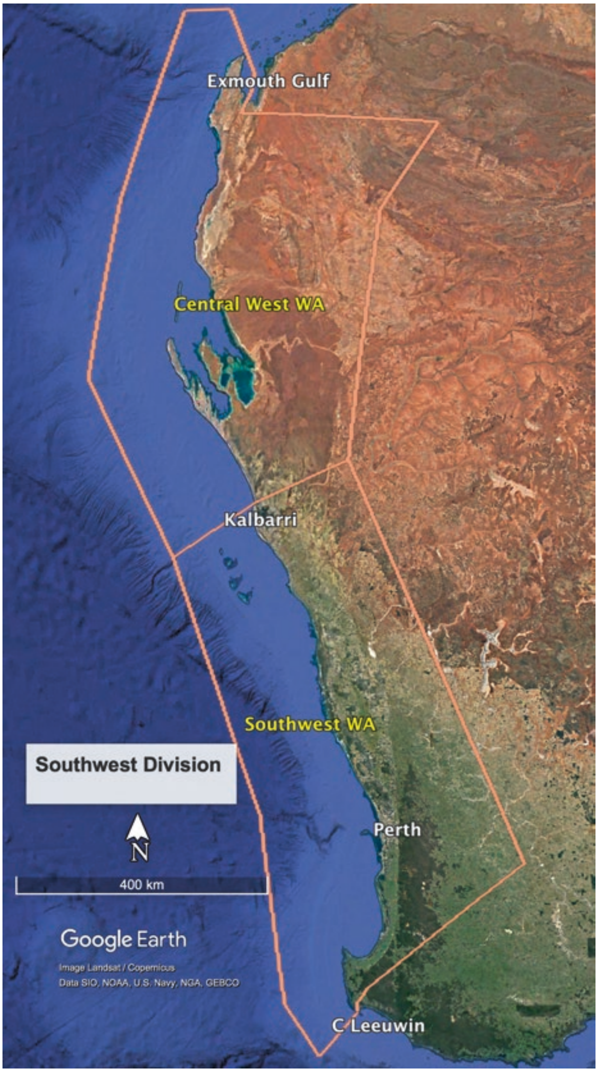


Fig. 31.1 The southwest division and its two regions: southwest WA and central west WA, divided by the Murchison River at Kalbarri. (Source: Google Earth)

carbonate combined with the climate has had a profound impact on the entire coast, leading to the formation of Pleistocene dune calcarenite along the entire coast, both onshore, and leaving a legacy of shore parallel lithified barriers submerged and partly submerged across the inner shelf. These in turn dramatically reduce wave height along long sections of the coast and in doing so impact the nature and evolution of the Holocene shoreline.

Despite the reduction in inshore wave energy, the coast remains exposed to predominately southwest swell and southerly winds and seas, which combine to transport sand northwards along the entire coast, producing a 1000 km long transport system from Geographe Bay to Shark Bay and a second 400 km long system from the Gascoyne River mouth to North West Cape.

This is also the most highly developed section of the Western Australian coast, centred on the city of Perth, with towns and communities spread from Margaret River in the south to Exmouth in the north. As a consequence, it has been the focus of considerable research into the coastal systems and their management, which will be discussed in Chaps. 32 and 33.

31.2 Geology

The southwest geology is dominated by two elongate sedimentary basins (Fig. 1.3). The 1300 km long Perth Basin averages 120 km in width and extends from the south coast to the Murchison River. At the coast it consists of Pleistocene Tamala limestone (dune calcarenite) capped by Holocene marine sediments (Quindalup dunes) (Playford et al. 1976). To the north is the Carnarvon Basin which extends to Exmouth Gulf up to the Dampier Archipelago, a distance of 800 km. It contains a mix of fluvial, coastal and shallow marine deposits and includes the red sandstones that dominate the coast between Geraldton and Kalbarri, while elsewhere Tertiary and Pleistocene limestone and Holocene marine sediments and some fluvial sediments dominate the coast. The only other bedrock occurs along the Leeuwin-Naturalist coast where Proterozoic granites in the Leeuwin Complex form some headland and points all capped by dune calcarenite. The coast has a long history of successive coastal sequences deposited when the Plio-Pleistocene sea-level highstands were close to present (Kendrick et al. 1991). The sediments are predominately carbonate which have been lithified to form the Tamala limestone which forms a shallow (<10 m) shore parallel limestone platform usually several kilometres wide along the coast between Cape Naturaliste and Broken Anchor Bay, south of Kalbarri. Shore parallel Pleistocene barriers and in the north dune ridges are spread across the shelf platform forming shallow reefs and some low islands. The limestone outcrops continuously along the coast forming generally low outcrops, bluffs and cliffs and usually extends a few kilometres inland.

31.3 Climate

The climate of the southwest division is tied to the latitude, with the southern corner dipping to 34°S permitting it to be impacted during winter by the midlatitude cyclones and their frontal rainfall, with rainfall peaking at 960 mm at Cape Leeuwin with a pronounced winter maximum. It decreases up the coast to 730 mm at Perth,

Table 31.1 Climate data for southwest division stations (data from Bureau of Meteorology)

Location	Latitude (°S)	Summer max (°C)	Winter max (°C)	Summer (mm)	Winter (mm)	Total (mm)
Southwest WA						
Cape Leeuwin	34.4	23	16	180	780	960
Perth	32.0	32	18	119	608	727
Kalbarri	27.7	34	22	58	289	347
Carnarvon	24.8	33	22	74	151	225
Exmouth	21.9	38	24	137	123	260

440 mm at Geraldton and 260 mm at Exmouth, which has a slight summer maximum owing to the impact of tropical cyclones (Fig. 1.5a, b). Likewise, temperature rises from a mean summer maximum of 23 °C at the cape to 32 °C at Perth and 38 °C at Exmouth (Table 31.1; Fig. 1.5c, d). In doing so the climate zones transition from warm summer Mediterranean (CSb) in the south with mid, wet winters, to hot summer Mediterranean (Csa) between Busselton and Kalbarri, hot semi-arid (BSh) up to Shark Bay and finally hot desert (BWh) north to Exmouth (Fig. 1.8).

31.4 Waves and Tides

Tides along most of the coast are micro with a mean spring range of 0.8 m at Augusta, 1 m at Cape Hamelin, between 0.7 and 0.9 m up to Kalbarri, varying in Shark Bay between 0.5 and 1.8 m, increasing to around 1.5 m between Carnarvon at North West Cape, and finally increasing to meso into Exmouth Gulf reaching 2.6 m at Learmonth (Figs. 1.15 and 30.3). The tidal wave arrives from the Indian Ocean and reaches most of the coast about the same time (Fig. 30.3).

Two addition processes impact sea level along the coast. Within the coastal 'lagoons' between the calcarenite reefs and the shore, the water level is modulated by barometric pressure effects and offshore winds generating set-down, seiching, and storm surges at least equal to the spring tide range (Steedman 1977). At the same time, the ocean swell is attenuated by the shallow reefs, except where gaps occur resulting in higher energy 'windows', and variable wave refraction. Allison et al. (1980) found that resonance in the reef lagoon or basin between Perth and Geraldton generates sea-level oscillation between 0.2 and 0.4 m, and up to 1 m, with periods of hours to 1–2 days, which can produce horizontal currents up to 0.5 m s^{-1}. The passage of cold fronts also generate 'meterotsunamics', oscillations in sea level with a period <6 h. During 2014 Pattiaratchi et al. (2015) recorded >30 such events at Fremantle. Finally, shelf waves generated by the passage of alternating high- and low-pressure systems travel from west to east along the Southern Australia coast with periods of days. They arrive on the southwest coast before moving eastwards along the south coast. As the waves have amplitudes of 0.5 m and are occasionally higher, they are the same magnitude as the tides and consequently very important in determining sea level along the coast (Provis and Radok 1979).

The ocean wave climate consists of two major sources: one oceanic and the other local. The dominant deepwater waves are generated in the southern Indian Ocean by the continuous passage of the midlatitude cyclones (Fig. 16.3) which generated a moderate to high west to southwest swell which impacts the entire southwest coast. The swell is more southerly in summer swinging to the southwest in winter (Collins 1988). It is also modulated by the position of the sub-tropical high, with higher waves associated with the high shifting northwards allowing the lows to shift closer to the southern coast (Wandres et al. 2016). At Perth (32°S) the swell averages ~2 m with 12 periods from the southwest (Figs. 16.4 and 31.2), with waves rarely less than 0.5 m, averaging 2–3 m and reaching 3 m 40% of the time and 4 m 15% and 5 m 5%. The waves are >1.5 m year-round with a winter maximum (~2.5 m). The second source is the strong summer southerly sea breeze which average 25 km hr.$^{-1}$ and can reach 50 km hr.$^{-1}$ and the winter northwest winds which can generate short periods of high west to northwest waves. Lemm (1999) and Lemm et al. (1999) found that the deepwater waves off Perth have a H_s of 2 m (T_m = 8.8 s), with the summer sea breeze generating waves 1–2 m with a T_m < 8 s, while during winter midlatitude cyclones generate waves 1.5–2.5 m with a T_m < 8 s. On average 30 storms a year generate waves >4 m with extreme waves of 6.7 m and 9.8 m having a 1- and 100-year return period, respectively, estimates also sup-

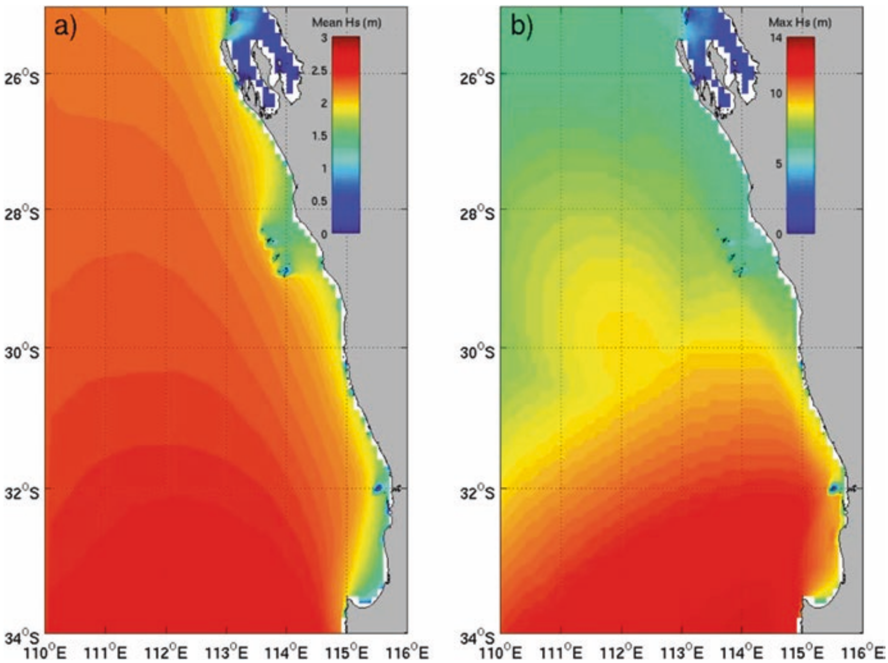


Fig. 31.2 Southwest division (**a**) significant wave height and (**b**) maximum wave height for the period 1997–2004. Note the attenuation in wave height in lee of the more prominent offshore islands and reefs. (From: Richardson et al. 2005, reproduced with permission of Geoscience Australia under the Creative Commons Attribution 4.0 International Licence)

ported by Li et al. (2011). Roncevich et al. (2009) provide the most recent analysis of the Perth wave climate. They found that offshore H_s = 2.2 m with a T_p = 12.6 s, while swell waves average 1.8 m (T = 13 s) and direction of 252 °, and seas 1.2 m (T = 6.8 s) with a direction of 232 °. Monthly mean wave height peaks in July (2.8 m) with March experiencing the lowest waves at 1.7 m, while overall direction has a narrow range from 217 to 251 °. They also found the interannual variation in height is much smaller than the seasonal variation, in agreement with Hemer et al. (2016; Fig. 1.12b). The inshore wave climate is however much reduced by the reefs with the sea breeze seas become particularly important along long sections of coast where the deepwater waves are significantly attenuated by the calcarenite reefs.

On the open reef-free coasts and in the higher energy 'windows', ocean swell prevails, while in lee of the reefs, which can attenuate up to 90% of the wave energy, wind waves which may average as little as 0.1–0.2 m provide the main source of wave energy (Hegge et al. 1996; Fig. 31.2). Masselink and Pattiaratchi (1998) reported that southwest summer sea breeze occurs on 60% of the days and generate both short seas and northerly longshore currents up to 2 m s^{-1}.Consequently, wave energy and associated beach types vary considerably along the shore in response to reef protection and associate wave energy. The longshore variation in wave height and direction has also led to the formation of numerous cuspate forelands and embayments with cellular circulation as described by Sanderson and Eliot (1996) and Sanderson et al. (2000).

31.5 Ocean Currents and Sea Temperature

The entire west coast is impacted by the Leeuwin Current, an eastern boundary current which originates in the warm tropical waters of the northeast Indian Ocean and moves southwards along the WA coast to Cape Leeuwin which it rounds and then moves along the south coast (Fig. 1.18). The Leeuwin Current brings warm topical waters down the western coast, with temperatures down the coast ranging north to south from 26 to 20 °C in summer and 20 to 15 °C in winter (Fig. 1.17). These warmer temperatures are responsible for the world's most polewater fringing coral reefs along the Ningaloo coast (24°S) and most poleward coastal atolls in the Houtman Abrolhos (29°S).

31.6 River and Estuaries

The northerly gradation in rainfall from humid to arid has a direct impact on drainage from the hinterland to the coast. Table 31.2 lists the 21 main rivers and streams that reach the coast, of which only the Lechenault and Peel-Harvey estuaries and the Swan, Murchison and Gascoyne rivers are permanently open, the remainder relying on winter rains to breach the river mouth berms and open to the sea. The only major

Table 31.2 Southwest Western Australian river and estuary entrance conditions, listed south to north (adapted from Hesp 1984 and Brearley 2005)

River/inlet	Permanently closed	Normally closed	Seasonally open	Permanently open	Type	Catchment (km^2)
Margaret			X		1	450
Carbanup-Toby			X			160
Vasse-Wonnerup			X			263
Capel			X			653
Lechenault				X	2	4600
Peel-Harvey				X	2iii	772
Swan-Avon				X	2iii	121,000
Moore			X		1	13,000
Hill			X		1	692
Irwin			X		1	4480
Greenough			X		1	12,800
Chapman			X		1	484
Buller			X		1	34
Oakajee			X		1	–
Oakabella			X		1	–
Bowes			X		1	714
Hutt	X				1	1078
Murchison				X	1	82,300
Woonamel			X		1	40,500
Gascoyne				X	1	76,254
Yardie			X		1	–
21	1	0	15	5		

Estuarine type: 1, riverine; 2, barrier estuary; i, small ovoid basin; ii, elongate; iii, large

rivers to deliver bedload to the coast are the sandy Murchison and Gascoyne which rely on tropical cyclone precipitation to rise and transport bedload downstream to their sandy river mouths. The very dry Woonamel and small Yardie also occasionally deliver sand and, in the case of the latter, gravel to the coast. All three rivers – the Murchison, Gascoyne and Woonamel – only flow following heavy rains and can go for several years without any significant flows.

31.7 Sediments and Shelf

Coastal sediments along the southwest division are predominately moderately well-sorted, medium sand averaging 69% carbonate ($\sigma = 30\%$) (Table 31.3). The carbonate is sourced from the shelf and inshore seagrass meadows and transported shoreward by the southwest swell and inshore seas.

Table 31.3 Southwest Western Australian division beach sand size

	Southwest div
n	284
Size (mm)	0.38
σ (mm)	0.21
Sorting	0.56
σ (sorting)	0.21
Carbonate (%)	68.6
σ (%)	29.5

The Rottnest Shelf extends from Cape Naturaliste to Dirk Hartog Island off Shark Bay and represents a transition from tropical to temperate biota. It has been described by Searle and Semeniuk (1985), James et al. (1999) and Richardson et al. (2005) as dominated by southwest swell and storms, together with the southerly flowing Leeuwin Current. Physically it is a narrow, incipiently rimmed shelf with submerged ridges and carbonate platforms. Surface sediments are predominately cool-water carbonates composed of bryozoans, molluscs and coralline algae occurring in thin discontinuous sheets. During the Quaternary barrier systems deposited on the shelf at lowstands of the sea have been lithified and now form shore parallel calcarenite ridges which have major impacts on inshore processes. Collins (1988) investigated the southern part of the shelf between Cape Naturaliste and Rottnest Island. He found it is broad in the south extending 10 km west of Cape Leeuwin-Naturaliste, north of which the shelf edge trends north-northeast narrowing to 15 km at Rottnest Island (Fig. 31.3). He describes it as a narrow, high energy wave-dominated open shelf, with limited carbonate productivity and only a thin (<1 m) blanket of carbonate and relict sediment, with little terrigenous input and with the inner shelf containing a shallowing-upward coarsening sequence. James et al. (1999) investigated the shelf north from Perth to the Carnarvon region and found the inner shelf dominated by skeletal sand, with quartoze skeletal sand north from Kalbarri and abraded intraclast skeletal sand along the Ningaloo Reef coast. Based on their findings, they divided the shelf into the southern Northern Rottnest Shelf a relatively shallow (<70 m) tectonically stable platform covered in seagrass meadows, rippled sand and hardgrounds and the northern gently sloping Carnarvon Ramp, which is slowly subsiding, providing high accommodation space and covered in seagrass meadows and rippled sand.

Stul et al. (2014a, 2014b, 2015) provide maps showing the coastal topography and inner shelf bathymetry between Cape Naturaliste and the Murchison River as well as the extent and boundaries of the coastal sediment primary, secondary and tertiary cells (compartments).

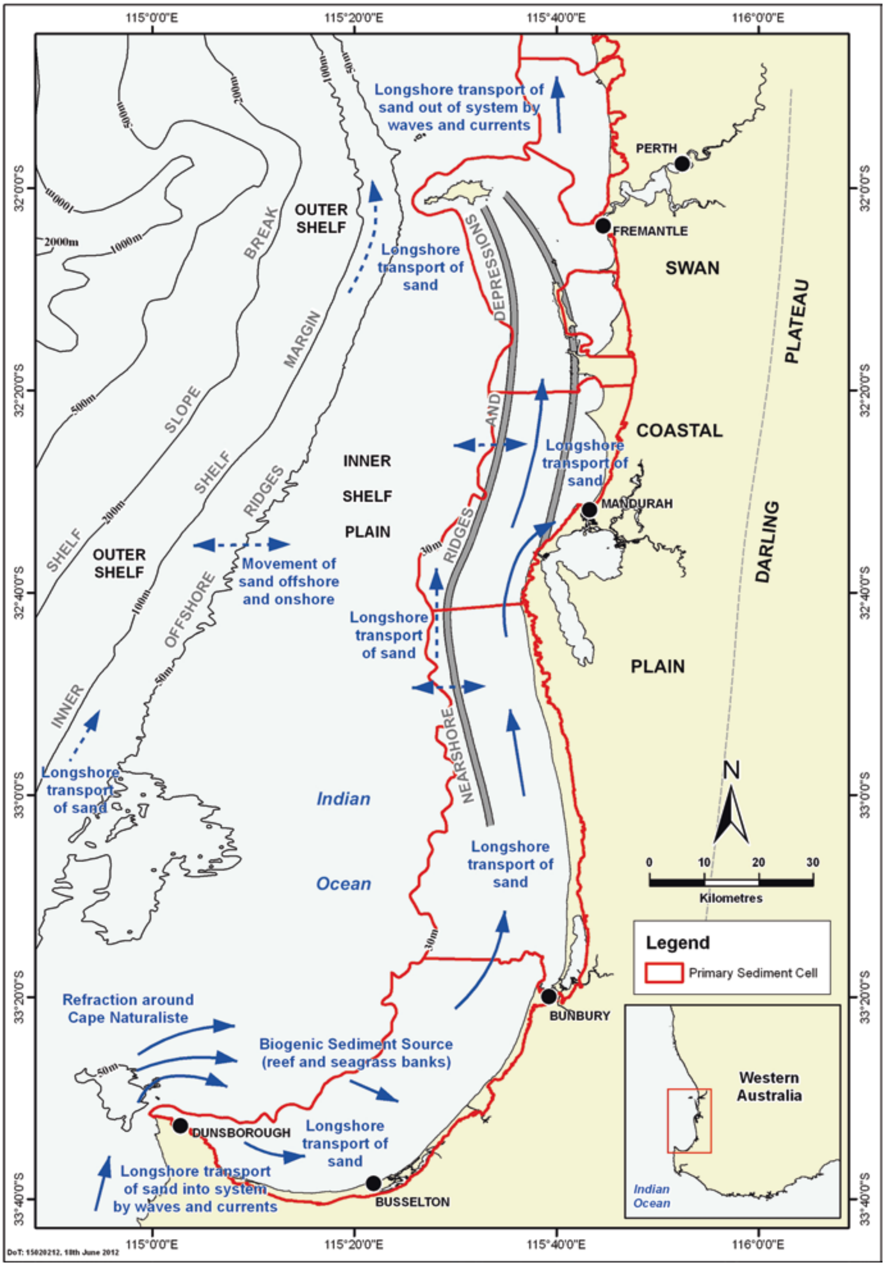


Fig. 31.3 The Cape Naturaliste to Perth coast and shelf showing bathymetry, main limestone ridges, longshore sand transport and red cell boundaries, which in this book correspond to the SC boundaries. (Source: Stul et al. 2015, after Collins 1988, reproduced with permission)

31.8 Sediment Transport

The southwest coast is dominated by carbonate-rich sediment which originates on the inner shelf and inshore seagrass meadows, as discussed in Sect. 31.10. Brooke et al. (2014) found that on the Perth Shelf during periods of high and intermediate sea level, the sediment is reworked shoreward by the marine transgression and during the subsequent stillstand resulting in the deposition of large-scale coastal carbonate barriers. Once at the coast, the sediment can then be transported northwards by the prevailing southerly waves and winds as shown in Fig. 31.3. Most the southwest division coast is long and continuous with an absence of bedrock and major headlands and changes in coastal orientation typical of the south coast. In addition, there are only five permanently open estuaries to act as sediment traps (Table 3.2). The combination of a smoother more continuous shoreline morphology orientated east and exposed to predominately southerly waves provides an ideal environment for northerly longshore sand transport (Fig. 31.3), as has occurred throughout the Quaternary and back into the Tertiary and has been responsible for the massive calcarenite deposits along the Kalbarri-Shark Bay coast. However, the transport is dependent on wave energy and local wind-driven currents, with the former substantially lowered by the inshore reefs resulting in areas of very low waves and low capacity for transport, which effectively interrupt and may stop the transport in the low energy nodes. The role of wave and tidal currents combined with topography in generating longshore sediment transport will be considered in more detail in the Chaps. 32 and 33.

31.9 Sea Level

The southwest WA sea-level history was first investigated by Fairbridge (1961) who based on studies on Rottnest Island proposed a highstand at +3–5 m 5.1 ka followed by a series of oscillations. Brown (1983) reviewed subsequent work in the southwest and found the PMT extended from 17 to 7 ka followed by a highstand at +1.5 m in Geographe Bay at 4.6 ka, +3 m at Geraldton at 6 ka, +1–1.5 m in Shark Bay at 3.6 ka and + 1 m in Exmouth Gulf at 4.5 ka. Semeniuk and Searle (1986) examined the sea-level record at three sites along a 170 km long section of the southwest coast. At the northern site (Whitfords), they found it was 1 m below present ~7.4 ka, reaching present sea level by 5.1 ka with no evidence for a higher sea level or oscillation in sea level as suggested by Fairbridge (1961). At the middle Rockingham Plain site, it reached an initial higher level + 2.5 m at 6.4 ka followed by a steady decline to present level. At the southern Leschenault Peninsula, Semeniuk and Searle found an initially 2–3 m higher level at 7 ka followed by a rise to 3–4 m (4.8–3.8 ka) and then a decline to its present level by 2.8 ka. They attribute the marked variations in the Holocene record to local tectonism, a suggestion rejected by Baker et al. (2005). Likewise, Collins (1988) in a summary of sea-level data for region concluded sea level reached a peak of +3 m in the late Holocene followed by a regression to present sea level. Baker et al. (2005) working on Rottnest Island as well as locations in the southwest and south coast concluded that regional sea level rose to peaks at 6.5 and 4.2 ka followed by sharp ~1 m falls sea-level peaks at 5.2 and 3.8 ka. Because of the regional synchronicity, they found no evidence of local tectonism or hydro-isostatic influence. The most recent investigation by Gouramanis et al. (2012) based on dating of coastal swamp deposits on Rottnest Island found that sea level probably increased with stepwise increases at 6.75, 6.2 and 5.6 ka, reaching a highstand between ~4.5 and 4.3 ka, then falling to the present level after 1 ka.

Recent decadal scale trends in WA sea level were investigated by Haigh et al. (2011). They found intra-annual variability strongly correlated with the SOI. In the longer term (since 1897), they found at Fremantle that the sea level rise was consistent with global trends (1.5 mm $year^{-1}$); however, the southern sites around to Esperance, with a shorter record, showed a trend less than the global average (0.5–1 mm $year^{-1}$), while the northern Pilbara-Kimberley sites were higher (1.7–2.5 mm $year^{-1}$), a pattern not wholly explained by vertical land movement. All sites however showed increasing rates since 1986.

31.10 Biological Processes

The southwest coast and beaches are largely composed of wave and wind deposited carbonate detritus, with carbonate material comprising on average 70% of the beach sand. The source of this material is biota that inhabits the shelf and seagrass meadows and which therefore plays a major role in the past and present supply of sediment to the coast.

The south and southwest and WA coast contain diverse and extensive temperate seagrass meadows extending along 1500 km of the south coast and 1000 km of the southwest coast and occurring in many of the 51 estuaries (Carruthers et al. 2007). They range from the shallow subtidal to >50 m depth and support a rich biota including bryozoans, amphipods and sponges. As mentioned above the shelf biota has been investigated by Collins (1988) and James et al. (1999) who found that it is dominated by cool-water carbonates composed of bryozoans, molluscs and coralline algae. Shark Bay has amongst the largest seagrass meadows in the world (4500 km^2) which are a mix of temperate and tropical species (Table 2.12). In parts of the bay, the beaches and sand flats sediments are composed entirely of seagrass-derived biota.

Mangroves are spread along the coast in suitable habitats north from Bunbury. There is only one species *Avicennia marina* between Bunbury and Shark Bay, increasing to seven species in Exmouth Gulf (Table 2.10; Semeniuk et al. 1978). The mangroves are however very limited in extent owing to a lack of suitable habitat along much of the coast, except for Shark Bay and Exmouth Gulf.

The southwest division has both the most poleward coral atolls in the world at 29°S on the Houtman Abrolhos and the most poleward fringing reef in the world at Ningaloo (22–24°S) (Table 2.13). The poleward extent can be directly attributed to the warm Leeuwin Current which brings warm tropical water down the west coast. The fringing Ningaloo reefs are enhanced by the absence of freshwater drainage and sediments, allowing the reefs to grow right to the shore.

The southwest has a rich and diverse coastal dune vegetation with hairy spinifex (*Spinifex hirsutus*), *Spinifex longifolius*, sea rocket (*Cakile maritima*) and beach daisy (*Arctotheca populifolia*) dominating the incipient foredune, while on the seaward side of the foredune they are gradually replaced by low acacia shrubs (*Acacia cyclops*, *Acacia rostellifera*, coastal daisy), with larger shrubs on the crest and leeward size which grade into a stable shrub community (*Acacia rostellifera*, coastal daisy). The dune vegetation is well adapted to the environment and climate, and even along the arid desert coast, the dunes remain well vegetated.

31.11 Beach Systems

The southwest division is predominately a sandy coast with 1702 km (61%) consisting of 1015 sandy beaches (Table 31.4). When the Zuytdorp Cliffs are removed, the percentage rises to 68%. The beaches are predominately low energy WD R (50%) and in sheltered locations like Shark Bay TD B + SF (25%, Table 31.4), the latter always fringed by seagrass meadows. The predominance of low energy WD and TM beaches is a product of the sheltering effect of the inner shelf calcarenite reefs and in the north the fringing coral reefs which lower wave height at the coast, coupled with the very extensive sheltered Shark Bay and Exmouth Gulf shorelines. Exposed higher energy TBR occupy just 93 km (5%) of the coast, all located in higher energy windows. Hegge et al. (1996) found there were two beach regimes along the southwest coast, the open ocean exposed beaches whose state was largely dependent on wave height and the sheltered beaches where they found the beach state was more dependent on sand size. The beaches and the controls on their type

Table 31.4 Southwest division beach types and states

BS	BS	No.	%	km	% (km)	mean (km)
4	TBR	38	3.7	92.7	5.4	2.4
5	LTT	103	10.1	181	10.6	1.8
6	R	570	56.2	848.6	49.9	1.5
10	B + RSF	13	1.3	38.7	2.3	3.0
11	B + SF	217	21.4	416.6	24.5	1.9
12	B + TSF	26	2.6	37.5	2.2	1.4
14	R + RF	12	1.2	37.5	2.2	3.1
15	R + CF	36	3.5	49.7	2.9	1.4
		1015	100	1702	100	1.7

and state will be more fully discussed in Chaps. 32 and 33. Gallop et al. (2012) investigated the impact of the rock (calcarenite and coral reefs) on the beach systems (R + RF, R + CF) and identified four types along the WA coast. They found that while these beaches are sheltered by the presence of the rock substrate, they often experience greater erosion and slower recovery than more exposed non-rocky beaches.

31.12 Barrier Systems

The southwest coast is a predominately sandy coast exposed to strong onshore southwest though south winds. The combination of southerly waves and winds have deposited 156 Holocene barrier systems along 1326 km (48%) of the coast. They are predominately north-trending transgressive dunes of which 28% are presently unstable. They are largest in the southwest region (WA05–08) extending on average up to 2.9 km inland with an average height of 23 m, while in the central west region (WA 09–10), they extend on average 1.2 km inland and average 10 m in height (Table 31.5). The division barriers have a total volume of 39,796 M m^3 which represents 30,009 m^3 m^{-1}, which is less but still comparable in size to the higher energy southern coast barrier systems, which average 54,554 m^3 m^{-1} (Table 30.4). There has been a number of investigation of the southwest barrier systems, particularly by Semeniuk, Searle and their colleagues. Their results are discussed in the following chapters.

31.13 Sediment Compartments

The large-scale identification and application of coastal sediment compartments on the Australian coast commenced in southwest Western Australia with Sanderson and Eliot (1996, 1999) using beach sediments to identify coastal littoral cells

Table 31.5 Southwest division barrier characteristics

	SW region	CW region	SW division
No.	57	99	156
Total length (km)	700.3	625.8	1326.1
Mean min width	970	275	–
Mean max width	2930	1240	–
Mean height (m)	23	10	–
Area (ha)	166,504	104,155	270,659
Unstable (ha)	31,373	10,760	42,133
Total volume (M m^3)	31,302	16,863	48,165
Unit volume (m^3 m^{-1})	44,799	23,790	36,320

Table 31.6 Southwest division: regions and PCs

PC No.[a]	Name	Boundaries	Beach ID[b]	No. beach	km[c]	Total km
Southwest WA						
WA05.01.		C Leeuwin-C Naturaliste	WA 618–730	113	1818–1930	112
WA06.01	Geographe Bay	C Naturaliste-Robert Pt	WA 731–789	59	1930–2119	189
WA06.02	Perth coast	Robert Pt-Moore R	WA 790–906	117	2119–2272	153
WA07.01		Moore R-North Hd	WA 907–987	81	2272–2416	144
WA07.02		North Hd- Glenfield Beach	WA 988–1090	103	2416–2608	192
WA08.01.02		Glenfield Beach-Anchor Bay	WA 1091–1116	26	2644–2665	21
WA08.02		Broken anchor -Murchison R	WA 1117–1133	17	2665–2734	69
WA05–08		*Region WA05–08*		*516*		*916*
Central West WA						
WA09.01	Zuytdorp Cliffs	Murchison R-Steep Pt	WA 1134–1187	54	2734–2912	211
WA09.02		Steep Pt-C Peron north	WA 1188–1367	180	2912–3397	452
WA09.03	Shark Bay	C Peron North-Grey Pt	WA 1368–1426	59	3397–3802	405
WA09.04	Gascoyne R delta	Grey Pt-Pt Quobba	WA1427–1436	10	3802–3897	95
WA10.1		Pt Quobba-Alison Pt	WA 1437–1488	52	3897–4029	132
WA10.02	Ningaloo Reef	Alison Pt-North West C	WA 1549–1602	114	4029–4267	238
WA10.03	Exmouth Gulf (W)	North West C-Giralia	WA1603–1633	31	4267–4393	126
WA09–10		*Region WA09–10*		*500*		*1659*
Southwest		**Division**		**1016**		**2575**

[a]NCCARF compartment number
[b]ABSAMP beach ID
[c]Clockwise distance from State border

(compartments) along the southwest coast, building on the work of Searle and Semeniuk (1985). Based on sediment characteristics, they were able to distinguish six sediment cells between Moore River and Cliff Head. Further they identified closed and open cells indicating the general northerly transport is interrupted and even stopped at the closed cells.

This pioneering work has since been greatly expanded upon and integrated into the management of the WA coast by Stul et al. (2007) and Eliot et al. (2011) and applied to large sections of the WA coast (Stul et al. 2012, 2014a, b, c, 2015; Eliot et al. 2013). The ACSCP and this book use the compartments identified and mapped by the above authors. In the southwest division, there are two regions: the southwest and central west, which both contain seven PCs each (Table 31.6). In addition, Elliot et al. (2011) mapped 100 TCs in this division. The southwest regions, their PCs and SCs are discussed in Chaps. 32 and 33.

31.14 Summary

The southwest division trends essentially due north traversing 13° of latitude. In doing so its climate transforms from more humid Mediterranean to hot desert and from temperate to tropical waters. Tides are micro throughout and deepwater wave energy which is moderate to high decreases slightly to the north. Against this process background is the overriding influence of the carbonate-rich sediment, a product of the rich shelf and coastal biota assisted by the arid climate and consequently lack of terrigenous sediments. The carbonate-rich barrier sediments have been acted on by the seasonally arid to very arid climate to develop calcrete soils and over time blanket much of the coast in dune calcarenite leading to the lithification of both low- and highstand barrier systems. The lowstand barriers have been drowned by the PMT but remain as shore parallel reefs across the shelf, coupled in the north with fringing coral reefs. The reefs have a profound influence on the inshore wave climate leading to substantial wave attenuation that lowers wave height in places to ~0.1 m and to wave refraction which leads to the formation of highly crenulate shoreline with cuspate forelands and embayments. Beaches are predominately low energy WD plus a substantial number of TD, primarily in the microtidal but sheltered Shark Bay.

All these factors in turn impact the rates and direction of sand transport, the beach type/state and the overall Holocene evolution of the coast. The overall result is a carbonate-rich sedimentary coast with predominately northerly sand transport but at highly variable rates. This transport has occurred since the Tertiary and has accumulated as large transgressive inner barrier peninsulas in Shark Bay (Tamala limestone) and during the Pleistocene as the carbonate-rich Zuytdorp Cliffs and islands. These deposits rival in extent and volume the southeast Queensland sand islands, also located at the end of a > 1000 km long northerly sand transport system (Fig. 1.24).

References

Allison H, Grassia A, Litchfield R (1980) Resonance of coastal waters between Perth and Geraldton (Western Australia). In: 17th International conference on coastal engineering, Sydney, pp 344–345 (abstract)

Baker RGV, Haworth RJ, Flood PG (2005) An oscillating Holocene Sea-level? Revisiting Rottnest Island, Western Australia, and the Fairbridge eustatic hypothesis. J Coast Res SI 42:3–14

Brearley A (2005) Ernest Hodgkin's Swanland: estuaries and coastal lagoons of South-Western Australia. University of Western Australia Press, Perth, 550 p

Brown RG (1983) Sea level history over the past 15,000 years along the Western Australian coastline. In: Hopley D (ed) Australian sea levels in the last 15,000 years: a review. Occasional Paper 3, Department of Geography, James Cook University, Monograph Series, pp 29–36

Brooke BP, Olley JM, Pietsch T, Playford PE, Haines PW, Murray-Wallace CV, Woodroffe DD (2014) Chronology of Quaternary coastal aeolianite deposition and the drowned shorelines of southwestern Western Australia – a reappraisal. Quat Sci Rev 93:106–124

Carruthers TJB, Dennison WC, Kendrick GA, Waycott M, Walker DI, Cambridge ML (2007) Seagrasses of South–West Australia: a conceptual synthesis of the world's most diverse and extensive seagrass meadows. J Exp Mar Biol Ecol 350:21–45
Collins LB (1988) Sediments and history of the Rottnest shelf, Southwest Australia: a swell-dominated, non-tropical carbonate margin. Sediment Geol 60:15–50
Eliot I, Nutt C, Gozzard B, Higgins M, Buckley E, Bowyer J (2011) Coastal compartments of Western Australia: a physical framework for marine & coastal planning. Report to the Department of Environmental Conservation, Planning Transport. Damara WA Pty Ltd, Geological Survey of Western Australia, Innaloo, Western Australia
Eliot I, Gozzard B, Eliot M, Stul T, McCormack G (2013) Geology, geomorphology and vulnerability of the Pilbara Coast, In the Shires of Ashburton, East Pilbara and Roebourne, and the Town of Port Hedland, Western Australia. Damara WA Pty Ltd and Geological Survey of Western Australia, Innaloo, Western Australia
Fairbridge RW (1961) Eustatic changes in sealevel. In Ahrens LH, Press F, Rankema K, Runcorn SK (ed), Physics and chemistry of the earth, vol 4. Pergamon, Oxford, pp 99–185
Gallop SL, Bosserelle C, Eliot I, Pattiaratchi C (2012) The influence of limestone reefs on storm erosion and recovery of a perched beach. Cont Shelf Res 47:16–27
Gouramanis C, Dodson J, Wilkins D, De Deckker P, Chase BM (2012) Holocene palaeoclimate and sea level fluctuation recorded from the coastal Barker Swamp, Rottnest Island, south-western Western Australia. Quat Sci Rev 54:40–57
Haigh ID, Eliot M, Pattiaratchi C, Wahl T (2011) Regional changes in mean sea level around Western Australia between 1897 and 2008. In: 20th Australasian coastal ocean engineering conference, pp 280–285
Hegge B, Eliot I, Hsu J (1996) Sheltered sandy beaches of southwestern Australia. J Coast Res 12:748–760
Hemer MA, Zieger S, Durrant T, O'Grady J, Hoeke RK, McInnes KL, Rosebrock U (2016) A revised assessment of Australia's national wave energy resource. Renew Energy xx:1–23. https://doi.org/10.1016/j.rene.2016.08.039
Hesp PA (1984) Aspects of the geomorphology of South Western Australian estuaries. In: Hodgkin EP (ed) Estuarine environments of the Southern Hemisphere. Department of Conservative and Environmental Bulletin, 161, pp 81–83
James NP, Collins LB, Bone Y, Hallock P (1999) Subtropical carbonates in a temperate realm: modern sediments on the southwest Australian shelf. J Sediment Res 69:1297–1321
Kendrick GW, Wyrwoll KH, Szabo BJ (1991) Pliocene–Pleistocene coastal events and history along the western margin of Australia. Quat Sci Rev 10:419–439
Lemm AJ (1999) Offshore Wave Climate, Perth (Western Australia), 1994–98. In: 14th Australasian conference on coastal and ocean engineering, Perth, Institution of Engineers Australia, 8 p
Lemm AJ, Hegge B, Masselink G (1999) Offshore wave climate, Perth (Western Australia), 1996–96. Marine Freshwater Res 50. https://doi.org/10.1071/MF98081
Li F, Bicknell C, Lowry R (2011) Extreme wave analysis for offshore Perth, 1994–2010. In: 20th Australasian Coastal Ocean Engineering Conference, Perth, Institution of Engineers Australia, pp 410–415
Masselink G, Pattiaratchi CB (1998) The effect of sea breeze on beach morphology, surf zone hydrodynamics and sediment resuspension. Mar Geol 146:115–135
Pattiaratchi C, Wijeratne S, Salehi A (2015) Meteotsunamis in South-Western Australia. In: 22nd Australasian conference on coastal and ocean engineering, Auckland, 659 p
Playford PE, Cockbain AE, Low GH (1976) Geology of the Perth Basin, Western Australia. Geol survey Western Austrealia bull 124, 311 p plus maps
Provis DG, Radok R (1979) Sea-level oscillations along the Australian coast. Australian J Mar Freshwater Res 30:295–301
Richardson L, Mathews E, Heap A (2005) Geomorphology and sedimentology of the South Western planning area of Australia: review and synthesis of relevant literature in support of regional marine planning. Geoscience Australia, Canberra. Record 2005(/17):123

Roncevich L, Li F, Bicknell C (2009) Perth offshore wave climate, directional and non- directional analysis, 1994–2008. Coasts and Ports 2009, pp 402–408

Sanderson PG, Eliot I (1996) Shoreline salients, cuspate forelands and tombolos on the coast of Western Australia. J Coast Res 12:761–773

Sanderson PG, Eliot I (1999) Compartmentalisation of beachface sediments along the southwestern coast of Australia. Mar Geol 162:145–164

Sanderson PG, Eliot I, Hegge B, Maxwell S (2000) Regional variation of coastal morphology in southwestern Australia: a synthesis. Geomorphology 34:73–88

Searle DJ, Semeniuk V (1985) The natural sectors of the inner Rottnest shelf adjoining the swan coastal plain, vol 67. J Royal Soc Western Australia, pp 116–136

Semeniuk V, Searle DJ (1986) Variability of Holocene sealevel history along the southwestern coast of Australia – evidence for the effect of significant local tectonism. Mar Geol 72:47–58

Semeniuk V, Kenneally JF, Wilson PG (1978) Mangroves of Western Australia. Western Australia Naturalists Club, Handbook 12, 92 p

Steedman RK (1977) Mullaloo Marina: report on oceanography and marine environment. Shire of Wanneroo, Western Australia, 210 p

Stul T, Eliot I, Pattiaratchi C (2007) Sediment cells along the Perth metropolitan coast. In: Coasts and Ports Australasian Conference, Institution of Engineers Australia, Melbourne

Stul T, Gozzard JR, Eliot IG, Eliot MJ (2012) Coastal sediment cells between Cape Naturaliste and the Moore River, Western Australia. Damara WA Pty Ltd and Geological Survey of Western Australia, for WA Department of Transport, Fremantle

Stul T, Gozzard JR, Eliot IG, Eliot MJ (2014a) Coastal sediment cells for the Northampton Region between Glenfield Beach and the Murchison River, Western Australia. Report prepared by Seashore Engineering Pty Ltd and Geological Survey of Western Australia for the Western Australian Department of Transport, Fremantle

Stul T, Gozzard JR, Eliot IG, Eliot MJ (2014b) Coastal sediment cells for the mid-west region between the Moore River and Glenfield Beach, Western Australia. Report prepared by Seashore Engineering Pty Ltd and Geological Survey of Western Australia for the Western Australian Department of Transport, Fremantle

Stul T, Gozzard JR, Eliot IG, Eliot MJ (2014c) Coastal sediment cells for the Pilbara region between Giralia and Beebingarra Creek, Western Australia. Report prepared by Seashore Engineering Pty Ltd and Geological Survey of Western Australia for the Western Australian Department of Transport, Fremantle

Stul T, Gozzard JR, Eliot IG, Eliot MJ (2015) Coastal sediment cells for the Vlamingh Region between Cape Naturaliste and Moore River, Western Australia. Report prepared by Seashore Engineering Pty Ltd and Geological Survey of Western Australia for the Western Australian Department of Transport, Fremantle

Wandres M, Pattiarcatchi C, Wijeratne EMS, Hetzel Y (2016) The influence of the sub-tropical high-pressure ridge on the Western Australia wave climate. J Coast Res SI 75:567–571

Chapter 32
Southwest Western Australia Region

Abstract The southwest coast of Western Australia extends north from Cape Leeuwin for 916 km to the Murchison River mouth at Kalbarri and includes the Perth coast and Rottnest Island. In doing so it extends the length of the low relief Perth Basin and into the southern higher relief Carnarvon Basin. The climate is Mediterranean with rainfall decreasing northward. The coast has several small- to moderate-sized rivers and streams most of which drain to closed estuaries. Coastal sediments are carbonate-rich derived from the shelf and seagrass meadows. The southwest swell dominates the deepwater wave climate, while breaker wave energy is attenuated and refracted by the near continuous nearshore limestone platform containing shore-parallel calcarenite reefs, with the limestone also extending inland as lithified Pleistocene barriers. The extensive beach systems range from sheltered to exposed and contain numerous sandy forelands induced by wave refraction over the reefs. The barriers, depending on wave energy and shoreline orientation, range from regressive to transgressive, with strong southerly winds responsible for extensive north-trending transgressive dunes. This chapter describes the coastal processes, sediments and sediment transport and the beaches, barrier and sediment transport within each sediment compartment.

Keywords Southwest Western Australia · Rottnest Island · Perth Basin · Carnarvon Basin · Calcareous sediments · Beaches · Barriers · Sediment transport · Sediment compartments

32.1 Introduction

The southwest WA region extends for 916 km between Cape Leeuwin and the mouth of the Murchison River at Kalbarri. The coast is composed of two geological units: a narrow band of Proterozoic granite between Cape Leeuwin and Cape Naturaliste, much of it blanketed by Pleistocene dune calcarenite (Tamala Limestone), and the low sedimentary Perth Basin that extends from the south coast right through to the Murchison River. Apart from the southern Geographe Bay, most

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of the coast faces west into the prevailing southwest swell and winds. More details on the geology, climate and coast processes are provided in Chap. 31.

This is the most highly developed part of the Western Australian coast with cities, towns and coastal communities spread from Augusta in the south to Kalbarri in the north, with the large Perth in the centre. From the south the main towns and communities are Margaret River (4500), Dunsborough (5500), Busselton (15,500), Bunbury (33,000, region 67,000), Mandurah (88,000), Rockingham (14,500), Kwinana (40,000), Fremantle (32,000), Perth and its northern suburbs to Two Rocks (2,000,000) and then the smaller towns of Guilderton (200), Seabird (100), Ledge Point (210), Lancelin (600), Wedge Island (shacks), Grey (shacks), Cervantes (500), Jurien (1800), Green Head (300), Leeman (400), Dongara (1400), the large Geraldton (37,500), Horrocks (150), Gregory (<100) and Kalbarri (1500). As a consequence of the high coastal population, there has been considerable development along the coast including the construction of a number of marinas, groynes and training walls. These will be discussed in the following SCs.

The climate ranges from Mediterranean in the south (960 mm at Cape Leeuwin, Csb) to warmer Mediterranean in the north (347 mm at Kalbarri, Csa) (Table 31.1 and Fig. 1.8) with a pronounced winter maximum in the rainfall. A series of 18 small rivers and streams drain the coastal hinterland, of which only 4 are permanently open: the Leschenault Inlet, Peel-Harvey (trained), the Swan Estuary (trained) and the Murchison. Of the remaining, 13 are open during the winter season, and 1 is permanently closed (Table 31.2). None of the rivers are delivering bedload to the coast, though they would have deposited terrigenous sediment across the shelf during low sea levels.

32.2 Sediments

Sediments along the southwest region are predominately well- to moderately well-sorted, fine to medium carbonate-rich sand, with carbonate averaging 71% (Table 32.1). The high proportion of carbonate reflects both the lack of terrigenous sediments and the productive cool-water carbonate shelf, coupled with sufficient wave energy to erode the carbonate and transport the detritus shorewards in large quantities. There is considerable longshore variation in both sand size and percent carbonate (Fig. 32.1) indicative of lack of longshore transport, variable sediment sources and numerous closed SCs and TCs.

Table 32.1 Southwest region beach sand characteristics

	Southwest	Rottnest Is.
n	207	24
Size (mm)	0.36	0.41
σ (mm)	0.20	0.24
Sorting	0.53	0.52
σ (sorting)	0.12	0.17
% carbonate	71.2	81.4
σ (%)	27.2	18.4

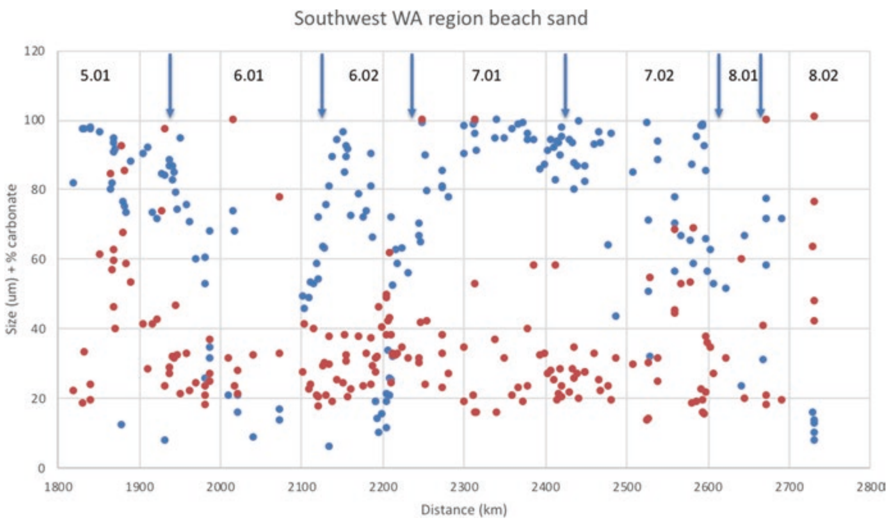

Fig. 32.1 Southwest Western Australia region and PCs sand size (red, μm) and percent carbonate (blue). Arrows indicate PC boundaries. Distance from SA/WA border

32.3 Coastal Processes

Most of the southwest region faces west into the prevailing southwest waves and south through westerly winds. As seen in Chap. 31, deepwater wave energy is moderate to high averaging ~2 m (T = 12 s) from the southwest along the entire division (Fig. 31.2), with a seasonal winter shift more to the west. Tides are micro along the entire coast ranging from 1 m at Cape Hamelin to 0.7 m at Kalbarri. Nearshore and breaker wave height is severely constrained along large sections of the coast by shore-parallel calcarenite reefs which in the most sheltered locations reduce wave height to 0.1–0.2 m. Owing to the reduction in deepwater waves, the locally generated predominately southerly wind waves and wind-generated currents become increasingly important and make a significant contribution to coastal processes including longshore sand transport (Masselink 1996; 1998). Also as discussed in 31.4, seiching, resonance within the reef 'lagoon', meterotsunamis and shelf waves all contribute to variations in sea-level and coastal processes.

32.4 Beaches

The southwest region is characterised by its extensive near continuous beach systems, with 516 beaches occupying 815 km (89%) of the coast, the remainder predominately low dune calcarenite bluffs together with some calcarenite-capped granite in the south. The beach types and states reflect the overall low level of

Table 32.2 Southwest WA region beach types and states

BS	BS	No.	%	Length (km)	%	Mean length (km)
4	TBR	30	5.8	65.9	8.1	2.2
5	LTT	54	10.5	116.8	14.3	2.2
6	R	414	80.2	581.4	71.3	1.4
11	B + SF	16	3.1	50.8	6.2	3.2
14	R + RF	2	0.4	0.2	0.0	0.1
		516	100	815.1	100	1.6

Table 32.3 Southwest WA region and PC barrier dimensions

PC:WA	WA05.01	WA06.01	WA06.02	WA07.01	WA07.02	WA08.01	WA08.02	Region
No.	19	9	7	5	10	4	3	57
Total length (km)	64.5	164.3	100.5	123.5	176.5	22	49	700.3
Mean min width	800	410	720	2900	1150	425	400	–
Mean max width	1500	1120	3800	8800	2450	875	1900	–
Mean height (m)	44	12	19	34	16	16	20	–
Area (ha)	13,264	13,355	27,850	63,000	40,735	1650	6650	166,504
Unstable (ha)	450	3222	1100	7250	16,300	500	2480	31,373
Total volume (M m^3)	2582	2430	4032	12,600	8616	283	830	31,302
Unit volume (m^3 m^{-1})	40,034	14,791	40,124	102,024	48,820	12,840	16,938	44,799

breaker wave energy, with 91% by number and 86% by length sheltered WD R and LTT, together with 3% and 6% sand flats, and just 6% and 8% exposed TBR (Table 32.2). Short (2005) provides a description of all the region beaches.

32.5 Barriers

Pleistocene inner barrier systems line much of the coast with Holocene outer barrier systems occupying 700 km (76%) of the coast (Table 32.3). They range from extensive regressive foredune ridge plains in Perth region to massive transgressive dunes in the north together with clifftop dunes in the south. Like the beaches, the barrier are composed of carbonate-rich sand which over time leads to the development of calcrete soils and the lithification of the dunes into dune calcarenite. The calcarenite has a profound impact on the subsequent coastal morphology, dynamics and evolution, as indicated by the impact of the drowned Pleistocene lower sea-level barriers

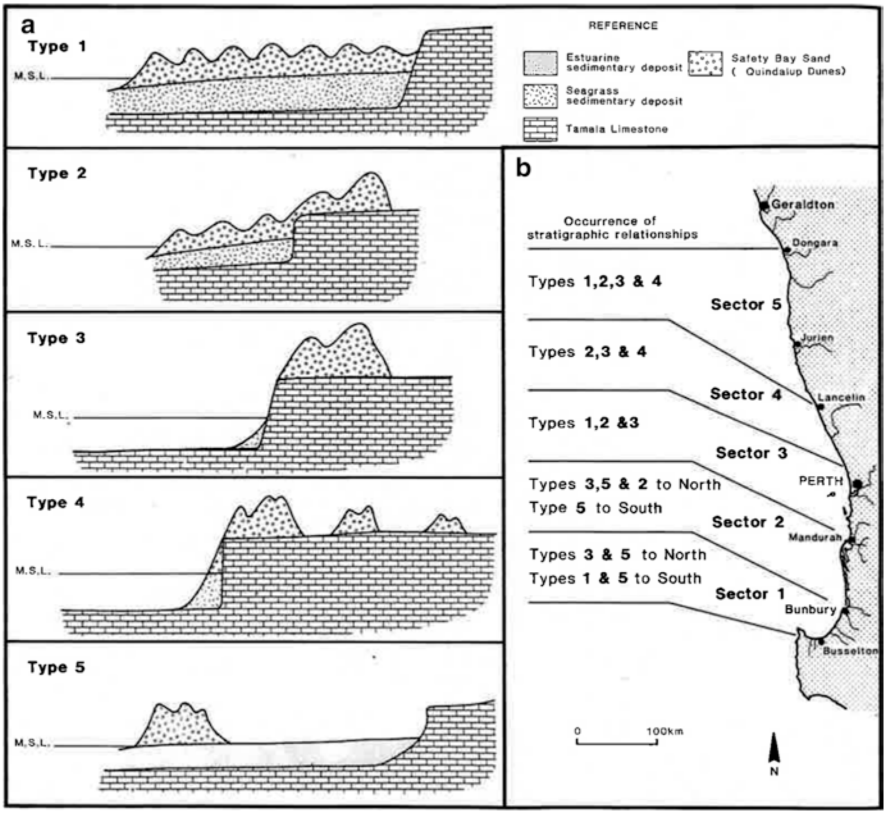

Fig. 32.2 The five barrier types and their distribution along the southwest WA coast as characterised by Semeniuk et al. (1989) (published with permission of the Royal Society of Western Australia)

on the present shelf and coast. The barriers cover an area of 166,504 ha, of which 19% is presently unstable. They have a total volume of 31,302 M m^3 and a per metre volume of 44,799 m^3 m^{-1}, which is comparable to the higher energy southern coast.

Semeniuk et al. (1989) identified five barrier types between Geographe Bay and Dongara (SCs:WA06.01.01-07.02.04) (Fig. 32.2). Type 1 is a regressive beach-foredune ridge plain; type 2 has inner dune transgression over dune calcarenite and outer regressive ridges; type 3 has transgressive dunes on top of the dune calcarenite and a narrow Holocene beach (i.e. clifftop dunes); type 4 has episodes of dune transgression over the calcarenite and a Holocene beach; and type 5 has an outer Holocene barrier separated from the calcarenite by an interbarrier depression. As indicated in Fig. 32.2, these can occur in close proximity with all five types found along the southwest coast.

32.6 Sand Transport

The coast north from Geographe Bay faces west and is exposed to southerly swell and wind waves and strong southerly winds. The combination of oblique southerly waves, wind-driven northerly currents and a sandy shore provide the ideal environment for northerly longshore sand transport. As the coast has few headlands and physical obstacles, the potential transport is primarily dependent on wave energy and angle at the shore. However, the substantial wave attenuation and refraction that occurs across the Pleistocene reefs leads to both long sections of very low wave height (0.1–0.2 m) and refracted waves arriving more normal to shore. These two combine to lower, stop and even reverse sand transport in certain locations, as will be discussed below in the SCs.

In Geographe Bay a series of shallow migratory shore transverses sand waves 1–3 km long, with ~1 km spacing extend from the shore to 5 m depth and occupy the southern 40 km of the bay shore. The sand waves are asymmetrically in section with a gentle stoss slope rising to a scarped downdrift crest. The crests are covered with pioneer *Amphibolis antarctica* and then *Posidonia* seagrass, while the swales are bare sand (Paul 1978). They have a considerable impact of shoreline behaviour modifying inshore wave attenuation and refraction and contributing to longshore sand transport (Pattiaratchi et al. 2017) as will be discussed in Sect. 32.8.1.

The southwest region contains 6 PCs and 17 SCs (Table 32.4 and Fig. 32.3) which will each be discussed below. There have been detailed assessments of most of this region and the compartments along the Vlamingh coast (PCs:WA06.01-02) (Stul et al. 2015), the Mid-West coast (PCs:WA07.01-02) (Stul et al. 2014a) and the Northampton coast (PCs:WA08.01-02) (Stul et al. 2014b). Each of these will be discussed below in the relevant PCs (Sects. 32.8, 32.9, 32.10, 32.11, 32.12 and 32.13).

32.7 PC/SC:WA05.01.01 Cape Leeuwin–Cape Naturaliste

PC:WA05.01 contains just one SC (WA05.01.01) which extends from Cape Leeuwin essentially due north for 112 km to Cape Naturaliste (Fig. 32.4a). This is an exposed high energy west-facing coast, which is littered with near continuous calcarenite reefs, rocks and headlands, including many with a granite base, which both break the coast up into numerous small beaches, as well as generating considerable wave attenuation and refraction of the inshore waves, resulting in a large number of sheltered lower energy beaches. In addition, Pleistocene dune calcarenite and Holocene transgressive dunes blanket much of the coast usually extending a few kilometre inland and rising to 100–200 m. As a consequence, the coastal strip was unsuitable for agriculture and remained undeveloped and is now contained in the Leeuwin-Naturaliste National Park. The park occupies 103 km (92%) of the coast, the remainder occupied by the small coastal communities of Hamelin, Prevelly Park, Gracetown

Table 32.4 Southwest Western Australia region: PCs and SCs

PC no.[a]	Name	Boundaries	Beach ID[b]	No. beach	km[c]	Total km
Southwest WA						
WA05.01.01		C Leeuwin-C Naturaliste	WA 618-730	113	1818–1930	112
WA06.01.01	Geographe Bay	C Naturaliste-Casuarina Pt	WA 731-761	31	1930–2018	88
WA06.01.02		Casuarina Pt-Robert Pt	WA 762-789	28	2018–2119	101
WA06.01				*59*		*189*
WA06.02.x1	Rottnest Island		RI 1-63	(63)	1–36	(36)
WA06.02.01		Robert Pt-Challenger Beach	WA 790-818	29	2119–2174	55
WA06.02.02	Perth coast	Challenger Beach-Pinnaroo Pt	WA 818-862	44	2174–2217	43
WA06.02.03		Pinnaroo Pt-Pt Moore R	WA 863-906	44	2217–2272	55
WA06.02				*117*		*153*
WA07.01.01		Moore R-Ledge Pt	WA 907-921	15	2272–2301	29
WA07.01.02		Ledge Pt-Wedge Is Pt	WA 922-935	14	2301–2342	41
WA07.01.03		Wedge Is Pt-Thirsty Pt	WA 936-963	28	2342–2380	38
WA07.01.04		Thirsty Pt-North Hd	WA 964-987	24	2380–2416	36
WA07.01				*81*		*144*
WA07.02.01		North Hd-Green Hd	WA 988-1012	25	2416–2436	20
WA07.02.02		Green Hd-Illawong	WA 1013-1052	40	2436–2477	41
WA07.02.03		Illawong-Cliff Hd	WA 1053-1057	5	2477–2499	22
WA07.02.04		Cliff Hd-Leander Pt	WA 1058-1061	4	2499–2528	29
WA07.02.05		Leander Pt-Nine Mile Beach	WA 1062-1071	10	2528–2546	18
WA07.02.06		Nine Mile Beach-C Burney	WA 1072-1077	6	2546–2583	37
WA07.02.07		C Burney-Glenfield Beach	WA 1078-1090	13	2583–2608	25
WA07.02				*103*		*192*
WA08.01.01		Glenfield Beach-Bowes R	WA 1091-1104	13	2608–2644	36
WA08.01.02		Bowes R-Broken Anchor Bay	WA 1105-1116	12	2644–2665	21
WA08.01				*26*		*57*
WA08.02.01		Broken Anchor -Murchinson R	WA 1117-1133	17	2665–2734	69
WA05–08		Region WA05-08		516		916

[a]NCCARF compartment number
[b]ABSAMP beach ID
[c]Clockwise distance from SA/WA border

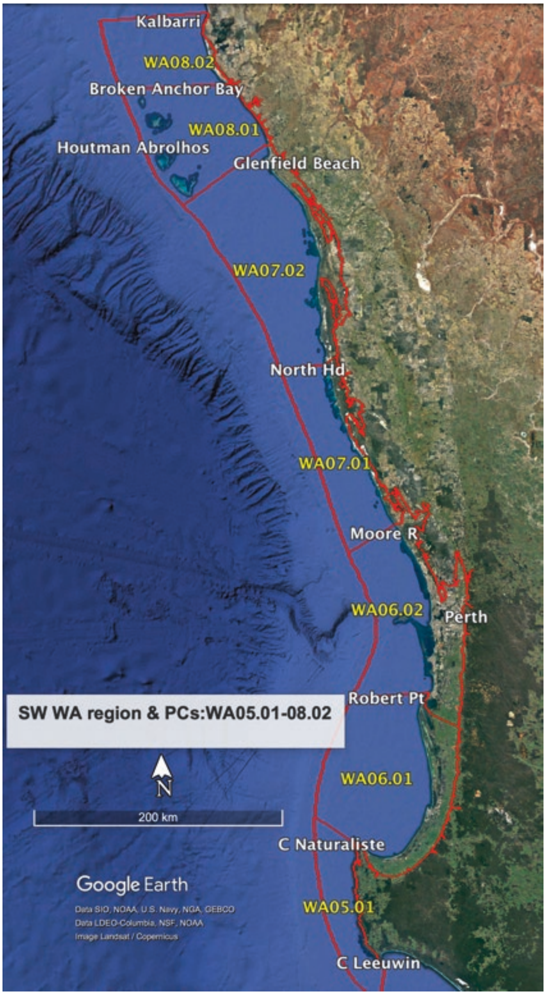

Fig. 32.3 The southwest Western Australia region and its seven PCs. (Source: Google Earth)

and Yallingup. There is just one river, the Margaret, which is seasonally closed and not delivering any bedload material to the coast. The beach sand is predominately well- to moderately well-sorted fine though medium to coarse sand (mean, 0.5 mm; σ, 0.21 mm) averaging 83% carbonate (σ = 18%). As shown in Fig. 32.1 there is considerable longshore variation in size (0.18–0.92 mm) and percent carbonate (12–98%), indicative of both variable sediment sources and lack of longshore transport owing to the numerous closed TCs.

This SC contains 113 beaches with an average length of just 0.6 km (Table 32.5). They are predominately reef-sheltered R and LTT (82%), with just 16 TBR occupying 17% of the beaches by length. The beaches occupy 68 km (91%) of the shore and include the longer LTT Deepende (5.3 km, WA 631; Fig. 32.5a) and Boranup (7.8 km, WA 643) both located in the south and sheltered by inshore reefs. Most of

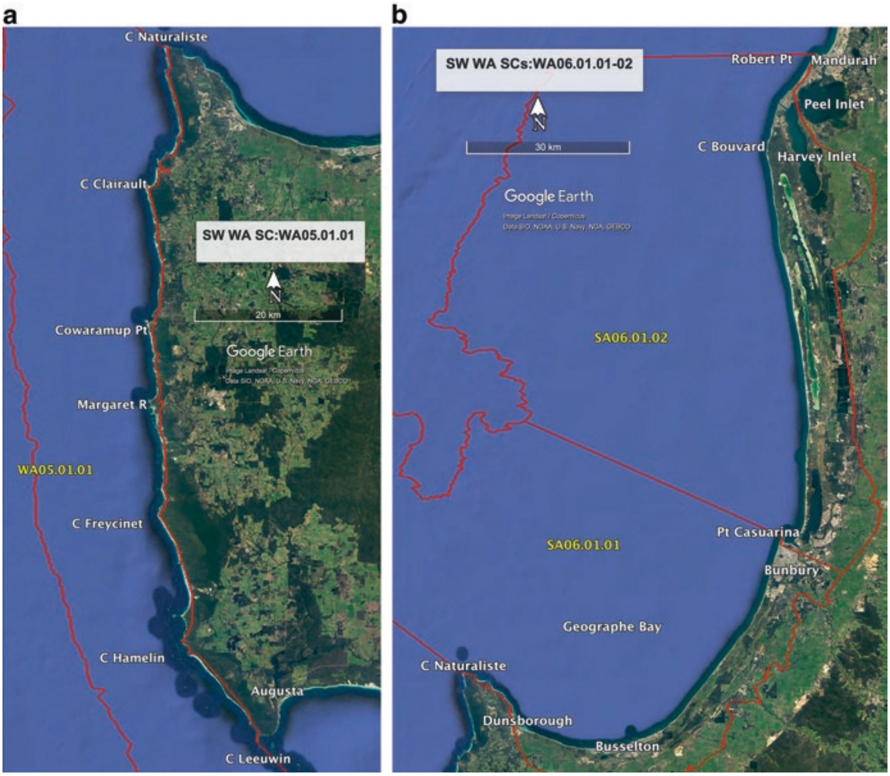

Fig. 32.4 (**a**) PC/SC:WA05.01.01 and (**b**) SCs:WA06.01.01-02. (Source: Google Earth)

Table 32.5 PC/SC:WA05.01.01 beach types and states

BS	BS	No.	%	km	%	Mean (km)	σ (km)
4	TBR	16	14.3	11.6	17.1	0.7	0.6
5	LTT	17	15.2	20.8	30.7	1.2	2.0
6	R	77	68.7	35.2	51.9	0.5	0.7
14	R + RF	2	1.8	0.2	0.3	0.1	–
		113	100	67.8	100	0.6	–

the beaches range from a few tens to hundreds of metre in length and are bordered by calcarenite rocks, reefs and rocky points (Fig. 32.5b).

There are 19 Holocene barriers occupying 65 km (58%) of the coast, the remainder primarily Pleistocene dune calcarenite. All the barriers consist of transgressive dunes, most climbing up over the Pleistocene systems, and some reaching heights of 220 m, with an average maximum elevation of 90 m. Along the southern and central section of the coast, the dunes extend few kilometre inland,

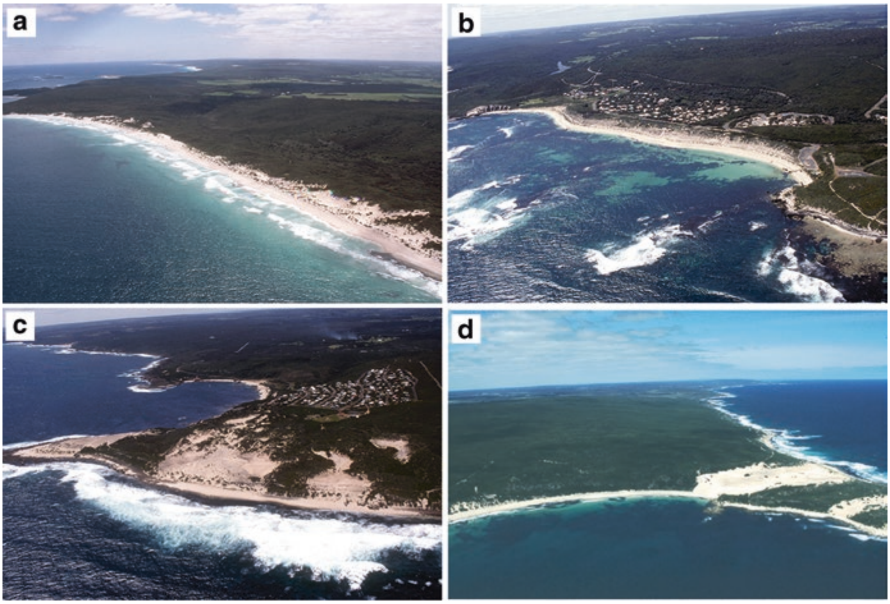

Fig. 32.5 (**a**) Deepende beach (WA 631) receives moderate waves and has a rip-dominated surf zone; (**b**) Gnarabup beach (WA 658) is sheltered in lee of inshore calcarenite reefs, with Prevelly Park community located behind the foredune; (**c**) headland overpassing of the dunes at Cowaramup Point (WA 677), and the community of Gracetown behind; and (**d**) headland overpassing at Injidup Point (WA 705). (Photos: AD Short)

while north of Cowaramup, they reach only a few hundred metre inland. The Holocene barriers have a total volume of 2582 M m^3 (40,034 m^3 m^{-1}), compared to a total Pleistocene volume on the order of 42,000 M m^3 which represents 450,000 m^3 m^{-1}.

While this coast is oriented obliquely to the prevailing southwest swell, there is little evidence of longshore transport owing to the numerous reefs and points and as indicated by the highly variable sediment size and percent carbonate. There has been headland overpassing at Cape Clairault and in the recent past at Cowaramup (Fig. 32.5c), at Injidup Point (Fig. 32.5d) and at Cape Naturaliste, which is defined by Stul et al. (2015) as an open compartment boundary. Today however the beaches have receded into their sheltered embayments, the sand ramps have been eroded and the dunes are essentially stable with only 3% unstable. This is a closed SC, apart from the past Cape Naturaliste overpassing, containing a number of primarily closed TCs with some linked by overpassing.

32.8 PC:WA06.01 Geographe Bay

PC:WA06.01 includes the open north-facing shallow Geographe Bay which curves into the north-trending coast up to Robert Point at Mandurah (Fig. 32.4b). It extends for 189 km from Cape Naturaliste to the point and is very much dominated by near continuous sandy beaches. It includes the towns of Dunsborough, Busselton, Bunbury and Mandurah and contains three SCs. Sediments along this section of coast are predominately moderately well-sorted, fine to medium sand, with percent carbonate decreasing from 60%–98% in the south to between 20% and 60% in the north (mean, 63%; σ, 25%) (Fig. 32.1). The PC has 59 beaches that occupy 175 km (93%) of the coast, the remainder the granite to the east of Cape Naturaliste and some small sections of calcarenite. The beaches range from very sheltered B + SF to low energy R and LTT (Table 32.6). The beaches are part of nine barrier systems, which grade from regressive in the south to transgressive in the north (Fig. 32.2), and occupy a similar length of shore (164 km, 87%) and have a total volume of 2430 M^3 m^3, with a low per metre volume of 14,791 m^3 m^{-1} (Table 32.3), the result of both northerly orientation of the southern bay and generally lower wave conditions.

32.8.1 SC:WA06.01.01 Cape Naturaliste–Casuarina Point

SC:WA06.01.01 encompasses Geographe Bay, an open 40 km wide north-facing bay bounded by dune-capped granite of Cape Naturaliste in the west and the low calcarenite Casuarina Point at Bunbury in the east with 88 km of curving, predominately sandy coast in between (Fig. 32.4b). The southern bay is relatively shallow with the 5 m contour usually located 2–3 km offshore in the south, narrowing to ~1 km north of the Capel River mouth. Beaches occupy 78 km (89%) of the shore, with a mix of calcarenite and granite along the 15 km long southwestern section between Cape Naturaliste and Dunsborough, with sand then extending up to Casuarina Point where there is a 1 km long section of beachrock. The beaches are all sheltered by Cape Naturaliste and their initial northeast and then northwest orientation (Fig. 32.4b). They are predominately B + SF (46 km, 52%) particularly between Point Dalling and Peppermint Grove (Fig. 32.6a), with the remainder R-LTT in lee of Cape Naturaliste and north of Peppermint Gove.

Table 32.6 PC:WA06.01 beach types and states

BS	BS	No.	%	km	%	Mean (km)	σ (km)
5	LTT	7	11.9	5.8	3.3	0.8	0.7
6	R	42	71.2	123.8	70.7	2.9	8.8
11	B + SF	10	16.9	45.5	26.0	4.6	5.6
		59	100	175.1	100	3.0	–

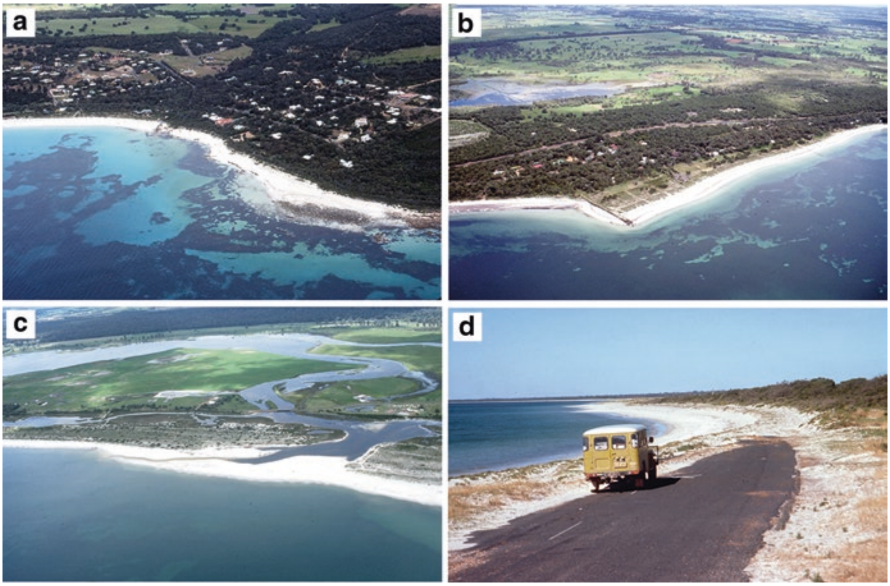

Fig. 32.6 (**a**) Low energy beaches, reefs, seagrass and sand flats in Eagle Bay (WA 736); (**b**) groyne-trapping easterly moving sand at Siesta Park (WA 748); (**c**) the deflected mouth of Wonnerup Inlet (WA 754); and (**d**) shoreline and road erosion caused by a migratory sand wave-salient on Wonnerup beach (WA 756). (Photos: AD Short)

As mentioned in Sect. 32.6, the sand flats have well-developed obliquely attached transverse sand waves which extend up to 1.5 km in to the bay and have amplitudes up to 3 m. The waves move slowly counter-clockwise up the coast, and as they do, their protruding points of shoreline attachment also migrate causing the shoreline to accrete on the downdrift side and erode ~10 m on the embayed updrift side which generates a natural zone of shoreline oscillation. Unfortunately this zone has been developed in some locations placing infrastructure (Fig. 32.6d) and property at risk. In addition, wave refraction over the sand waves induces zones of higher and lower breaker waves which strengthen currents over the crests and accentuate shoreline erosion in the embayments (Pattiaratchi et al. 2017). Since the 1950s this localised erosion has resulted in the construction of groynes, seawalls and sand tubes (Paul 1978). Based on a comparison of the 1965 aerial photographs and 2017 Google Earth images (Fig. 32.7), the sand waves appear to migrate on the order of ~10 m year^{-1}, which agrees with Pattiaratchi et al. (2017) who measured sand wave migration of 7.5 m year^{-1}. Figure 32.7 also shows the considerable variation in sand wave morphology and the buildup of sand and seagrass against the southern Port Geographe training wall (Pattiaratchi et al. 2015), with erosion threatening the road on the northern side. The seagrass accumulation at Port Geographe continues to occur on the updrift side even following the 2014 realignment of the entrance wall and replacement of downdrift groynes and beaches with a seawall. Elsewhere the

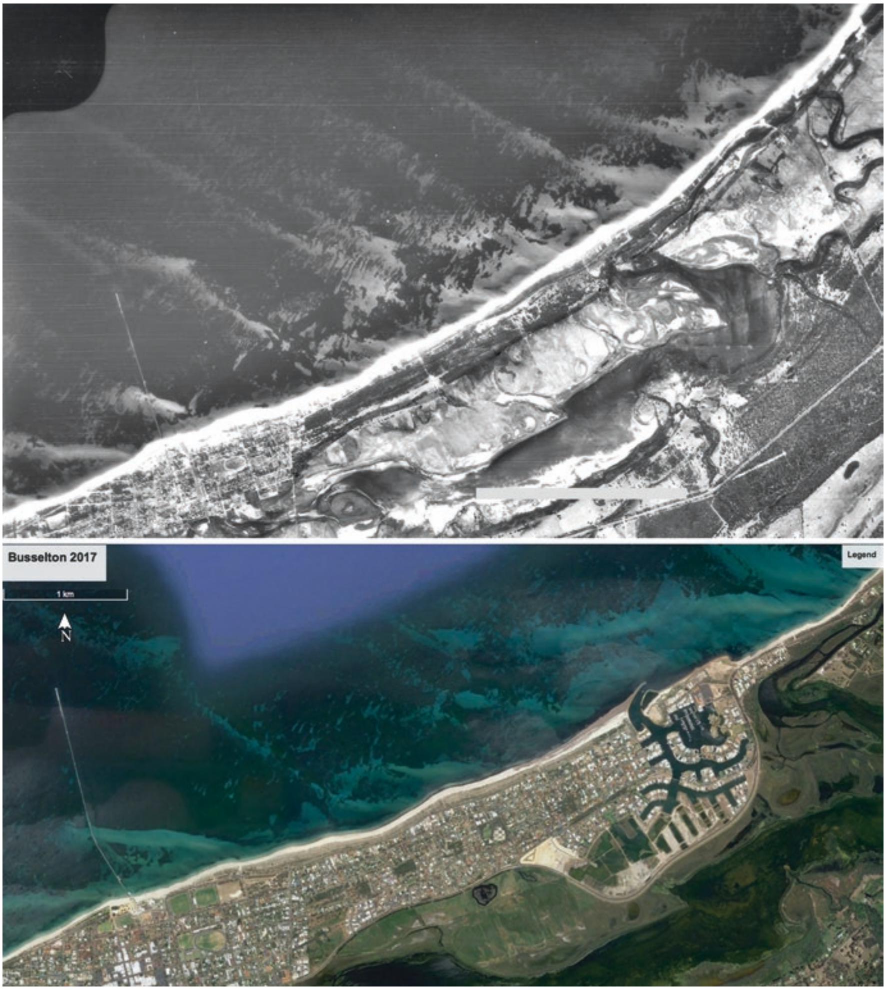

Fig. 32.7 (**a**) Aerial photograph (5.01.65) and (**b**) Google Earth image (6.11.17) of the Busselton shoreline and its migratory transverse sand waves and also the Port Geographe development with seagrass building up against the oblique entrance wall. (Source: Google Earth)

northerly sand transport is causing the easterly deflection of inlets (Fig. 32.6c) and buildup against any groynes or obstacles (Fig. 32.6b).

Barr et al. (2017) provide an overview of the issues and management of the Busselton coast, the most highly developed in the SC. They reported shoreline recession of 2–3 m year^{-1}, extreme ocean levels to 1.8 m and potential inundation of much of the town with a 3.4 m ocean level. At present these issues are being addressed with mixed success by minor sand nourishment, dune restoration, groynes, seawalls and minimum floor levels. They also recommended a better understanding of the migratory shore transverse sand waves which have a major impact on shoreline stability.

There are six barrier systems along this coast, two small barriers at Bunker and Eagle bays (Fig. 32.6a) and the 68 km long Dunsborough-Busselton-Bunbury barrier which is cut into four systems by tidal inlets (Fig. 32.6c). Most of the barriers range in width from 130–510 m with the widest reaching 1 km. In the south and central section, the barriers are regressive consisting of a few low beach-foredune ridges, generally backed by a backbarrier depression and inner Pleistocene barrier (types 1 and 5, Fig. 32.2). North from Minninup they increase to 20–40 m in height and become more unstable consisting of generally vegetated blowouts and parabolics extending up to 1 km inland (type 3, Fig. 32.2). They cover an area of 2755 ha, most of which is well-vegetated and stable and have a total volume of 310 M m^3 (4290 $m^3 m^{-1}$) an order of magnitude less than the adjoining and substantially higher energy Leeuwin-Naturaliste SC. This volume is however the same order of magnitude as the 500 M m^3 volume estimated for Geographe Bay barriers by Searle et al. (1988a, b).

32.8.2 SC:WA06.01.02 Casuarina Point–Robert Point

SC:WA06.01.02 commences at Casuarina Point and after curving round in the small Koombana Bay trends almost due north for 70 km to Cape Bouvard where it curves around the calcarenite coast to trend north-northeast to the northern boundary at Mandurah's Robert Point (Fig. 32.8b) a total distance of 101 km (Fig. 32.4b). This SC is bookended by the major towns of Bunbury and its port in the south and Mandurah in the north, with Mandurah spreading down the coast for 15 km to Melros. There has been considerable modification of the Koombana Bay shoreline including the construction of an attached breakwater on Point Casuarina-McKenna Point; harbour jetties and facilities in lee of the breakwater; a large inner harbour facility; relocation of the Leschenault Inlet entrance to a new trained entrance called The Cut located 3 km northeast of the old entrance; and diversion of the mouth of

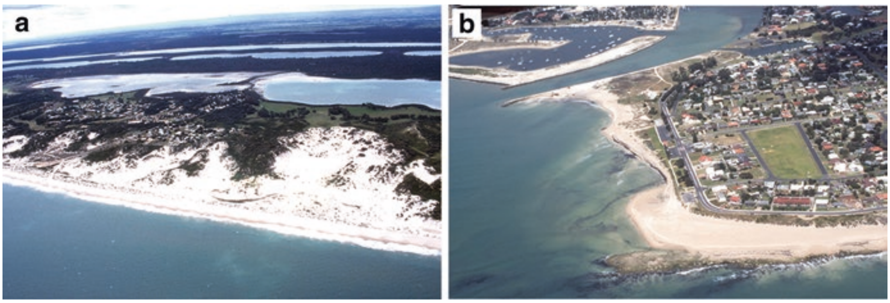

Fig. 32.8 (**a**) Active blowouts at Preston Beach (WA 771); and (**b**) Halls Head beach (WA790) is bounded by Robert Point (foreground) and the trained entrance to the Peel Inlet. (Photos: AD Short)

the Preston River along the lee of the inner harbour facilities. There is an erosion hotspot at The Cut and at Binningup located 18 km to the north (DOT 2016).

The inner shelf consists of a limestone platform that is >10 km wide in the south, narrowing to ~6 km north from Myalup where a ridge is located along the outer edge of the platform and extends in a discontinuous fashion to Robert Point. The platform and its ridges modulate wave height and direction along the shore.

Beaches occupy most of the coast (97 km, 96%) and are composed of moderately well-sorted fine to medium sand with carbonate ranging from 10% to 70% (mean, 39%; σ, 22%). The coast remains sheltered by both Cape Naturaliste and inshore reefs resulting in low breaker waves (~0.5 m) and predominately R and some LTT beaches. The beaches are near continuous with Binningup beach 22 km long and Myalup-Cape Bouvard 54 km. The barriers are transgressive along their entire length consisting of generally blowout-parabolic rising to 20–30 m and reaching 40 m in places and extending on average 2 km inland and up to 3 km at Cape Bouvard (types 2 and 3, Fig. 32.2). The Bouvard barrier is backed by a series of elongate lakes occupying the backbarrier depression then the Pleistocene barrier (type 5) which reaches the coast at Cape Bouvard. There is minor to moderate dune activity up to Yalgorup (Fig. 32.8a), with generally stable dunes to the north, with overall 20% of the dunes unstable (type 2). The barriers cover an area of 16,110 ha and have a volume of 2740 M m^3 (16,679 m^{3-1}), both substantially larger than the southern part of this SC. It is also close to the 3000 M m^3 Searle et al. (1988a) estimated for the Leschenault-Preston barrier system.

The evolution of this section of coast has been intensively studied by Semeniuk and Meagher (1981), Semeniuk and Johnson (1982, 1985), Semeniuk (1983, 1985, 1996, 1997), Semeniuk and Searle (1987) and Semeniuk et al. (1988, 2000). Semeniuk (1996) proposes a model of barrier evolution which is related to the Holocene sea level transgression and the relative depth of the nearshore limestone reefs, which affect both wave attenuation and refraction and thereby sediment transport and shoreline orientation. The initially sheltered coast regressed seawards in lee of the reefs as sheltered cuspate forelands until ~8 ka, following which the reefs were inundated allowing breaker wave energy to increase leading to erosion of the forelands and dune transgression which has now largely stabilised. An overview of the long elongate Leschenault Inlet estuary which is impounded behind the Bouvard barrier is presented by Semeniuk et al. (2000).

Semeniuk (1997) also explains the variation in quartz-carbonate sedimentation in this region, finding that when the coast was sheltered by nearshore reefs, seagrass meadow and carbonate production was high, and the carbonate-enriched sand was transported shorewards to build regressive beach-foredune ridge systems. Then as sea level rose and it became more exposed, quartz sand was sourced from the south and transported northwards aggrading the dune-capped barriers with no shoreline progradation.

32.8.3 Sand Transport

Figure 31.3 provides an overview of both the onshore and northerly longshore sand transport between Cape Naturaliste and Perth. Sand is moving counter-clockwise across the inner shelf and along the Geographe Bay shoreline (PC:WA06.01), with the PC and two SCs all having ‘open’ boundaries (Stul et al. 2015). The transport is evident from the east-northerly deflection of the tidal inlets (Toby, Wonnerup; Fig. 32.6c); the ongoing erosion problems associated with the transport (Paul 1978; Andrews 1981); the orientation of the shore transverse sand waves that extend from Dunsborough to Wonnerup Inlet; the migratory cuspate forelands attached to these sand waves; and the trapping of sand and seagrass on the west/southern side groynes (Fig. 32.6b) and training walls, as at Port Geographe (Fig. 32.7b; Pattiaratchi et al. 2011, 2015) and Port Bouvard. Brearely (2005) stated that at Toby Inlet the transport rate was 25,000 m^3 year^{-1}, while Semeniuk and Searle (1987) estimated that 100,000 m^3 year^{-1} was moving along this coast, though neither gave reasons for their estimation. Byrne et al. (1987) calculated rates of 80,000 m^3 year^{-1} at Bunbury, decreasing to 60,000 m^3 year^{-1} at Leschenault and 40,000 m^3 year^{-1} at Preston and then peaking at 150,000 m^3 year^{-1} at Dawesville, before dropping to 75,000 m^3 year^{-1} at Mandurah, while Moloney and Paul (1999) calculated 85,000 m^3 year^{-1} for Dawesville.

This latter rate is confirmed by the mechanical bypassing via slurry lines at the Dawesville canal and Mandurah of 100,000 and 85,000 m^3 year^{-1}, respectively, together with an addition 10,000 m^3 year^{-1} trucked from the southern Dawesville sand trap to the northern Falcon St (Bicknell 2006). Bicknell also found that the majority of the sand was moved by southwesterly swell waves with most movement occurring during winter storms when it moved as pluses estimated to be between 10,000 and 30,000 m^3. Based on the above it appears that some sand is entering the PC bypassing and overpassing Cape Naturaliste. Then commencing in the south at Dunsborough, the sand moves east and then northwards along the Geographe Bay shoreline, with the volume increasing northwards and peaking at about 100,000 m^3 year^{-1}. As there is no net recession at Dunsborough, the source of the sand must be from the nearshore and around and over Cape Naturaliste. This PC is therefore leaky, receiving sand at its southern boundary and exporting sand at its northern boundary (Fig. 31.3). The transport is driven by the prevailing southwest swell, particularly during high wave events when storm waves refract around Cape Naturaliste and reach the entire bay shoreline (Brearely 2005, p. 252).

Thom et al. (2018) provide a more detailed assessment of the main components relating to inner shelf sand transport along this coast, particularly along and across the shallow carbonate platforms. They found sources which include erosion of cemented carbonate-quartz sands that form submarine linear ridges, pavements and platforms, together with biogenic production across the reefs and seagrass banks. The sand is transported both onshore and longshore by the southerly swell and wind waves. A similar mechanism is expected to operate along the length of the southwest’s carbonate platforms.

Stul et al. (2015) provide a detailed study of the sediment cells (compartments) in this region between Cape Naturaliste to Moore River (PC:WA06.01-02). They mapped the entire region identifying primary, secondary and tertiary sediment cells for which they provide a rationale for the selection of the cells and their offshore and alongshore boundaries. They also provide maps for each cell and note whether each boundary is fixed or ambulatory and open or closed. Besides the 2 PCs and 5 SCs listed in Table 32.4, Eliot (2011) mapped 16 TCs along this section of coast.

32.8.4 PC Overview

The Geographe Bay to Mandurah coast is sheltered in lee of Cape Naturaliste and has acted as a major sediment trap, with sand deposited in near continuous Pleistocene and Holocene barriers, as well as conduit for northerly sand transport. The inner partly lithified Pleistocene barrier parallels much of the modern coast, with an elongate interbarrier depression, occupied by elongate lakes and lagoons, separating it from the outer Holocene barrier. As Semeniuk (1997) has shown, the Holocene barrier evolution is linked to the Holocene sea level and the role of nearshore limestone reefs (submerged Pleistocene barriers) which modulate wave energy and sediment production along the coast. When the coast was sheltered by the reefs, seagrass meadows supplied carbonate-rich sediment to the cuspate forelands, while when the coast is more exposed to waves, northerly longshore transport supplied quartz-rich sand to build stationary-transgressive dune systems, with both scenarios varying in time and space Semeniuk and Semeniuk (2019).

At present the coast is experiencing counter-clockwise longshore sand transport that increases northwards with increasing wave energy, reaching on the order of 100,000 m^3 $year^{-1}$ at Dawesville-Mandurah. The northerly increase in wave energy is also reflected in the transformation of the barriers from regressive in the south to transgressive in the north. As indicated above the coast is highly sensitive to changes in sea level, and a rising sea level will increase wave height and exposure, which would be expected to accelerate longshore transport and dune activity, as well as inundating and changing the ecology the extensive wetlands, lakes and lagoons (Semeniuk and Semeniuk 2013). This PC presently has coastal erosion hotspots along the Busselton coast at Wonnerup, The Cut and Binningup (DOT 2016), with the number would likely increase with rising sea level.

32.9 PC:WA06.02 the Perth Coast

PC:WA06.02 straddles the Perth coastline (Fig. 32.3), with Perth located on the Swan estuary, the largest open estuary on the southwest coast. The Perth coastline and hinterland is composed of Pleistocene dune calcarenite (Tamala Limestone). Its geology is described by Playford et al. (1976) and Kendrick et al. (1991) and the

Table 32.7 PC:WA06.02 beach types and states

BS	BS	No.	%	km	%	Mean (km)	σ (km)
5	LTT	9	7.7	34.5	24.5	3.8	4.9
6	R	102	87.2	101.1	71.7	1.0	1.7
11	B + SF	6	5.1	5.3	3.8	0.9	0.7
		117	100	140.9	100	1.2	–

geology of Rottnest Island by Playford and Leech (1977). Perth is bordered by a complex of large regressive barriers to the south, Garden and Rottnest calcarenite islands offshore and a series of small- to moderate-sized stable to transgressive barriers to the north. The overriding control on the coast's Holocene evolution has been the nearshore limestone platform and Pleistocene calcarenite ridges and islands located on the platform that affect wave attenuation and refraction. The attenuation maintains a largely low energy coast with $H_b \sim 0.5–1$ m, substantially lower than the H_o, while the refraction leads to the formation of several large cuspate forelands and embayments. The PC contains four SCs (Table 32.4) including Rottnest Island and three on the mainland located between Robert Point in the south and Moore River in the north a shoreline distance of 153 km. The beach sand is well to moderately well-sorted fine to medium sand (mean = 0.34 mm; σ = 0.13 mm), with carbonate averaging 58% (σ = 28%; range = 10–96%). As Fig. 32.1 indicates, there is considerable longshore variation in size and percent carbonate indicating there is unlikely to be significant longshore transport, together with a variation of local sources of carbonate and terrigenous sediment. There are 117 mainland beaches in this PC occupying 141 km (92%) of the shore. They range from a few sheltered B + SF in lee of points, to more extensive R and LTT along the reef-sheltered open coast totalling 96% of the beaches by length (Table 32.7), with no higher energy systems. The beaches face west and are backed by a mix of regressive barriers, including major cuspate forelands, and transgressive systems extending up to 4 km inland. The barriers have a total volume of 4032 M m^3, with a reasonably large per metre volume of 40,124 $m^3\ m^{-1}$ (Table 32.3), indicating that parts of the coast, particularly south of Perth, have acted as a major sediment sink.

32.9.1 SC:WA06.02x1 Rottnest Island

SC:WA06.02x1 includes all of Rottnest Island located 16 km due west of Perth. The island is 11 km long east to west and 5 km at its widest (north to south) with an area of 19 km^2 (Fig. 32.9). It is surrounded by a ~1 km wide 10 m deep limestone platform which forms numerous reefs around most of the island shore (Fig. 32.10). The island is composed of Pleistocene dune calcarenite (Tamala Limestone) blanketed by hummocky Holocene dunes rising to a maximum height of 46 m at Wadjemup Hill, together with some remnant fringing Pleistocene coral reef limestone. The

Fig. 32.9 SC:WA06.02.x1, Rottnest Island. (Source: Google Earth)

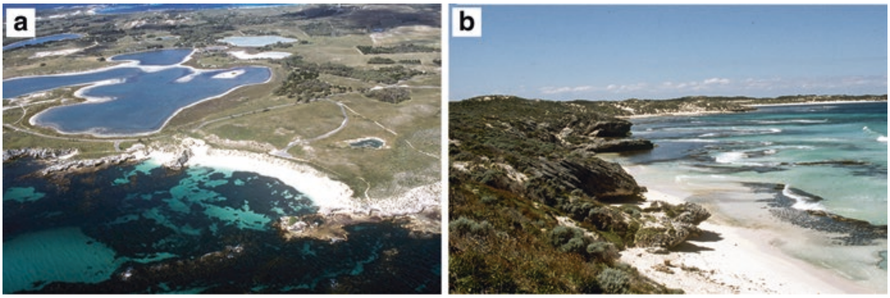

Fig. 32.10 (**a**) View south across Rottnest Island from North Point (RI 1); and (**b**) the beach at Salmon Bay (RI 31) is sheltered by intertidal and subtidal calcarenite reefs and typical of the island beaches. (Photos: AD Short)

beaches are composed of predominately well- to moderately well-sorted fine to medium carbonate-rich sand (mean = 87%, σ = 18%, Table 32.1), with Searle and Semeniuk (1988) providing a detailed examination of the island's beach sand. Rottnest has 36 km of irregular shoreline containing 63 small (mean length = 0.3 km) usually embayed and reef-protected R beaches which occupy 19 km (53%) of the shore. Stul et al. (2015) mapped ten TCs around the island, with most of the beaches separate TCs with little interaction or sand exchange as indicated by the longshore variation in both size and percent carbonate in Fig. 32.11. All the beaches are protected by a combination of inshore reefs, headland and their orientation, resulting in usually low waves (~0.5 m) at the shore. As the island is blanketed by Holocene dunes (type 3, Fig. 32.2) and based on an assumption of an average dune cover 10 m thick, this would represent 190 M m^3 (5277 m^3 m^{-1}) of marine sand.

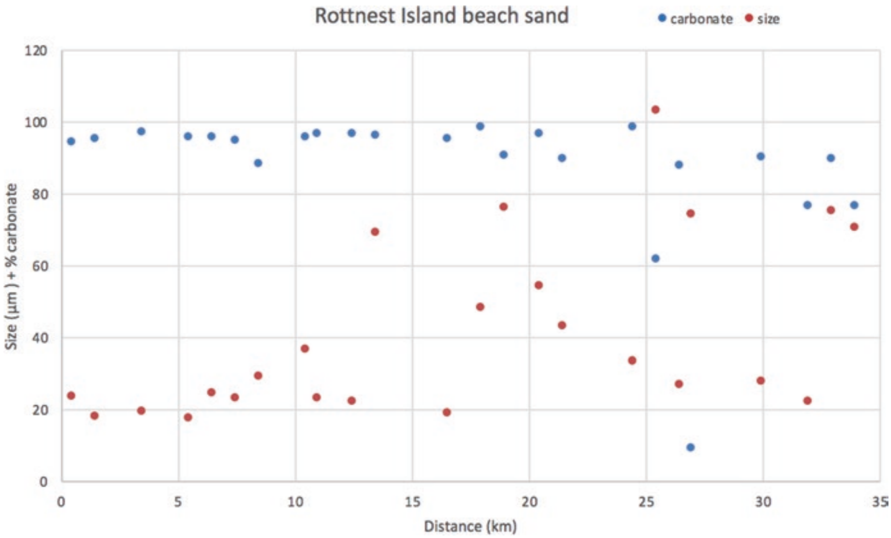

Fig. 32.11 Rottnest Island beach sand size (µm) and percent carbonate. Distance clockwise from North Point

32.9.2 SC:WA06.02.01 Robert Point–Challenger Beach

SC:WA06.02.01 commences at Mandurah's Robert Point and trends generally north for 55 km to Challenger Beach. It essentially encompasses the large Rockingham-Becher barrier system, a continuous barrier that commences at Mandurah and includes the large Becher and Rockingham cuspate forelands, terminating at the northern end of the foreland at Challenger Beach (Fig. 32.12). The limestone platform wides to 15 km off San Remo with an outer limestone ridge that continue north past Becher Point to Mersey Point where it shoals allowing the Becher-Rockingham forelands to prograde several kilometres seawards, with the ridge crest forming the 10 km long line of islands that lie across Warnbro Sound between Becher Point and Cape Peron. The ridge merges with the mainland at Cape Peron and continues on the northern side as 10 km long Garden Island, where it has been capped by Holocene dunes rising to 30–40 m.

This is a predominately sandy shore, with 29 beaches occupying 52.5 km (95%) of the coast, with dune calcarenite bluffs on Cape Peron making up the remainder. The coast is sheltered by the inshore shore-parallel calcarenite reefs which substantially lower waves at the shore and result in some B + SF in sheltered corners in lee of McKenna Point and Point Becher and in Safety Bay, with R beaches dominating the more open sections, together with LTT-TBR along the 18 km long more exposed San Remo-Secret Harbour beach (WA 793) (Fig. 32.13a) which lie south of the shoal reefs.

Fig. 32.12 SC:WA06.02.01: Robert Point to Challenger Beach. (Source: Google Earth)

This SC contains two major though continuous barrier systems which occupy all the coast and range from type 5 to 3 to 1 (Fig. 32.2). In the south is the 20 km long San Remo-Becher Point barrier (type 5 to 3), north of which is the 32 km long large Rockingham system (type 1). These are primarily regressive barriers capped by beach-foredune ridges, which increase in width and size from south to north, reaching 6 km in width and ~90 ridges in lee of Point Becher and Shoalwater Bay. This system was investigated by Searle et al. (1988a, b) who found it went through four evolutionary phases. It commenced with 20–25 m deep channel between the mainland and an offshore limestone reef at 8 ka, allowing waves to move though gaps in the barrier between 8 and 6 ka when beaches and small barriers began accumulating against the mainland Pleistocene limestone; between 6 and 4 ka sea level peaked at +2–3 m and by 6 ka the offshore reef continued to be eroded-submerged and the mainland regression continued including formation of the Point Becher and Rockingham forelands (Fig. 32.13b); as sea level fell to its present level by 2 ka, the

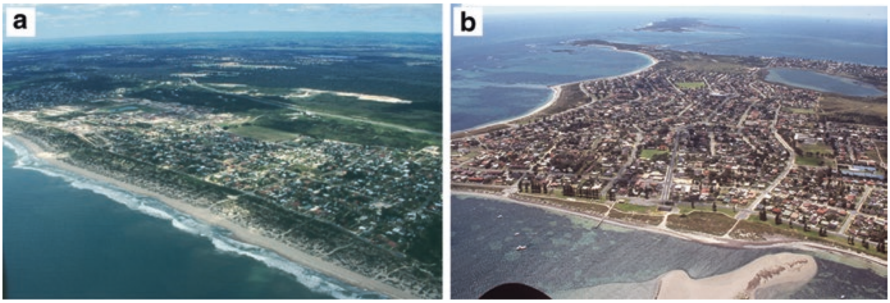

Fig. 32.13 (**a**) The moderate energy rip-dominate Secret Harbour beach (WA 793) and (**b**) view across the large Rockingham cuspate forelands, with foredune ridges underlying the entire field of view (WA796-799). (Photos: AD Short)

offshore reef was still largely submerged and barrier regression continued. At present the shoreline is experiencing some erosion on Point Becher, together with erosion hotspots along the northern Mandurah beaches and northern Warnbro (Waikiki) beach (DOT 2016). Searle et al. also found that this system has a volume of ~5000 M m^3, the largest in the southwest. Table 32.3 indicates the entire PC:WA06.02 has a volume of 4032 M m^3, of which just 700 M m^3 can be attributed to the Becher-Rockingham barrier. However, if the subaqueous volume is included, as mapped by Searle et al., it increases to 2750 M m^3. Given the nature and orientation of the regressive ridges, it appears that sediment was derived from the south converging on Point Becher, which it continues to bypass, and into Warnbro Sound and also from the nearshore with sand bypassing around Mersey Point and along Safety Bay to supply the sound, which has acted as a major sediment trap. Likewise, it appears that Shoalwater Bay and Rockingham beaches also acted as local sediment sinks as the entire systems prograded seawards. Today the barriers are largely covered by housing and infrastructure with only the Port Kennedy Scientific Park maintaining some of the original ridges. Stul et al. (2015) provide a conceptual sediment transport paths for Mandurah and Warnbro Sound (Fig. 31.3). At Mandurah they show sand bypassing around Robert Point and continuing northwards past San Remo and beyond to Becher Point, in addition to on-offshore transport across the platform. In the sound they show sand moving northwards along the outer limestone ridge across the mouth of the sound, moving shorewards across the sound floor and northwards along the sound beaches.

32.9.3 SC:WA06.02.02 Challenger Beach–Pinnaroo Point

SC:WA06.02.02 is centred on the city of Perth and the Swan estuary and located to the lee of the prominent Garden and Rottnest islands (Fig. 32.14). This is the most highly developed section of the Western Australian coast including from the south

Fig. 32.14 SC:WA06.02.02: Challenger Beach to Pinnaroo Point encompasses Perth and the Swan estuary. (Source: Google Earth)

the Jervoise Bay-Woodman Point Australian Maritime Complex, the Coogee marina, the Fremantle marina and fishing harbour, the Fremantle moles (training walls) and harbour facilities (Fig. 32.15a), all of which will interrupt the natural movement of sediment. Within the sound waves refraction around Garden Island generates a southerly reversal in sand transport along the coast south of Fremantle contributing to the Woodman Point cuspate foreland. At the Coogee marina, located to the north of the point and constructed in 2005, the attached breakwaters have interrupted an estimated 17,500 m^3 $year^{-1}$ of southerly sand transport leading to updrift accumulation and downdrift erosion, the latter anticipated by the

Fig. 32.15 (**a**) View of the heavily modified Swan River entrance and Fremantle harbour moles, with Bathers beach (WA 833) in the centre and Challenger and Fishing Boat harbours to the right; (**b**) Cottesloe Beach (WA 839); (**c**) view along Sorrento beach (WA 858) and its three groynes; and (**d**) Pinnaroo cuspate foreland (WA 863-3). (Photos: AD Short)

construction of a 350 m long seawall. To overcome this issue, periodic sand bypassing was initiated in 2009 (Hamilton and Hunt 2011). At Port Beach (WA 835) on the northern side of Fremantle Harbour walls, Barr and Boreham (2005) found that past beach progradation was linked to sand sourced from dredged material. Since this supply has ceased, the beach has been eroding requiring nourishment.

North from the harbour facilities, Port Beach is the start of a more natural shoreline containing sandy beaches separated by calcarenite bluffs, together with a few groynes (Fig. 32.15b, c) and a surfing reef (Pattiaratchi 1999; Pattiaratchi et al. 1999; Olsson and Pattiaratchi 2005). This series of beaches (WA 836-60) continue for 25 km to Hillarys marina, on the north side of which is the SC boundary at Pinnaroo Point (WA 862-3; Fig. 32.15d). This SC has a total coastline of 43 km and contains 44 beaches which occupy 35 km (81%) and have an average length of 0.8 km, most located north from Port Beach. The southern part of the SC is sheltered by broad (15–20 km) shoal (<10 m) limestone platform, with Garden and Rottnest islands emerged parts of the platform as shown in Fig. 32.14, as well as the inshore calcarenite reefs, with wave height averaging 0.5 m and generally R conditions prevailing particularly south of Fremantle. In Cockburn Sound in lee of Garden Island Riedel and Trajer (1978) recorded two wave sources a low swell (T = 14 s) and seas (T = 8.5 s), with highest waves arriving between July and September. North of Rottnest Island the platform narrows to <5 km allowing waves averaging 0.5–1 m to reach the shore between Port Beach and Trigg (WA 835-843) and maintain LTT and shifting to TBR during higher wave conditions, including strong sea breeze conditions. The platform then wides to ~5 km between Trigg and Pinnaroo Point. The morphodynamics of the more exposed Perth beach systems and the role of the summer sea breeze have been investigated by Masselink (1996), Masselink and Pattiaratchi (1996) and Masselink et al. (1997). Eliot and Travers (2011) investigated the shoreline changes at Scarborough Beach since 1942 and found they are driven by a combination of seasonal changes in sea level, tide, waves and wind, with the sea-level signature dominating and driving both seasonal and intra-annual shoreline changes.

The Perth coast is dominated by Pleistocene dune calcarenite which forms the offshore islands and reefs and outcrops along much of the coast as low bluffs forming the boundaries of many of the beaches. This is a type 3 coast (Fig. 32.2) containing a narrow strip of sandy beaches formed in lee of the reefs and abutting the calcarenite and some dunes deposited on top of the calcarenite. The beach sand is predominately moderately well-sorted, fine-medium, averaging 40% carbonate ($\sigma = 27\%$) but ranging from 10% to 90% and with considerable longshore variation (Fig. 32.1). Barrier systems back 25 km of the coast (58%). In the south is the Woodman Point cuspate foreland, while between Swanbourne and Pinnaroo Point is a series of transgressive dunes, blanketing the calcarenite, that extend between 2 and 4 km inland and in the north averaging between 20 and 30 m in height but reaching 70 m in places. The barriers have a volume of 813 M m^3 (33,163 $m^3\ m^{-1}$), most contained in the northern Pinnaroo Point foreland (Fig 32.15d). Most of the barriers and dunes have been heavily developed, with only Woodman Point and a strip of Pinnaroo Point left in a reasonably natural state. Sediment transport along this SC is predominately northerly along the shallow platform (Fig. 31.3) and north of Fremantle, with a reversal south of Fremantle where it converges on Woodman Point. Stul et al. (2015) mapped TCs along the Perth coast and found Woodman Point the only closed boundary. There are erosion hotspots at Kwinana and O'Connor (Coogee) beach, both possible related to adjacent structures, and north of Fremantle at Waterman, MAAC and Mullaloo beaches (DOT 2016).

32.9.4 SC:WA06.02.03 Pinnaroo Point–Moore River

SC:WA06.02.03 commenced at the tip of Pinnaroo Point cuspate foreland and gently curves to the north-northwest for 44 km to the mouth of the Moore River at Guilderton (Fig. 32.16). This is a highly developed section of coast with Perth's northern suburbs extending almost continuously for 25 km from Pinnaroo to Alkimos, followed by the satellite communities of Yanchep and Two Rocks. In addition to the extensive residential development, there is a large boat ramp at Ocean Reef and boat marinas at Mindarie Keys and Two Rocks. Each of these consists of north-trending attached breakwaters and a northerly entrance groyne all designed to both sheltered the marinas from waves and to minimise sand transport into the

Fig. 32.16 SC:WA06.02.03: Pinnaroo Point to Moore River. (Source google Earth)

marinas. This is a predominately reef-sheltered sandy coast and consists of a series of slightly protruding sandy forelands (Pinnaroo, Burns beach, Yanchep) and beaches (Pinnaroo, Tamala Park, Quinns, Alkimos), separated by 'swales' consisting of low dune-capped calcarenite bluffs, as far as Yanchep. To the north the beaches are more continuous, though still separated by slight salients at Wreck Point and Mallee Reef and patches of calcarenite, all backed by stable transgressive dunes. Stul et al. (2015) mapped 12 TCs within this SC, while DOT (2016) identified erosion hotspots at Mullaloo, Quinns Beach and Two Rocks.

North of Pinnaroo Point, the limestone platform is >5 km wide and contains a series of distinct shore-parallel calcarenite reefs up to Moore River and beyond, which lower breaker waves to ~0.5 m. A total of 44 beaches occupy 53 km (96%) of

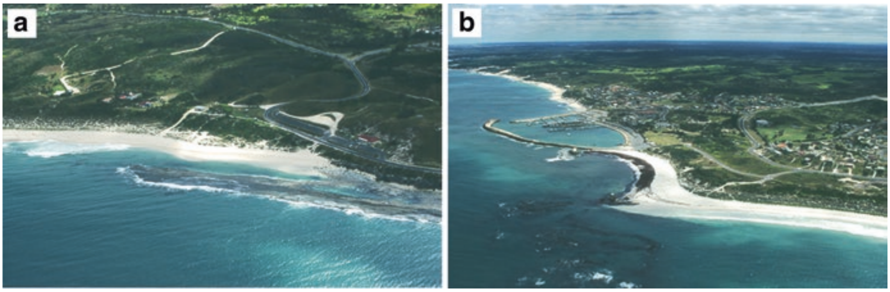

Fig. 32.17 (**a**) Yanchep beachrock reef, lagoon and beach (WA 896) and (**b**) Wreck Point (WA 900) and Two Rocks boat harbour. (Photos: AD Short)

the shore, with an average length of 1.2 km, with the northern beach extending for 10 km to the seasonally closed Moore River mouth. The beaches are high in carbonate (mean = 73%, σ = 14%), with well- to moderately well-sorted medium sand. The low waves and fine to medium sand combine to maintain R beaches for much of the coast. There is a more exposed section between Yanchep and Wreck Point (WA 896-900) where the inshore reef narrows and where waves average ~1 m and the beaches are LTT, switching to TBR during higher waves.

Gallop et al. (2011, 2012) investigated the impact of the inshore limestone reefs and rock topography on beach morphodynamics at Yanchep beach and lagoon (WA 895-896; Fig. 32.17a) during sea breeze and storm erosion and recovery. They found the sheltered beaches underwent greater volume changes during the sea breeze cycle, while the exposed beaches recovered more by overnight accretion when the sea breeze ceased, while during storms the more sheltered beaches experience less beach erosion but had a slower post-storm recovery.

There are two long near continuous barrier systems along this section occupying 43 km (81%) of the coast. They both consist of well-vegetated stable transgressive dunes extending up to 6 km inland and to heights of 50 m, with a mean height around 30 m. They have a total volume of 2520 M m^3 with a reasonably high per metre volume of 58,600 m^3 m^{-1}, reflecting the size and extent of the transgressive dunes. They are predominately the type 3 barriers (Fig. 32.2), except south of Two Rocks where there is a 150 wide, 3 km long type 2 regressive system.

32.9.5 PC Overview

This is the most highly developed PC on the WA coast extending from Dunsborough in the south to Guilderton in the north and includes the near continuous development from Mandurah through to Perth and up to Two Rocks. It also contains several marinas and port facilities including the Fremantle harbour moles (training walls) (Fig. 32.15a), together with Garden and Rottnest islands. Sand is transported northwards and shorewards, including some minor reversals, and in the past has accumulated in several large regressive and transgressive barrier systems. According to Stul et al. (2015), Woodman Point cuspate foreland is the only naturally closed sediment boundary, which has been joined by the man-made Australian Maritime Complex and Fremantle harbour moles, in also blocking longshore transport. All the coast north from Fremantle is open, though the four marinas (Hillarys, Ocean Reef, Mindarie Keys and Two Rocks (Fig. 32.17b)) all interrupt but not stop the transport. The overall dynamics of this coast is largely controlled by the inshore calcarenite reefs which in turn control deepwater wave attenuation and refraction which determines shoreline wave energy and configuration, and the rates and direction of sand transport. The northerly transport is driven by the attenuated southerly swell coupled with summer southwest sea breeze wind and waves, all overlain on a calcarenite basement and hinterland.

Rising sea level will have a dramatic impact of this PC which already has 12 coastal erosion hotspots spread from The Cut at Bunbury to Two Rocks (DOT 2016). As nearshore waters deepen and wave attenuation and refraction decrease, higher waves will reach the shore and accelerate in longshore sand transport. Masselink and Hughes (1998) found that the swash transport along the northern Perth beaches increased at the cube of the time-averaged velocity, implying small increases in wave height and swash velocity can lead to a substantial increase in longshore swash zone transport. The combination of rising sea level and accelerated sand transport will induce general beach recession and shoreline instability. However, given the complex platform topography, there will be variable response within and between the 12 TCs. The rising sea level will also impact the shoreline of Swan Estuary and all the backing wetlands by rising the groundwater and causing saline intrusion. The location and nature of the wetlands, which are a characteristic of the Swan coastal plain and are classified as lakes, sumplands and damplands, are examined by Semeniuk and Semeniuk (2004, 2006), and their response to climate change is examined by Semeniuk and Semeniuk (2013).

32.10 PC:WA07.01 Moore River–North Head

PC:WA07.01 commences at Moore River and trends north-northwest for 108 km to Thirsty Point, before turning and trending more northerly for 36 km to North Head (Fig. 32.3), a total length of 144 km. The coast is sheltered by submerged calcarenite reefs its entire length, with the reefs only surfacing around Lancelin, resulting in a low wave energy coast with waves usually less than 1 m. The coast has nodal development at a number of sites, starting with Guilderton on the northern side of the Moore River and then a series of small communities and towns most located on subdued and more prominent cuspate forelands, including Seabird, Ledge Point, Lancelin, Wedge Island (shacks), Grey (shacks), Cervantes, Jurien Bay, Green Head and Leeman. The only major development on the coast is the Jurien Bay boat harbour. The coast essentially consists of a near continuous strip of low energy sandy

Table 32.8 PC:WA07.01 beach types and states

BS	BS	No.	%	km	%	Mean (km)	σ (km)
4	TBR	4	4.9	15.6	11.2	3.9	1.5
5	LTT	10	12.3	23.7	17.0	2.4	1.2
6	R	67	82.7	100.4	71.9	1.5	1.4
		81	100	139.7	100	1.7	–

beaches, with 81 beaches occupying 140 km (97%), together with sections of generally low calcarenite reefs and bluffs. The beaches are predominately low energy R-LTT (89%), the remainder more exposed and longer TBR (Table 32.8).

Most of the coast is blanketed by Holocene transgressive dunes, with five near continuous systems occupying 124 km (86%) of the coast and extending up to 9 km inland. They have a total volume of 12,600 M m^3 and the highest per metre volume in the region of 102,024 $m^3\ m^{-1}$ (Table 32.2). The beaches and barriers are discussed in more detail in the following four SCs (Table 32.4).

32.10.1 SC:WA07.01.01 Moore River–Ledge Point

SC:WA07.01.01 extends north-northwest for 29 km as a near continuous narrow strip of sand from Moore River to Ledge Point (Figs. 32.18a and 32.19a), with the only development north of Guilderton being the small Seabird community and Ledge Point (Fig. 32.19b). At Seabird, an erosion hotspot, a 0.5 km long seawall was built in 2016 to protect beachfront property, while Ledge Point has some beachfront houses and a solitary groyne. The nearshore consists of a 5–7 km wide shallow (<10 m deep) limestone platform, with shore-parallel calcarenite ridges located within 1 km of the shore and along the outer platform edge where some reach the surface (Stul et al. 2014b). The beach sand is composed of well- to moderately well-sorted, fine to medium carbonate-rich (81%) sand (Fig. 32.1). Fifteen reef-sheltered low energy R beaches occupy 28 km (97%) of the shore, the remainder low calcarenite bluffs. The beaches are backed by 25 km of predominately vegetated north-trending transgressive dunes extending up to 3 km inland, averaging 30 m in highest and rising to a maximum of 50 m (type 3, Fig. 32.2). They occupy an area of 4850 ha and are 98% vegetated and stable. The dunes indicate there have been two to three episodes of dune transgression, most likely occurring during the mid-Holocene sea-level highstand peaking between 7.5 and 7 ka (Semeniuk 1996; Gouramanis et al. 2012). The barriers have a volume of 970 M m^3 with a reasonably high per metre volume of 64,666 $m^3\ m^{-1}$. The entire SC is open to longshore sand transport, with sand being transported into the SC from the south, passing through the system and exiting around the northern Ledge Point sandy foreland, with the ongoing shoreline recession at Seabird suggesting parts of the coast are in retreat.

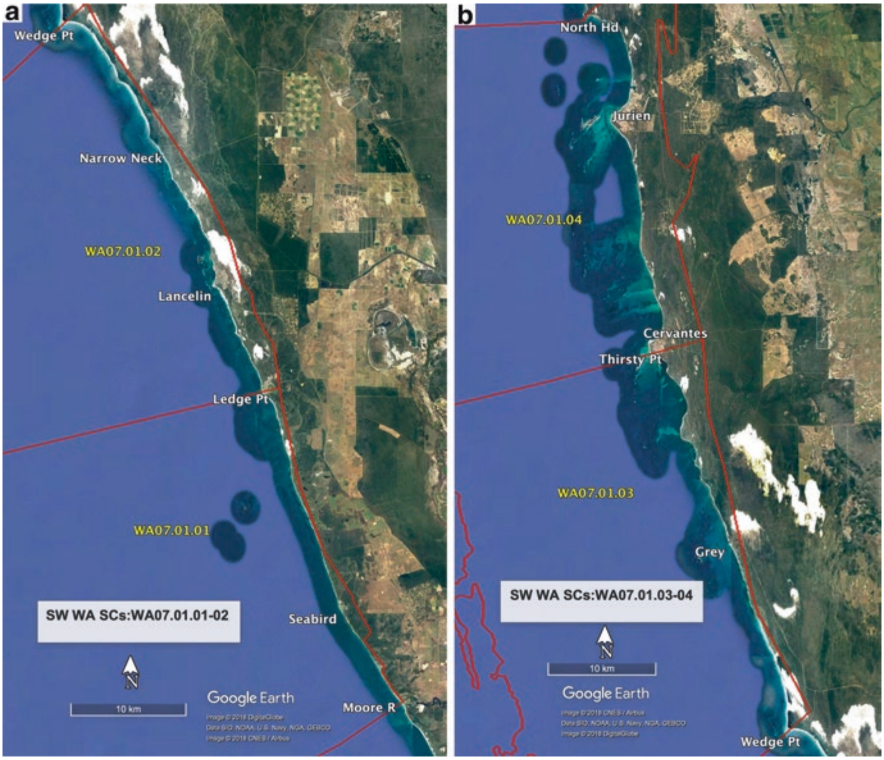

Fig. 32.18 (**a**) SCs: WA07.01.01-02: Moore River to Wedge Island and (**b**) SCs:WA07.01.03-04: Wedge Island to North Head. (Source: Google Earth)

32.10.2 SC:WA07.01.02 Ledge Point–Wedge Island Point

SC:WA07.01.02 commences at the tip of sandy Ledge Point (Fig. 32.19b) and trends north-northwest for 41 km to Wedge Island (Fig. 32.18a), another protruding cuspate foreland, with the larger community of Lancelin occupying a central foreland located in lee of a series of shallow inshore reefs (Fig. 32.19c) including Edward Island. The limestone platform is 5 km wide off Ledge Point narrowing to 3–4 km northwards. The inner 1 km is relatively shallow (<5 m), forming Edward Island at Lancelin, with linear calcarenite ridges scattered across the platform and shoaling to shallow and emerged reefs seawards of the Dide Point, Narrow Neck, Magic Reef and Wedge Island forelands. The shoreline consists of a near continuous strip of 14 low energy sandy beaches which total 40 km in length occupying 98% of the shore, the remainder low dune-capped calcarenite bluffs. The beach sand is well-sorted fine to medium (mean = 0.37 mm) and almost pure carbonate (mean = 96%, σ = 4%) (Fig. 32.1). The beaches range from R-LTT-TBR as

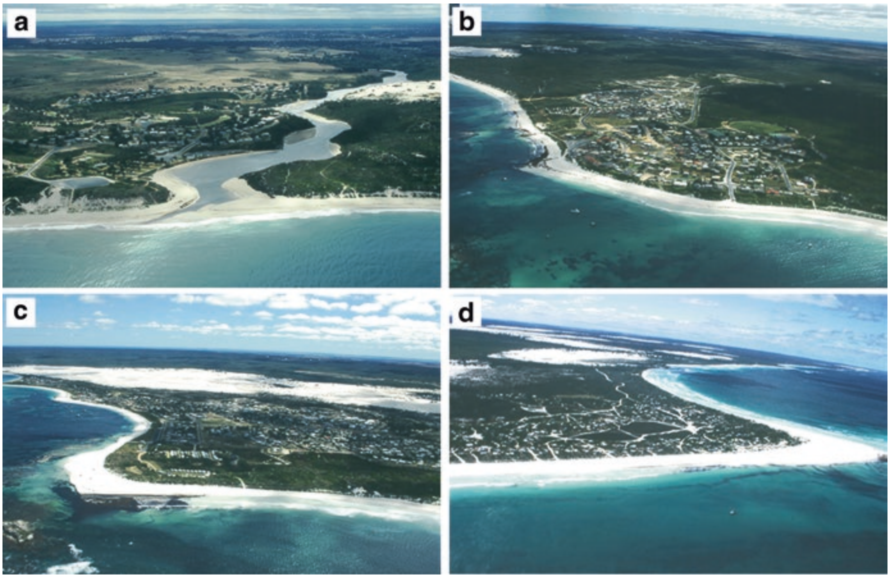

Fig. 32.19 (**a**) The usually blocked Moore River and Guilderton (WA 906-7); (**b**) Ledge Point and its beachfront houses (WA 921-23); (**c**) Lancelin and its backing active dunes (WA 925-27); and (**d**) Wedge Island cuspate foreland and shack community (WA 936-7). (Photos: AD Short)

variations in inshore morphology affect alongshore breaker wave height, with the higher energy beaches located north of Virgin Reef (WA 930) and between Magic Reef and Wedge Island point (WA 933-935) (Fig. 32.19d).

The beaches are backed by the low calcarenite bluffs which are capped by continuous transgressive dunes that trend north and increase in width from 5 km in the south to up to 15 km in the north, rising to an average height of 30–40 and a maximum height of 50 m in the south and 100 m in the north. They have total volume of 4639 M m^3 and a high per metre volume of 112,926 m^3 m^{-1}. The dune show evidence of two to three episodes of dune transgression (types 3–4, Fig. 32.2), with a 700 ha area north of Lancelin (Nilgen Nature Reserve) (Fig. 32.19c) and an area to the east of Wedge Island presently active with a total of 4000 ha (17%) of active dunes all trending north. It is very likely the dunes were most active during the mid-Holocene sea-level high (Semeniuk 1996) when the reefs were deeper, wave energy was higher and sediment transport was more active. Sand is moving northwards along the coast with all the PC, SC and TC boundaries open according to Stul et al. (2015). Rates are expected to be relatively low (10,000 m $year^{-1}$) and variable as wave height and direction change along the shore. The only erosion hotspot is at Lancelin (DOT 2016).

32.10.3 SC:WA07.01.03 Wedge Island Point–Thirsty Point

SC:WA07.01.03 continues north-northwest from Wedge Island point for 38 km to Thirsty Point (Fig. 32.18b). The only development on the coast are the two shack communities at Wedge Island and Grey, with Wedge Island located in the Wangarren Nature Reserve and Grey in Nambung National Park, while the Indian Ocean Drive is located 1–2 km inland and has a few access roads to the coast. The limestone platform is tied to Wedge Island point and parallels the coast to the north located ~3–5 km offshore with a near continuous reef along its outer edge which also forms the Green Islands off Grey and the Cervantes Islands which attach to the protruding Thirsty Point. The reef lowers wave height at the coast to ~0.5 m. Beach are composed of moderately well-sorted, fine sand (mean = 0.22 mm) and almost pure carbonate (mean = 98%) (Fig. 32.1). There are 28 beaches occupying 35 km (92%) of the shore, the remainder low calcarenite bluffs. Wave remains low for the most of SC, and the beaches are predominately R, with LTT and occasional TBR extending along a slightly higher energy section for 10 km north from Wedge Island to Flat Rock Point (WA 936-940).

Extensive north-trending transgressive parabolic dunes back the beaches and overlie the limestone. They occupy all of the coast and extend inland for between 6 and 15 km. They average 50 m in height reaching up to 150 m with a volume of 5600 M m^3 and a high per meter volume of 149,333 $m^3\ m^{-1}$. The longest dunes trend north paralleling the coast for up to 20 km, as longwalled parabolic dunes. There are a few areas of shoreline regression on the south and west side of Kangaroo Point (Fig. 32.20a), in Nambung Bay and on Thirsty Point (Fig. 32.20b) but no property at risk. The southern Kangaroo Point ridges post-date the dune transgression, while the western ridges have been partly buried by now vegetated parabolic dunes. The overall size and stability of the transgressive dunes and the presence of the regressive sequence indicate that there has been substantial changes in barrier morphodynamics. The dunes were probably most active during the mid-Holocene sea-level high (Semeniuk 1996) and then stabilising as sea level fell to its present level and wave height declined, when the lower wave conditions allowed the regressive sequences to develop. Based on Fig. 32.2 the transgressive dunes are of types 3–4 and the regressive type 1. The barriers occupy an area of 28,000 ha with 3000 ha (11%) presently unstable. The Indian Ocean Drive winds through the dunes and provides access to the famed pinnacles in Nambung National Park, the pinnacles formed in the Tamala Limestone during periods of extensive solution weathering associated with higher rainfall during the transition from interglacial to glacial periods (Lipar and Webb 2014).

32.10.4 SC:WA07.01.04 Thirsty Point–North Head

SC:WA07.01.04 commences at the tip of Thirsty Point (Fig. 32.20b) and trends essentially due north for 36 km to the protruding calcarenite bluffs of 20 m high North Head (Fig. 32.18b). This SC is dominated by two large cuspate forelands,

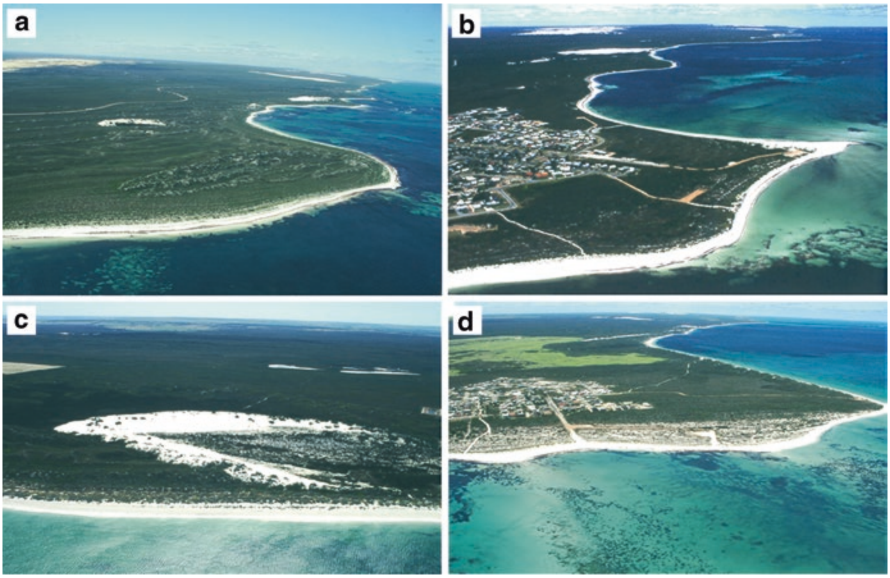

Fig. 32.20 (**a**) Regressive foredune ridges overlain by parabolic dunes on Kangaroo Point (WA 960-1); (**b**) Thirsty Point with part of Cervantes to the left; (**c**) large active parabolic dune at Black Point (QWA 966); and (**d**) Island Point at Jurien with recent shoreline progradation in foreground (WA 972-4). (Photos: AD Short)

Thirsty Point, site of Cervantes, and Island Point, site of Jurien (Fig. 32.20d), with the Indian Ocean Drive linking the two. Both points are located in lee of islands which are part of emerged sections of the north-trending submerged reefs. These reefs, which commence off Kangaroo Point, lie oblique to the coast and appear to be remnants of the crests of Pleistocene longwalled parabolic dunes, unlike the shore-parallel reefs south of Grey, that represent the old shore-parallel shorelines, foredunes and barriers. The reefs are scattered across the limestone platform and lie up to up 5–6 km offshore and substantially lower waves at the shore to ~0.5 m. The Jurien foreland has been prograding westwards for the past 5 ka, with ~2 km of progradation in the past 1800 years (Woods 1983). However, Woods also found that the now highly developed shoreline experiences cyclical erosional events, though a 100–300 m wide foredune buffer should provide significant protection against such an event. Likewise, Shepherd and Eliot (1995) identified major erosion cuts into the foredune ridge plains between Cervantes and Dongara dating 6.7-6 ka and 3-2 ka. They attribute the first phases to cessation of the PMT and the second to the initiation of dune transgression.

There are 24 low energy R beaches along this coast which are composed of moderately well-sorted, medium sand averaging 92% carbonate. They occupy the entire shore with boundaries formed by inflections in the shore and the solitary seasonally closed Hill River. The coast is backed by continuous north-trending transgressive dunes (Fig. 32.20c) which parallel the coast and extend up to 6 km inland, together with the regressive forelands. The dunes are scattered longwalled parabolics originating from Nambung Bay in the south and Ronsard Bay north of Cervantes, while northern Jurien Bay is backed by a series of overlapping parabolics. These dunes have a total volume of 1400 M m^3 and a lower per metre volume of 38,888 m^3 m^{-1}, reflecting the less dense dune fields.

Sand is moving northwards along this SC, as indicated by north-trending recurved spits on the northern side of Thirsty Head, sand building up against the Cervantes jetty and Jurien boat harbour breakwater, and north-trending sand waves located between Boullanger Island and Island point at Jurien. Given the low wave height rates are expected to be on the order of ~10,000 m $year^{-1}$.

32.10.5 PC Overview

This PC is a 144 km long section of near continuous sandy coast with beaches occupying 97% of the shore, the remainder usually low calcarenite bluffs. The calcarenite extends both inland and offshore as shore-parallel 5–10 km wide limestone platform containing initially shore-parallel and north from Grey shore-oblique calcarenite reefs. The platform and reefs, through wave attenuation and refraction, control wave height and direction at the shore and thereby the rates and direction of longshore sand transport and shoreline evolution and configuration. During the PMT and mid-Holocene higher sea level large volumes of sand were delivered to and transported along the coast. Strong southerly winds then transported sand from more south-facing sections of the coast northwards, paralleling the coast, as series of nested parabolics to longwalled parabolics. These dunes peak in area and volume between Ledge and Thirsty points and have the highest volume and per metre volume in the southwest region (Table 32.3), peaking at 150,000 m^3 m^{-1} between Wedge Island and Thirsty Point. Most of the dunes are now well-vegetated and stable. The dunes are composed of the same carbonate-rich sand which has originated on the limestone platform and inner shelf and been driven both onshore via channels in the platform and longshore close to the shore by the southerly swell, wind waves and wind-driven currents, as proposed for this region by Stul et al. (2015).

Rising sea level will dramatically impact this coast as water becomes increasingly deeper over the platform and reefs, thereby decreasing wave attenuation and increasing inshore wave height and rates of onshore and longshore sand transport, as well as localised beach erosion. These in turn may lead to a reactivation of some of the dune fields.

32.11 PC:WA07.02 North Head-Glenfield Beach

PC:WA07.02 extends north and then north-northwest for 192 km from North Head to Glenfield Beach on the northern side of Geraldton (Figs. 32.3 and 32.21). It is a predominately straight continuous sandy coast with few protrusions and 103

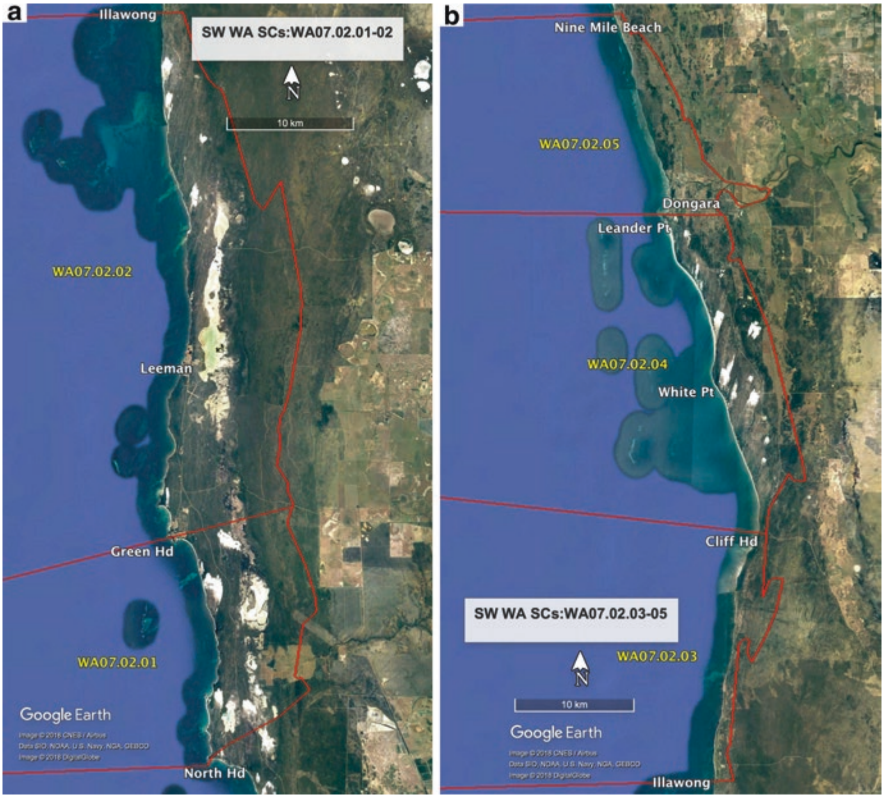

Fig. 32.21 (**a**) SCs: WA07.02.01-02: North Head to Illawong and (**b**) SCs:WA07.02.03-05: Illawong to Nine Mile Beach. (Source: Google Earth)

Table 32.9 PC:WA07.02 beach types and states

BS	BS	No.	%	km	%	Mean (km)	σ (km)
4	TBR	4	3.9	26.8	14.7	6.7	4.2
5	LTT	5	4.9	14.9	8.2	3	2.3
6	R	94	91.3	140.6	77.1	1.5	2.4
		103	100	182.3	100	1.8	–

beaches occupying 182 km (95%) of the shore (Table 32.9). Much of the southern half of the PC is contained in nature reserves, while the only development on the coast is at the small Green Head and Leeman in the south and the larger Dongara and city of Geraldton in the north, with the remainder of the coast largely vegetated transgressive dune fields. The limestone platform continues to parallel the coast widen up to 15 km south of Dongara and then narrowing to 1 km up to Cape Burney before finally widening to 5 km around Geraldton's Point Moore, a major sandy foreland which has prograded seawards across the platform. The platform contains elevated remnants of former shorelines and transgressive dune ridges all of which impact wave attenuation and refraction and thereby the nature of the backing shoreline and its barrier systems. Tides remain low (0.8 m at Geraldton), and deepwater waves remain dominated by the persistent moderate to high southwest swell which averages ~2 m offshore. However, the Houtman Abrolhos islands located 70 km due west of Geraldton form a major wave shadow in their lee that extends from Geraldton to Kalbarri (Fig. 31.2; Richardson et al. 2005). Inshore waves consequently depend on the amount of wave attenuation and refraction of the ocean swell, which is supplemented at the coast by southerly sea breeze-generated seas. Inshore waves however, remain generally low (<1 m). As a consequence, beaches are predominately low energy R and LTT (85%) (Table 32.9), with TBR only occurring where gaps in the reefs permit higher waves to reach the shore. Winds are dominated by southerly regional winds and sea breezes, while rainfall continues to slowly decrease northwards dropping to 450 mm at Geraldton. The strong southerly winds are responsible for the predominately north-trending longwalled parabolic dunes that back much of the coast and contribute substantially to the 8616 M m^3 (48,830 m^3 m^{-1}) of barrier volume along this PC (Table 32.3). The PC contains seven SCs (Table 32.4) which are discussed below.

32.11.1 SC:WA07.02.01 North Head–Green Head

SC:WA07.02.01 contains a 20 km long section of coast between the protruding North Head and the equally protruding Green Head linked initially by a sinuous north-trending section of sandy beaches and boundary calcarenite bluffs (Fig. 32.21a). The Indian Ocean Drive parallels the coast 1–2 km inland, and there is no development other than the camping area at Sandy Point and Green Head at the northern end. The Beekeepers Nature Reserve and Lesueur National Park are located to the east of the drive.

There are 25 beaches occupying 18.5 km (93%) of the coast, the remainder calcarenite bluffs forming points around North Head (Fig. 32.22a) and outcropping for 10 km to the north. The limestone platform widens from 3 km in the south to 5 km off Green Head, together with scattered reefs and the small Fisherman islands, all of which lower waves at the shore maintaining R beaches bordered by bluffs and small forelands. The beaches are composed of carbonate-rich (mean = 92%), well- to moderately well-sorted fine sand (Fig. 32.1). North-trending longwalled parabolic dunes have blown north out of the northern Jurien Bay and Greens Head's South Bay (Fig. 32.22b), to parallel the north-trending shoreline. The dunes average < 20 m in height, with 90% now well-vegetated and stable. They have a volume of 900 M m^3 and a per metre volume of 45,000 m^3 m^{-1}. Both the southern North Head and northern Green Head appear to be closed boundaries, with their southern orientation, low wave energy and extensive reefs impeding northerly sand transport. Stul et al. (2015) however suggest that sand may be moving northwards parallel to the coast along the shallow outer platform.

32.11.2 SC:WA07.02.02 Green Head–Illawong

SC:WA07.02.02 extends from Green Head to Illawong, a distance of 41 km. It trends essentially due north, with an initial series of embayed beaches and calcarenite bluffs, including Point Louise (Fig. 32.22c) extending 15 km north of the head and then a more continuous series of very low energy beaches up to Illawong, all backed by calcarenite-capped dunes rising to <20 m. The only development on the coast is the Green Head community, the small Leeman, which has a jetty, and a few shacks at Coolimba, Gum Tree Bay and Illawong. The Indian Ocean Drive parallels the coast usually <1 km inland. Forty generally short beaches (mean = 0.9 km) occupy 35 km (85%) of the shore, with calcarenite bluffs in the south making up the remainder. The beaches are all well sheltered by the Abrolhos wave shadow, the platform which widens to 7 km in the north, a shore-parallel inner reef located 2 km offshore and shallow inshore reefs, resulting in very low wave conditions at the shore (<<0.5 m) and R beaches throughout, with seagrass growing to the shore. Beach sands are carbonate-rich (mean = 89%), well- to moderately well-sorted and fine to medium. The beaches are backed by the calcarenite bluffs and hinterland which is blanketed by a 4 km wide series of north-northeast-trending

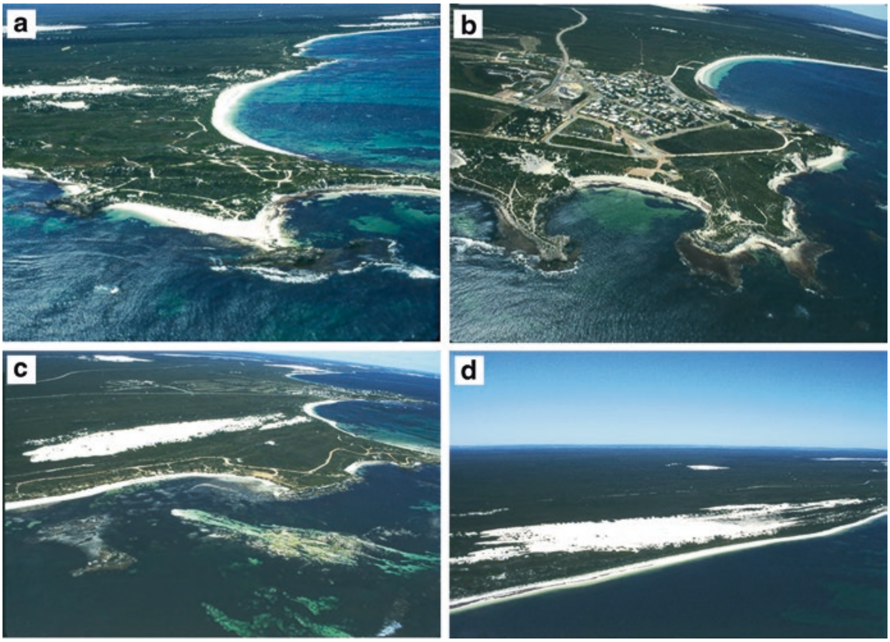

Fig. 32.22 (**a**) North Head (WA 988) with Jurien Bay in the background; (**b**) the small Green Head community with Dynamite Bay (WA 1014) in the foreground and South Bay (WA1008) to the south; (**c**) longwalled parabolic dune trending north from Anchorage Bay (WA 1016) in lee of Point Louise (WA 1020); and (**d**) longwalled parabolic dunes in Gum Tree Bay (WA 1048). (Photos: AD Short)

longwalled parabolic dunes (Fig. 32.22d), some up to 20 km long. They average < 20 m in height and have a volume of 600 M m^3 and per metre volume of 13,636 m^3 m^{-1}, both reasonably low for the southwest coast, a product of the lower wave energy along this sheltered SC. It is expected any longshore transport is restricted to the swash zone and the outer platform, with transport on the outer platform impeded by the shallow Beagle Ridge which extends 10 km west of Gum Tree Bay to the outer platform edge (Stul et al. 2015).

32.11.3 SC:WA07.02.03 Illawong–Cliff Head

SC:WA07.02.03 is a 22 km long very sheltered section of coast between Illawong and the low Cliff Head (Fig. 32.21b). It trends north-northeast and is very sheltered by the limestone platform that widens to 10 km in the north, together with a series of inner shore-parallel reefs and very shallow inshore area, lowering waves to <<0.5 m at the shore allowing seagrass to grow the shore (Fig. 32.23a). Apart from a few shacks and the Indian Ocean Drive, there is no coastal development. The shore consists of five essentially continuous low energy R sandy beaches and some small calcarenite outcrops. Most of the beaches are backed by a low narrow band of regressive foredunes up to 200 m wide. The absence of transgressive dunes is a product of the orientation of the coast parallel to the dominate southerly winds and the very low wave energy, resulting in the regressive barriers having a volume of

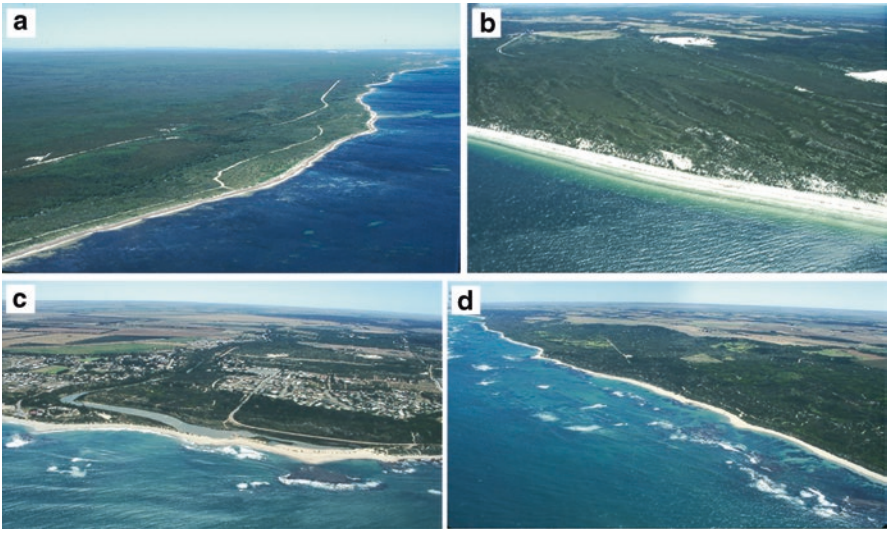

Fig. 32.23 (**a**) Very low energy R beach with seagrass growing to the shore, north of Freshwater Point (WA 1056); (**b**) well-vegetated longwalled parabolic dunes at Carsons beach (WA 1059); (**c**) the seasonally closed Irwin River mouth at Dongara (WA1064-5); and (**d**) reef-sheltered beach north of the Irwin River (WA 1067). (Photos: AD Short)

just 35 M m^3 and a very low per metre volume of 2300 m^3 m^{-1}. Given the very low energy nature of this coast and its reef-dominated inshore, the only longshore sand transport is expected to occur in the swash zone at very low rates and on the outer platform at higher rates.

32.11.4 SC:WA07.02.04 Cliff Head–Leander Point

SC:WA07.02.04 commences at Cliff Head where the coast turns and trends to the north-northwest to Leander Point at Dongara, a distance of 29 km (Fig. 32.21b). Apart from the Cliff Head shacks and the Indian Ocean Drive there is not development on the coast. This is a predominately sandy shore (99%) containing two subdued forelands at White Point and in lee of Jake Reef, with four essentially continuous beaches occupying the entire shoreline, including the longer Carsons and Ten Mile (WA 1059-60). The beaches are very sheltered and R in the south; however, north of White Point, the ~15km wide platform has a deeper seabed allowing higher waves (1 m+) to reach the shore, and TBR conditions and a 100 m wide surf zone to prevail for 23 km up to Dongara. Beaches are carbonate-rich (86%) and composed of well- to moderately well-sorted fine to medium sand. The shoreline orientation and higher wave energy has produced a continuous series of north-northeast-trending well-vegetated longwalled parabolics (Fig. 32.23b), which average about 4 km in length and form a 4 km wide band of the north-trending ridges which are generally <20 m in height. There are a few active areas which total about 500 ha and represent about 12% of the dunes. The dunes have a volume of 2100 M m^3 and a per metre volume of 72,414 m^3 m^{-1} and order of magnitude greater than the adjacent low energy southern SC. The wider and more energetic surf zone north of White Point is expected to generate moderate rates of northerly longshore sand transport (~10,000 m year^{-1}) to Dongara and beyond. If sand is bypassing Leander Point, it may begin to infill the port, which has already had some maintenance dredging. However, the small Grannies beach (WA1063) located on the northern side of the harbour breakwater is a coastal hotspot (DOT 2016), no doubt influenced by the presence of the harbour.

32.11.5 SC:WA07.02.05 Leander Point–Nine Mile Beach

SC:WA07.02.05 extends north-northwest from Leander Point for 18 km to Nine Mile Beach (Fig. 32.21b). The town of Dongara is located at the mouth of the seasonally open Irwin River (Fig. 32.23c) and in lee of reef-sheltered Leander Point. The reefs allowed the development of Port Denison, which has since been provided added protection with the construction of two attached 0.5 km long breakwaters constructed in 1977–1978 (Paul 1981), with the harbour housing a small marina and fishing fleet. The point, the river mouth and the entire shore up to Nine Mile are sheltered by shallow reefs extending around 0.5 km offshore (Fig. 32.23d), lowering waves at the shore to ~0.5 m. There are ten R beaches between the port and Nine Mile which occupy the entire shore, apart from a few calcarenite outcrops and the breakwaters. North of the Irwin River, the beaches are backed by a band of north-trending transgressive dunes that widen from 1 km in the south to 3 km at Nine Mile. They are all vegetated and stable and have a volume of 450 M m^3 and per metre volume of 30,000 m^3 m^{-1}. The river appears to be delivering bedload to the shore with a local decrease in carbonate to 30–50% around the river mouth and areas of lower carbonate (50–70%) northwards. It is expected that there would be northerly sand transport at moderate rates across and along the 5 km wide limestone platform and at low rates along the swash zone including bypassing Leander Point and moving along Nine Mile Beach to the adjoining SC. There is also evidence of past dune overpassing of Leander Point into the port area.

32.11.6 SC:WA07.02.06 Nine Mile Beach–Cape Burney

SC:WA07.02.06 commences at Nine Mile Beach where the coast turns and trends northwest for 37 km to the Greenough River mouth at Cape Burney (Fig. 32.24a). The coast has a straight near continuous exposed higher energy beach backed by

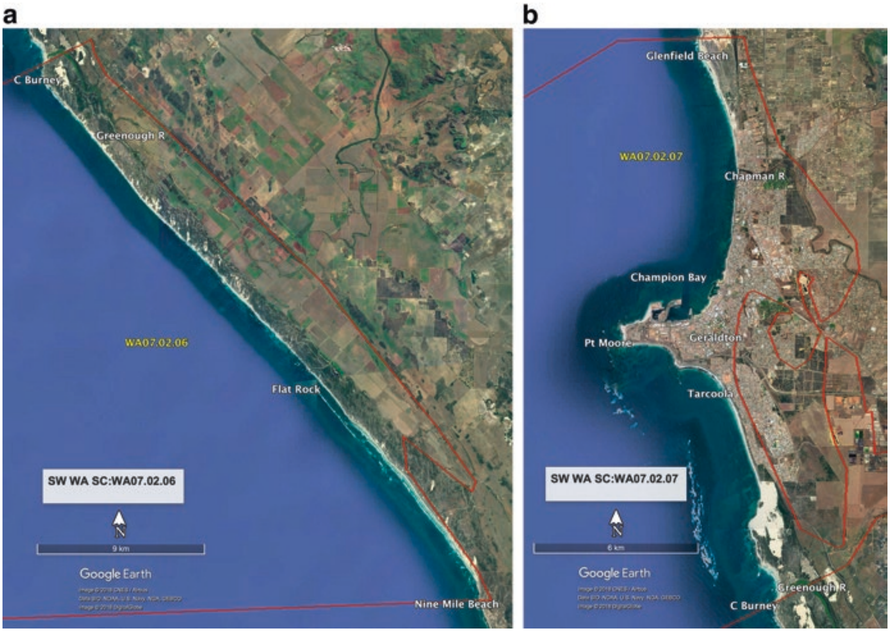

Fig. 32.24 (**a**) SC:WA07.02.05: Nine Mile Beach to Cape Burney and (**b**) SC:WA07.02.02: Cape Burney to Glenfield Beach. (Source: Google Earth)

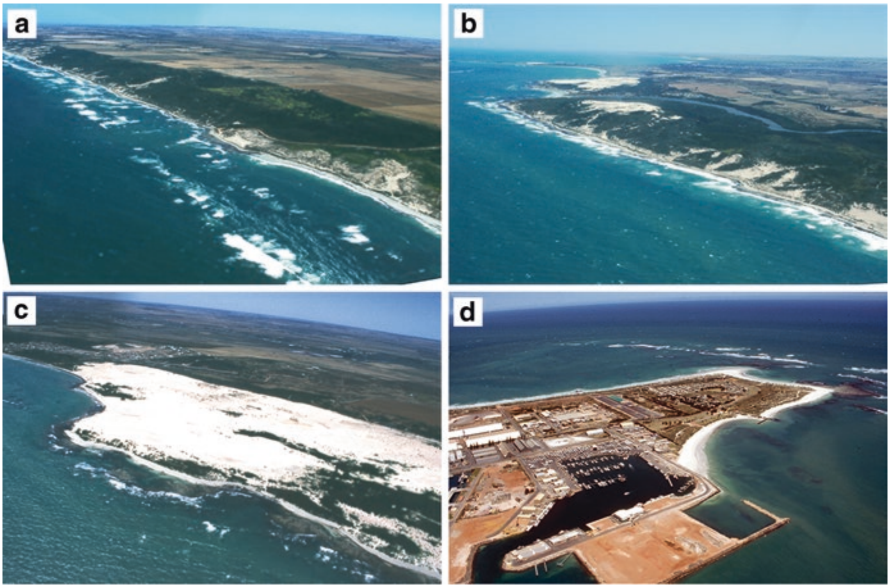

Fig. 32.25 (**a**) Reef-sheltered beach at Flat Rock (WA 1074); (**b**) the more exposed beach south of Cape Burney (WA1076) with the Greenough River behind; (**c**) the Southgate dunes overpass Cape Burney (WA 1079); and (**d**) reef-sheltered Point Moore and Geraldton harbour (WA1083-5). (Photos: AD Short)

transgressive dunes (Fig. 32.25a). There is no development on the coast other than access roads and tracks. The increase in wave energy is due to the increasing depth of the limestone platform owing to an absence of shallow reefs. However from 7 km north of Nine Mile, the beach is paralleled by a 500 m wide inshore reef, which narrows to ~100 m north of S-Bend. Waves averaging 1–1.5 m break on the inner reef, with wave height at the shore dependent of the elevation of the inner reef resulting in a highly variable inshore and surf zone morphology. There are six near continuous beaches along this section occupying 36.5 km (99%) of the shore. They are composed of moderately well-sorted fine to medium sand containing 72% carbonate ($\sigma = 24\%$). The southernmost beach extends for 11 km and is the most exposed with wave averaging 1.5 m maintaining a 300 m wide double-bar system. North from here the reef dominates and wave breaks heavily on the reef with the inner beach tending to be R, though where there are gaps in the reefs both beach and topographic rips prevail. The backing foredune averages 20 m in height with the transgressive dunes rising to 40–60 m and forming a continuous 1–2 km wide barrier the length of the shore, consisting of north-trending parabolic dunes up to 2 km long, with farmland behind. They have a volume of 1650 M m^3 and per metre volume of 45,833 m^3 m^{-1} and are predominately stable apart from several blowouts along the northern section (Fig. 32.25b). It is expected that sand is being transported northwards in the surf zone along the open southern beach, in the swash zone along the reef-sheltered section and in the shallow nearshore zone, as indicated by Stul et al. (2015). The rates will be highest in the surf zone and least in the swash zone.

32.11.7 SC:WA07.02.07 Cape Burney–Glenfield Beach

SC:WA07.02.07 encompasses the port and city of Geraldton located on and around the prominent sandy Point Moore foreland. The SC commences 10 km south of the point at Cape Burney-Greenough River mouth and extends 10 km north of the point to Glenfield Beach, with a total shoreline of 25 km (Fig. 32.24b). This is a heavily developed section of coast with beachfront suburbs extending from Tarcoola in the south to the Chapman River in the north, together with the 4 km of port and marina facilities and a series of groynes and attached and detached breakwaters, coupled with beach nourishment and sand bypassing of the port. Apart from the man-made structures, the coast is predominately a continuous sandy beach, with 13 beaches occupying 24 km (96%) of the shore and composed of carbonate-rich (84%) moderately well-sorted fine to medium sand (Fig. 32.1). The beaches vary considerably in orientation and exposure and range from TBR on the exposed southern Southgate-Tarcoola surfing beaches (WA 1078 and 1081) to R along the more sheltered shores including the port beaches, with wave energy increasing north of the Chapman River mouth to maintain TBR to LTT conditions along the northern Glenfield Beach (WA 1090). The coast has four small barrier systems, namely, the active transgressive dunes at Southgate; a 200 m wide stable foredune complex at Tarcoola; the regressive Point Moore foreland (now completely covered with housing and port facilities; Fig. 32.25d); and a regressive sequence at Glenfield that widens to 2 km in the north. These have a total volume of just 166 M m^3 and a relatively small per metre volume of 9485 m^3 m^{-1}. The small extent and size of the barriers can be attributed to the northerly orientation of part of the coast and the areas of low wave energy.

Tecchiato et al. (2016) conducted a detailed field investigation of sediment transport in and around Point Moore and Geraldton harbour. They recorded the deepwater wave averaging between 1 and 1.5 m and reached 2.5 m arriving year-round almost exclusively from the southwest, while seas also arrive from the southwest and ranged from 0.5 to 1.5 m. However, the 4 km wide 10 m deep limestone platform substantially reduces inshore wave height to <1 m such that the depth of closure in the Champion Bay is only 5 m. They found that carbonate-rich sand is supplied from the seagrass meadows and macroalgal carbonate factories within 2 km of the shore. The seagrasses are common on sheltered hardgrounds blanketed by fine sand, while macroalgae were found on high energy limestone reefs with 60% of the carbonate sand consisting of modern bioclasts, indicating the meadows and macroalgae are a major continuing source of sand, with the most productive area on the exposed high energy outer reefs (Tecchiato et al. 2015). The other 40% come from erosion of the limestone and local erosion of calcarenite bluffs. Tecchiato et al. (2015) also found that the distribution of mobile sand is regulated by wave-induced sediment transport working within the pre-existing seabed topography. At the coast

Tecchiato et al. (2016) found that sand sourced from the offshore and from south of Cape Burney and the active Southgate dunes (Fig. 32.25c) is moving northwards towards Point Moore and accumulating on the northern Pages beach (WA 1085) at a rate of 12,500 m^3 $year^{-1}$. Sand is also settling in the port and port channel which requires ongoing maintenance dredging. The sand then moves northwards along the northern beaches to the Chapman River mouth and then onto Glenfield Beach (Fig. 32.26). They also found that the river was supplying quartz sand to the adjacent nearshore which was remaining stationary indicating little interaction with the longshore transport. The middle of Champion Bay was also identified as a sediment sink leading to a shortfall in transport out of the bay and shoreline erosion of the northern beaches of between 1 and 3 m $year^{-1}$, with erosion hotspots at Point Moore and Beresford (DOT 2016). In order to combat the impact of the port on sediment transport and erosion along the northern beaches, sand bypassing has been occurring from Pages beach to the northern beaches on the order of 10,000–16,000 m^3 $year^{-1}$ (WorleyParsons 2010). In 2017 the Beresford beach (WA 1089) breakwater was extended and the beach inbetween nourished with 60,000 m^3 of sand (Plain et al. 2017) resulting in the detached breakwater now almost connected by a cuspate foreland to the shore. Figure 32.26 illustrates the bathymetry, sediment cells (TCs) and boundaries, transport paths and shoreline state identified by Tecchiato et al. (2016).

32.11.8 PC Overview

This is overall a north- to north-northwest-trending section of largely undeveloped dune-backed coast. Its morphodynamics is controlled by the persistent southwest swell which is attenuated by the Houtman Abrolhos wave shadow (Fig. 31.2) and across the 5–10 km wide limestone platform and its numerous reefs and small islands, resulting in low but highly variable wave height and direction at the shore. The result is a predominately low energy coast with low energy R-LTT beaches except where gaps in the reef permit higher waves and TBR beaches to form (Table 32.9). Sand is moving northwards driven by the waves and wind-driven currents along the shore, in the few surf zones and across and along the limestone platform, though with many interruptions. Rates are expected to be both spatially and temporally highly variable ranging from a few 1000 to perhaps 10,000 m^3 $year^{-1}$. Rising sea level will impact this coast by increasing water depth across the platform and reef thereby leading to an increasing inshore wave height which will accelerate rates of sand transport. While this may increase the onshore transport of sand, it will also lead to shoreline changes and more sand moving northwards. The coastal erosion hotspots at Seabird and Lancelin (DOT 2016) are likely to increase, while the Geraldton port and hotspot are being managed by engineering, bypassing and nourishment works. Because of the complex nature of the inner shelf and shoreline detailed studies, such as that at Geraldton (WorleyParsons 2010; Tecchiato et al. 2016), will need to be undertaken to realistically assess the potential impacts at a management scale.

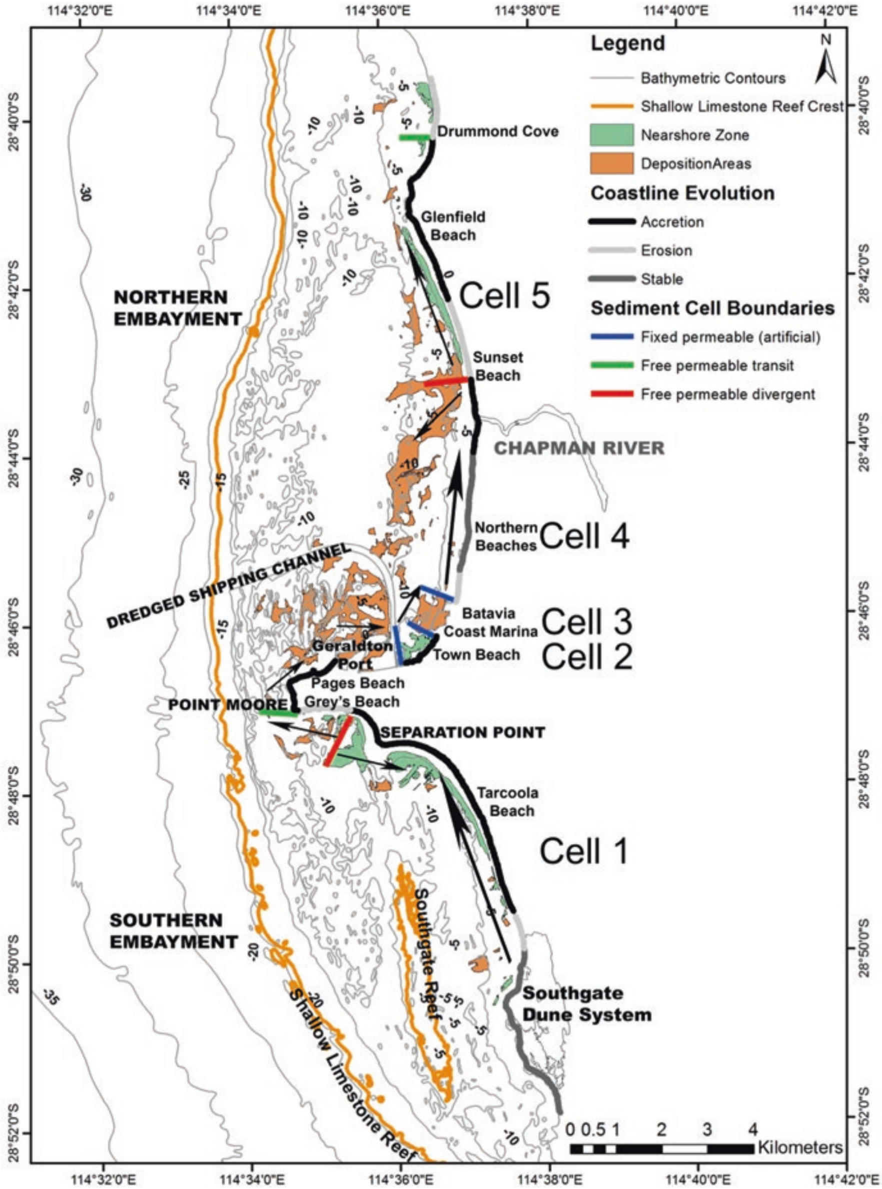

Fig. 32.26 The Geraldton coast (SC:WA07.01.07), its bathymetry, sediment cells, boundaries, shoreline stability and direction of longshore sand transport. (From: Tecchiato et al. 2016. Reproduced with permission of Elsevier Ltd.)

32.12 PC:WA08.01 Glenfield Beach–Broken Anchor Bay

PC:WA08.01 commences at Glenfield Beach on the northern side of Geraldton and curves gently to the north-northwest for 57 km to Broken Anchor Bay (Fig. 32.27a). This is a relatively continuous, though sinuous coast, cut by six small seasonally closed rivers: Buller, Oakajee, Oakabella, Woolawar, Bowes and Hutt. The rivers cut though sedimentary rocks which rise to over 100 m within a few kilometres of the coast, with their seaward slopes blanketed by climbing dunes, together with dunes at each of the river mouth. The sedimentary rocks of the Carnarvon Basin first outcrop on the coast at Drummond Cove (Fig. 32.28a), with the basin extending 900 km north to James Point where it borders the Pilbara craton. The transition from the Perth to the Carnarvon Basin marks a major change in coastal geology and geomorphology, with the low calcarenite bluffs and abundant carbonate sediments of the Perth Basin, replaced by the steeper, higher sedimentary rocks of the Carnarvon Basin.

The coast has a 100 km wide shallow shelf which includes the Houtman-Abrolhos islands which lie between 60 and 80 km offshore and parallel the coast from Greenough River to Broken Anchor Bay. Closer to shore the limestone platform

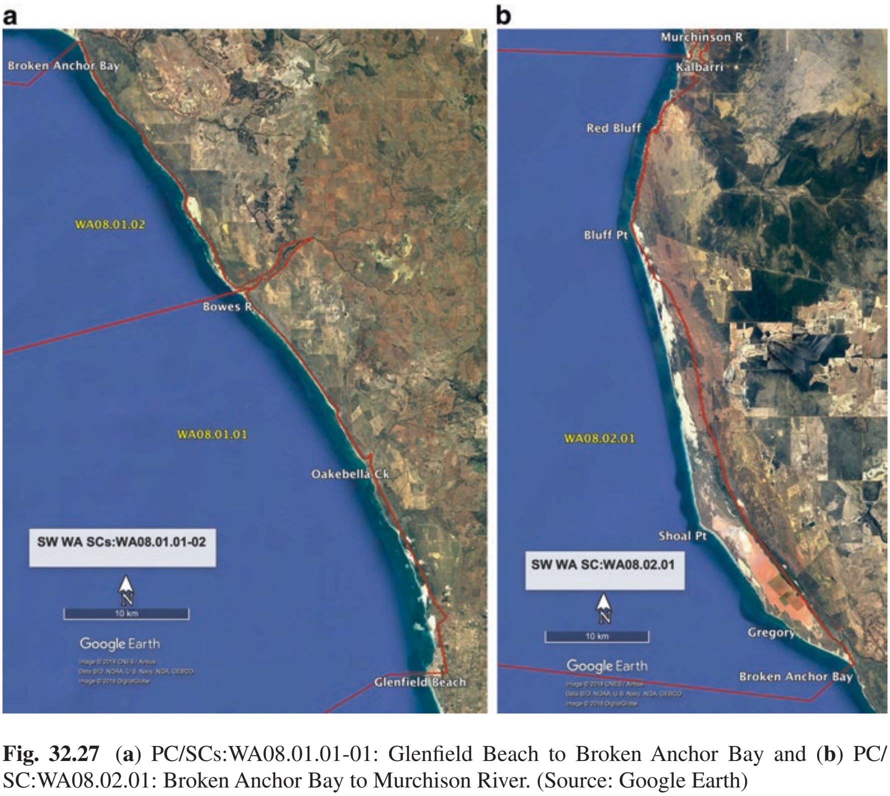

Fig. 32.27 (**a**) PC/SCs:WA08.01.01-01: Glenfield Beach to Broken Anchor Bay and (**b**) PC/SC:WA08.02.01: Broken Anchor Bay to Murchison River. (Source: Google Earth)

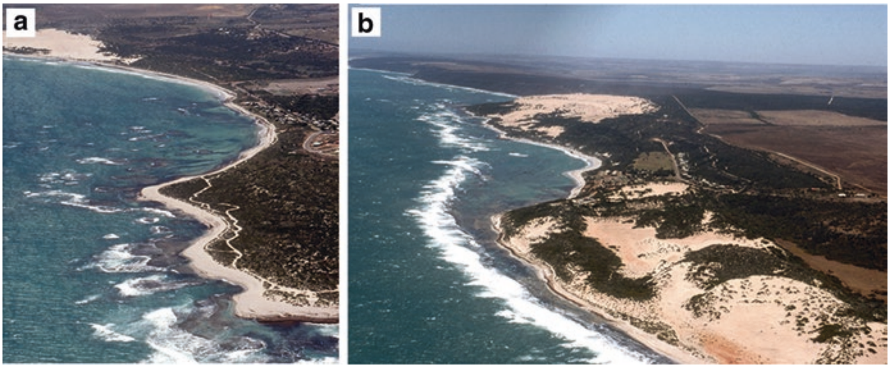

Fig. 32.28 (**a**) The reef-induced crenulate shoreline at Drummond Cove (WA 1091-3) and (**b**) climbing transgressive dunes either side of the reef-sheltered Horrocks (WA 1006-7). (Photos: AD Short)

Table 32.10 PC:WA08.01 beach types and sates

BS	BS	No.	%	km	%	Mean (km)	σ (km)
4	TBR	4	15.4	3.9	7	1	0.3
5	LTT	4	15.4	4.6	8	1.2	0.6
6	R	18	69.2	47.8	85	2.7	2.4
		26	100	56.3	100	2.2	–

parallels the entire PC. It is 3 km wide in the south gradually narrowing northwards and usually <10 m deep. The offshore wave climate is characterised by 2 m southerly swell (T = 12–15 s) (Fig. 31.2). The offshore islands and inner platforms and in place shallow calcarenite reefs, including beachrock reefs, control wave attenuation and refraction and the level of wave energy and direction at the shore where it is often reduced to 0.25 m (Burling and Schepis 1999). The only development on the coast is at Drummond Cove located adjacent to Glenfield Beach and the small fishing community at Horrocks, though a major port has been proposed for Oakajee River mouth (Mocke et al. 2009). The highway trends inland, with the regional centre of Northampton located 18 km inland and most of the coast backed by pastoral properties.

The shoreline is continuous and sandy with 26 beaches occupying 56 km (99%) of the shore. They are predominately sheltered R (85% by length), together with a few LTT (8%) and more exposed TBR (7%) (Table 32.10). The beaches are backed by four narrow barriers all north-trending transgressive dunes. They extend between 400 and 900 m inland and have a total volume of 283 M m^3 and relatively small per metre volume of 12,840 $m^3\ m^{-1}$, the smallest in the southwest region (Table 32.3). The smaller size of the barrier can be in part related to the lower wave energy and the steeper bedrock, north from Drummond Cove, which limits accommodation space. The PC has two SCs which are discussed below.

32.12.1 SC:WA08.01.01 Glenfield Beach–Bowes River

SC:WA08.01.01 extends for 36 km from Glenfield Beach to the Bowes River (Fig. 32.27a). The coast trends relatively straight to north-northwest and then north and is backed by slopes rising to 20 m within 1 km in the south and to between 40 and 80 m north of the Buller River, with steep valleys cut in the slopes by the Buller, Oakajee, Oakabella, Woolawar and Bowes rivers whose river mouths form indentations at the shore. The limestone platform is 3 km wide off Glenfield Beach narrowing to 2 km and then to 1 km north of Woolawar Gully. It contains extensive sections of shallow shore-parallel calcarenite reefs (beachrock) which also outcrop along parts of the coast. The beach sand is moderately well-sorted and fine to medium and remains dominated by carbonate derived from the platform seagrass meadows, but the proportion decreases from 52% at Drummond Cove to 51% at Coronation Beach and just 23% at the Bowes River mouth, indicating the river is a source of terrigenous sand. Thirteen reef-sheltered sandy beaches separated by a few rocky outcrops, some salients and the river mouths occupy 35 km (98%) of the shore. They are predominately low energy R and LTT, with just two TBR at the deeper mouths of Oakabella Creek and Woolawar Gully.

The beaches are backed by a narrow (<500 m) wide band of north-trending transgressive dunes that have climbed the backing slopes and widen to 1.5 km closer to Bowes River where they climb slopes to 80 m height. They occupy an area of 950 ha which are 80% stable. They have a low volume of 142 M m^3 and per metre volume of 10,960 $m^3\ m^{-1}$.

32.12.2 SC:WA08.01.02 Bowes River–Broken Anchor Bay

SC:WA08.01.02 continues to trend north-northwest from the Bowes River for 21 km to Broken Anchor Bay and the mouth of the Hutt River (Fig. 32.27a). Between the two usually closed river mouths are some cliffs and sandstone slopes and rising steeply to between 80 and 130 m within 1 km of the coast. The only settlement is at the reef-sheltered Horrocks and the only access at the river mouths and Horrocks. Shallow shore-parallel beachrock reefs extend north from the Bowes River and form a 6 km long lagoon north from Horrocks, with the community located at the more sheltered southern end of the lagoon (Fig. 32.28b). The beach sand at Horrocks is well-sorted fine sand with 66% carbonate, and the beach while sheltered by the reef is a coastal hotspot (DOT 2016). Twelve essentially continuous reef-sheltered beaches fringe the entire shore. They are predominately low energy R and LTT, with just the Bowes River mouth TBR. Higher waves however break over many of the beachrock reefs and generate topographic rips, with the rip feeder currents moving sand northwards and perhaps contributing to the beach erosion at Horrocks. North-trending transgressive dune have moved up to 1 km inland, climbing the backing sandstone slopes, particularly in lee of the more south-facing section of the shore, resulting in near continuous dunes between Bowes River and Whaleboat Cove and again at Broker Anchor Cove. They are however largely absent along the central cliffed section. The dunes have a relatively low volume of 140 M m^3 (15,555 m^3 m^{-1}).

32.12.3 PC Overview

The 57 km long Glenfield to Broken Anchor Bay PC represents a geological transition from the Perth to Carnarvon Basin. To the south the Perth Basin coast has a boarder (~10 km) limestone platforms and lower hinterland which is blanketed in near continuous north-trending carbonate-rich transgressive dunes which extend up to 5 km inland, with per metre volumes on the order of 50,000 to 100,000 m^3 m^{-1}. North from Glenfield the platform narrows to 3 km and then 1 km, allowing higher waves close to shore; however shallow inshore reefs and shore-parallel beachrock reefs lower these waves at the shore. At the same time the low flat limestone hinterland is replaced by sandstone slope of the Carnarvon Basin rising in places to over 100 m and also forming section of sea cliffs. While north-trending dune transgression continues, it is more limited by the steeper slopes and lack of accommodation space, which is restrict the dunes to a narrow band usually less than 1 km and a lower per meter volume on the order of 10,000 m^3 m^{-1}. In addition, sediment to the south is predominately derived from the broader carbonate platform and 60–90% carbonate (Tecchiato et al. 2015), while north from Glenfield the proportion of carbonate decreases (50–60%) (Table 32.1). The decrease can be attributed to the narrower carbonate platform, together with the supply of river-derived terrigenous sands including heavy minerals, resulting in low carbonate beaches at the river mouths. The predominately southerly swell, seas and winds drive the sand northwards along the shore which has no major interruptions, other than the beachrock reefs.

Rising sea level will reactivate this coast with deeper water over the platform and inshore reefs leading to higher breaker waves and more active beaches and sand transport, as well as a possible reactivation of the largely stable vegetated transgressive dunes. It will also drive sediment into the several river mouths and inundate along their lower reaches.

32.13 PC/SC:08.02.01 Broken Anchor Bay–Murchison River

The northernmost PC and SC in the southwest region commences in Broken Anchor Bay and trends roughly northwest for 20 km to Shoal Point, where it turns and trends straight north-northwest for 30 km to Bluff Point before turning again to trending roughly north-northeast for 19 km to Kalbarri and the mouth of the Murchison River, in all a distance of 69 km (Fig. 32.27b). The only development on the coast is the small Gregory in the south and the growing Kalbarri in the north, together with the gypsum mine in southern Hutt Lagoon. The Port Gregory road

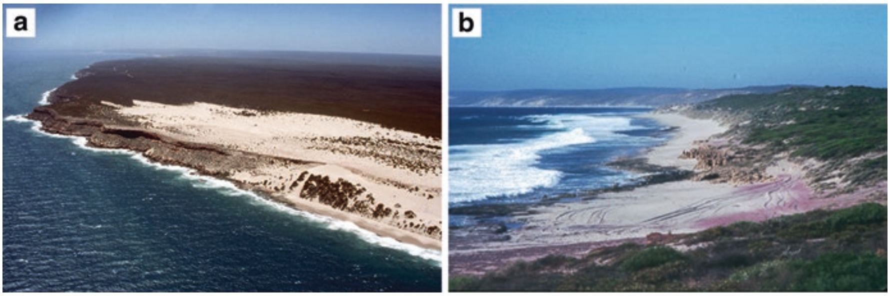

Fig. 32.29 (**a**) Climbing transgressive dunes at Bluff Point (WA 1126) and (**b**) reef-fringed Red Bluff beach (WA 1129) with its pink garnet beach sand. (Photos: AD Short)

parallels the coast and provides some access points in the south and several viewing points along the northern cliffed and Kalbarri section. This coast continues the transition that started at Glenfield Beach, with the limestone platform continuing to narrow to just a few hundred metre and to become essentially absent north of Bluff Point where the 80 m high horizontally bedded red sandstone cliffs dominate the coast to Kalbarri. As a consequence, wave energy increases, and where accommodation space is available, dunes become more extensive (Fig. 32.29a). The geomorphology of the sandstone cliffs and in places calcarenite capping is described by Scott Jr and Johnson (1993). The beach sands remain carbonate-enriched but also reflect the supply of terrigenous quartz sand from the large Murchison River, together with the rivers to the south. They are predominately well- to moderately well-sorted medium to coarse (mean = 0.53 mm) sand, averaging 37% (σ = 28%) carbonate, dropping to ~10% along the Kalbarri-Murchison shore (Fig. 32.1) together with small percentages of river-derived heavy minerals (Stul et al. 2014a). On the southern Kalbarri beaches (WA 1129-1131), the river- and cliff-derived garnet gives the beaches a pink hue (Fig. 32.29b).

There are 17 beaches along this coast which occupy 53 km (77%) of the shore, the remainder a mix of calcarenite/beachrock outcrops and the sandstone cliffs particular north of Bluff Point (Fig. 32.29a). Most of the beaches are paralleled by near continuous beachrock reefs, which either lie just off the shore forming numerous salients or form the shore, including the Kalbarri beaches and the reef-barred mouth of the Murchison River. At Gregory the reef lies up to 500 m offshore and forms a 5 km long lagoon which provides shelter for the jetty located towards the center of the lagoon shore. While waves average 1.5–2 m along this coast, they break heavily on the beachrock reefs resulting in lower waves at the shore and predominately R and LTT beaches (65% by length), with only three longer TBR beaches in Broken Anchor Bay where the reef is absent, at the mouth of the Hutt River and either side of reef-free Shoal Point (Table 32.11).

Between Broken Anchor Bay and Bluff Point is a series of three long barrier systems in Broken Anchor Bay and either side of Shoal Point, which extend along 49 km (85%) of the shore. They are all north-trending active and stable transgres-

Table 32.11 PC/SC:WA08.02.01 beach types and states

BS	BS	No.	%	km	%	Mean (km)	σ (km)
4	TBR	3	17.6	18.6	35.1	6.2	–
5	LTT	1	5.9	1.9	3.6	1.9	–
6	R	13	76.5	32.5	61.3	2.7	4.2
		17	100	53	100	3.1	–

sive dunes ranging in width from 0.5 to 3 km and climbing Bluff Point at the northern end (Fig. 32.29b). North of Bluff Point, the coast trends north-northeast, and the winds blow offshore which combined with the cliffs precludes the development of dune systems. The southern dunes have a total volume of 830 M m^3 and a per unit volume of 16,938 $m^3 m^{-1}$ (Table 32.3).

32.13.1 PC Overview

This is a reasonably exposed coast, with most of the wave energy expended breaking on the beachrock reefs and northern cliffs. The higher proportion of terrigenous material (quartz, heavy minerals and garnet) indicates the rivers have supplied sediment to the inner shelf at low sea level which has been reworked onshore during and following the PMT, to be complemented by relict and modern shelf carbonate. The prevailing southerly swell, seas and winds are expected to drive potentially high rates on northerly transport in the nearshore, with lower rates along the more sheltered and interrupted shoreline.

Rising sea level will dramatically impact this coast by increasing water depth over the beachrock reefs and thereby wave energy at the shore. This should lead to an acceleration in northerly sand transport and recession of the sandy shoreline. It will also drive sand into the Hutt River mouth and the larger permanently open Murchison River mouth, as well as increasing the tidal prism and salinity in its lower reaches.

32.14 Regional Overview

The southwest region extends for nearly 1000 km from the southwest tip of Australia at Cape Leeuwin north to the Murchison River, incorporating all the Perth Basin coast and southern Carnarvon Basin. The coast begins in the humid south and finishes in the semi-arid north, with only 4 of its 18 rivers permanently open, including the Murchison. The absence of major rivers and terrigenous sand supply is replaced by massive carbonate production on the inner shelf and seagrass meadows (Collins 1988), which supplies both relict and modern carbonate sediment (Tecchiato et al.

2015; Thom et al. 2018). The carbonate production is enhanced by the presence of a limestone platform along the entire coast to Broken Anchor Bay. The platform is up to 30 km wide in the south, 10 km wide north from Perth finally narrowing to 1 km north from Geraldton. The limestone forms both the platform, much of the shoreline and the immediate hinterland. It has an overriding impact on the entire coast. Offshore it causes wave attenuation and refraction which both lowers waves substantially at the shore and controls wave direction, which leads to the formation of numerous salients. At the shore it outcrops as calcarenite cliffs, bluffs, reefs and rocks, including shore-parallel beachrock and dune ridge reefs, all of which further modulate the waves, dissect the shore and impede longshore sand transport. The prevailing southerly swell, seas and winds all act to transport sand both shorewards and northwards on the inner shelf, the platform and along the shore where possible (Thom et al. 2018). While this is a potentially high energy coast, rates are substantially impeded by the lowered waves and the numerous physical impediments along the shore, perhaps reaching a maximum ~100,000 m^3 $year^{-1}$ at Mandurah (Bicknell 2006), but expected to be substantially lower along much of the coast.

The high deepwater wave energy is attenuated by the reefs and platform along much of the shore reducing breaker waves to <1 m and even <0.5 m, resulting in a dominance of low energy R-LTT (60%) and TM beaches (29%) and just 5% more exposed TBR systems. Despite the relatively low wave height, barrier systems remain substantial along much of the coast. This can be attributed to three factors:

First, a supply of sand (relict terrigenous and carbonate detritus) from the shallow inner shelf to the shore .

Second, the mid-Holocene sea-level highstand which provided a higher energy window to transport sand shoreward and when most both the dunes and barriers were emplaced.

Third, the strong southerly winds to transport the sand northwards and landwards, with most barrier-dune systems extending between 1 km to a few kilometre inland, together with longwalled parabolic dunes extending up to several kilometres to the north.

Climate change will bring a range of impacts to this region. Rising sea level will deepen the shelf, platform and inshore reefs, all of which will lead to higher waves at the shore, more dynamic beach systems and enhanced onshore and longshore sand transport. What happens at the shore will depend on the balance between sand moving into each compartment from on and along shore and the amount moving out, including that lost to reactivated tidal inlets, flood tide deltas and possibly dune transgression. Much of the coast is backed by transgressive dunes which are presently 81% vegetated and stable. If a predicted drier climate was accompanied by strong winds, the dunes may be reactivated and pose a threat to backing land and property, as well as representing a loss of beach sand. All the inlets, lagoons and wetlands will be reactivated with greater tidal prism and tidal exchange, inundation of low-lying shorelines and increasing salinization. As the major population centres Busselton, Bunbury Mandurah, Perth-Fremantle and Kalbarri are all located on estuaries, they will need to address the impact of sea-level rise in each of their systems.

References

Andrews WS (1981) Mandurah – entrance management and beach restoration. In: 5th Australian conference on coastal and ocean engineering, Perth, Institution of Engineers Australia, pp 204–206

Barr S, Boreham P (2005) Port beach erosion study historic influences on a modern shoreline. In: 17th Australasian conference on coastal and ocean engineering, Adelaide, Institution of Engineers Australia, pp 275–280

Barr SA, Staples O, Eliot I, Darby O, Abrahamse D, Stul T (2017) Adaptation to coastal inundation in a low lying, highly dynamic regional area. Aust Coast Ports 2017:1037–1043

Bicknell C (2006) Review of sand bypassing at Dawesville and Mandurah: coastal engineering investigation. Department of Planning Infrastructure, Fremantle, Tech Report 446, 34 p

Brearely A (2005) Ernest Hodgkin's Swanland: estuaries and coastal lagoons of South-Western Australia. University of Western Australia Press, Perth, 550 p

Burling MC, Schepis JP (1999) Wave penetration modelling and design issues for a proposed port development at Oakajee River, Western Australia. In: 14th Australasian conference on coastal and ocean engineering, Perth

Byrne AP, Rogers MP, Byrne G (1987) Dawesville channel, Western Australia – coastal process studies. In: 8th Australasian conference on coastal and ocean engineering, Institution of Engineers Australia, pp 303–306

Collins LB (1988) Sediments and history of the Rottnest shelf, Southwest Australia: a swell-dominated, non-tropical carbonate margin. Sediment Geol 60:15–50

DOT (2016) Coastal management hotspots in WA. Department of Transport, Perth. https://www.nccarf.edu.au/settlements-infrastructure/sites/www.nccarf.edu.au.settlements-infrastructure/files/Tim_Stead.pdf

Eliot I (2011) Coastal compartments of Western Australia: a physical framework for marine and coastal planning. Damara Pty Ltd, Geological Survey of WA and Department of Environmental Conservation, Perth, 87 p

Eliot M, Travers A (2011) Dynamics of Scarborough Beach, city of Stirling, Western Australia. In: 20th Australasian conference on coastal and ocean engineering, Institution of Engineers Australia, pp 220–225

Gallop SL, Bosserelle C, Pattiaratchi C, Eliot I (2011) Rock topography causes spatial variation in the wave, current and beach response to sea breeze activity. Mar Geol 290:29–40

Gallop SL, Bosserelle C, Eliot I, Pattiaratchi C (2012) The influence of limestone reefs on storm erosion and recovery of a perched beach. Cont Shelf Res 47:16–27

Gouramanis C, Dodson J, Wilkins D, De Deckker P, Chase BM (2012) Holocene palaeoclimate and sea level fluctuation recorded from the coastal Barker Swamp, Rottnest Island, South-Western Western Australia. Quat Sci Rev 54:40–57

Hamilton D, Hunt T (2011) Port Coogee coastal monitoring. In: 20th Australasian conference on coastal and ocean engineering, Institution of Engineers Australia, pp 286–291

Kendrick GW, Wyrwoll KH, Szabo BJ (1991) Pliocene–Pleistocene coastal events and history along the western margin of Australia. Quat Sci Rev 10:419–439

Lipar M, Webb JA (2014) The formation of the pinnacle karst in Pleistocene aeolian calcarenites (Tamala limestone) in southwestern Australia. Earth Sci Rev 140:182–202

Masselink G (1996) Sea breeze activity and its effect on coastal processes near Perth, Western Australia. J R Soc West Aust 79:199–205

Masselink G (1998) The effect of sea breeze on beach morphology, surf zone hydrodynamics and sediment suspension. Mar Geol 146:115–135. https://doi.org/10.1016/S0025-3227(97)00121-7

Masselink G, Hughes MG (1998) Field investigation of sediment transport in the swash zone. Cont Shelf Res 18:1179–1199

Masselink G, Pattiaratchi C (1996) Morphodynamic impact of sea breeze on a beach with beach cusp morphology. J Coast Res 14:393–406

Masselink G, Hegge B, Pattiaratchi CB (1997) Beach cusp morphodynamics. Earth Surf Process Landf 22:1139–1155

Mocke R, Carlton B, Jupp R, Cork S, Sigurdarson S (2009) Planning and design for the Oakajee Port development project in Western Australia. Coasts and Ports 2009, Wellington, pp 49–55

Moloney B, Paul MJ (1999) Dawesville Channel and Mandurah ocean entrance sand bypassing and monitoring. In: 14th Australasian conference on coastal and ocean engineering, Perth, 8 p

Olsson D, Pattiaratchi C (2005) Rip currents in the vicinity of coastal structures. In: 17th Australasian conference on coastal and ocean engineering, Adelaide, Institution of Engineers Australia, pp 239–244

Pattiaratchi C (1999) Design studies for an artificial; surfing reef: cable station, Western Australia. In: 14th Australasian conference on coastal and ocean engineering, Perth, Institution of Engineers Australia, pp 101–108

Pattiaratchi C, Masselink G, Hurst P (1999) Surfability of the Perth metropolitan coastline: an assessment. In: 14th Australasian conference on coastal and ocean engineering, Perth, Institution of Engineers Australia

Pattiaratchi C, Wijeratne S, Bosserelle C (2011) Sand and seagrass wrack modelling in Port Geographe, south-western Australia. In: 20th Australasian conference on coastal and ocean engineering, Institution of Engineers Australia, pp 564–569

Pattiaratchi C, Wijeratne S, Roncevich L, Holder J (2015) Interaction between seagrass wrack and coastal structures: lessons from Port Geographe, south-western Australia. In: 22nd Australasian Coastal Ocean Engineering Conference, Auckland, pp 653–658

Pattiaratchi C, Wijeratne S, Roncevich L, Holder J (2017) The influence of nearshore sandbars on coastal stability in Port Geographe, South-West Australia. Aust Coast Ports 2017:865–871

Paul MJ (1978) Shoreline movements in Geographe Bay, Western Australia. In: 4th Australian conference on coastal and ocean engineering, Institution of Engineers Australia, pp 207–212

Paul MJ (1981) Denison fishing boat harbour. In: 5th Australian conference on coastal and ocean engineering, Perth, pp 39–43

Plain R, Blumberg G, Cross J, Dufour M (2017) Beresford foreshore coastal protection project – getting dirty in the west. Coastal Conference. http://www.coastalconference.com/2017/papers2017/Rick%20Plain.pdf

Playford PE, Leech REJ (1977) Geology and hydrology of Rottnest Island. Geological Survey Western Australia, Report 16, 98 p

Playford PE, Cockbain AE, Low GH (1976) Geology of the Perth Basin, Western Australia. Geological Survey Western Australia Bull 124, 311 p plus Maps

Richardson L, Mathews E, Heap A (2005) Geomorphology and sedimentology of the South Western planning area of Australia: review and synthesis of relevant literature in support of regional marine planning. Geoscience Australia, Canberra, Record 2005/17, 123 p

Riedel HP, Trajer FL (1978) Analysis of five years of wave data, Cockburn sound. In: 4th Australian conference on coastal and ocean engineering, pp 143–147

Scott JH Jr, Johnson (1993) Lateral variation in the geomorphology of a Pleistocene rocky coastline at Kalbarri, Western Australia. J Coast Res 9:1013–1025

Searle DJ, Semeniuk V (1988) Petrology and origin of beach sand along the Rottnest shelf coast, southwestern Australia. J R Soc West Aust 70:119–128

Searle DJ, Semeniuk V, Woods PJ (1988a) The sedimentology and stratigraphy of a cuspate foreland, South-Western Australia. J Coastal Res 4:551–564

Searle DJ, Semeniuk V, Woods PJ (1988b) Geomorphology, stratigraphy and Holocene history of the Rockingham-Becher plain, South-Western Australia. J R Soc West Aust 70:89–109

Semeniuk V (1983) The Quaternary stratigraphy and geological history of the Australind-Leschenault Inlet area. J R Soc West Aust 66:71–83

Semeniuk V (1985) The age structure of a Holocene barrier dune system and its implications for sea level history reconstruction in southwestern Australia. Mar Geol 67:197–212

Semeniuk V (1996) An early Holocene record of rising sea level along a bathymetrically complex coast in southwestern Australia. Mar Geol 131:177–193

Semeniuk V (1997) Pleistocene coastal palaeogeography in southwestern Australia – carbonate and quartz sand sedimentation in cuspate forelands, barriers and ribbon shoreline deposits. J Coast Res 12:468–489

Semeniuk V, Johnson DP (1982) Recent and Pleistocene beach/dune sequences, Western Australia. Sediment Geol 32:301–328

Semeniuk V, Johnson DP (1985) Modern and Pleistocene rocky coast sequences along carbonate coastlines, southwestern Australia. Sediment Geol 44:225–261

Semeniuk V, Meagher TD (1981) The geomorphology and surface processes of the Australind-Leschenault Inlet coastal area. J R Soc West Aust 64:33–51

Semeniuk V, Searle DJ (1987) Beach rock ridges/bands along the high energy coast in southwestern Australia – their significance and use in coastal history. J Coast Res 3:331–342

Semeniuk V, Semeniuk CA (2004) Sedimentary fill of basin wetlands, central Swan coastal Plain, southwestern Australia. Part 1: sediment particles, typical sediments, and classification of depositional systems. J R Soc West Aust 87:139–186

Semeniuk V, Semeniuk CA (2006) Sedimentary fill of basin wetlands, central; Swan coastal plain, southwestern Australia.Part 2: distribution of sediment types and their stratigraphy. J R Soc West Aust 89:185–220

Semeniuk CA, Semeniuk V (2013) The response of basin wetlands to climate changes: a review of case studies from the Swan Coastal Plain, South-Western Australia. Hydrobiologia 708:45–67

Semeniuk TA, Semeniuk V (2019) Geoheritage significance of three Pleistocene formations recording a succession of climates and sea levels on the Yalgorup Plain in southwestern Australia. Aust J Earth Sci. https://doi.org/10.1080/08120099.2018.1532459

Semeniuk V, Searle DJ, Woods PJ (1988) The sedimentology and stratigraphy of a cuspate foreland, southwestern Australia. J Coast Res 4:551–564

Semeniuk V, Cresswell ID, Wurm PAS (1989) The Quindalup dunes; the regional system, physical framework and vegetation habitats. J R Soc West Aust 71:23–47

Semeniuk V, Semeniuk TA, Unno J (2000) The Leschenault Inlet estuary: an overview. J R Soc West Aust 83:207–228

Shepherd MJ, Eliot IG (1995) Major phases of coastal erosion ca.6700-6000 and ca.3000-2000 BP between Cervantes and Dongara, Western Australia. Quat Int 26:125–130

Short AD (2005) Beaches of the Western Australian Coast: Eucla to Roebuck Bay. Sydney University Press, Sydney, 433 p

Stul T, Gozzard JR, Eliot IG and Eliot MJ (2014a) Coastal sediment cells for the Northampton region between Glenfield Beach and the Murchison River, Western Australia. Report by Seashore Engineering Pty Ltd and Geological Survey of Western Australia for the Western Australian Department of Transport, Fremantle, 51 p

Stul T, Gozzard JR, Eliot IG and Eliot MJ (2014b) Coastal sediment cells for the mid-west region between the Moore River and Glenfield Beach, Western Australia. Report prepared by Seashore Engineering Pty Ltd and Geological Survey of Western Australia for the Western Australian Department of Transport, Fremantle, 63 p

Stul T, Gozzard JR, Eliot IG and Eliot MJ (2015) Coastal sediment cells for the Vlamingh region between Cape Naturaliste and Moore River, Western Australia. Report prepared by Seashore Engineering Pty Ltd and Geological Survey of Western Australia for the Western Australian Department of Transport, Fremantle, 99 p

Tecchiato S, Collins L, Parnum I, Stevens A (2015) The influence of geomorphology and sedimentary processes on benthic habitat distribution and littoral sediment dynamics: Geraldton, Western Australia. Mar Geol 359:1480–1162

Tecchiato S, Collins L, Stevens A, Soldati M, Pevzner R (2016) Carbonate sediment dynamics and compartmentalisation of a highly modified coast: Geraldton, Western Australia. Geomorphology 254:57–72

Thom BG, Eliot I, Eliot M, Harvey N, Rissik C, Sharples C, Short AD, Woodroffe CD (2018) National sediment compartment framework for Australian coastal management. Ocean Coast Manag 154:103–120

Woods PJ (1983) Selecting a harbour site based on studies of coastal evolution and sedimentology at Jurien, Western Australia. In: 6th Australian conference on coastal and ocean engineering, Brisbane, pp 59–63

WorleyParsons (2010) Coastal processes study – Greys beach to Sunset Beach. Report prepared for City Geraldton-Greenough. WorleyParsons, Perth, 105 p

Chapter 33
Central West Western Australia Region

Abstract The central west region of Western Australia is a generally arid section of coast extending from the Murchison River mouth north to Exmouth Gulf and including Shark Bay, with a total shoreline of 1660 km. While two larger rivers, the Murchison and Gascoyne, reach the coast building extensive deltas, this is predominately a carbonate-rich coast, with sediments derived from the inner shelf limestone platform and in Shark Bay the extensive carbonate banks and their seagrass meadows. The open coast is exposed to persistent moderate to high southerly swell which in the north is attenuated and refracted across the Ningaloo fringing reefs, while Shark Bay and Exmouth Gulf have sheltered shorelines. Tides are micro the length of the open coast and in Shark Bay, increasing to meso into Exmouth Gulf. The coast is a mix of calcarenite and bedrock bluffs and cliffs and beach systems which range from exposed wave-dominated to very shelter tide-dominated in the bays. Likewise, barrier systems range from extensive regressive systems associated with the deltas to massive Holocene dune transgression, much overlapping Pleistocene dune calcarenite, which rises to 250 m along the Zuytdorp Cliffs, with most capped by extensive Holocene clifftop dunes. This chapter examines the region's coastal processes, beaches, barriers, sediment transport and sediment compartments.

Keywords Central west Western Australia · Shark Bay · Exmouth Gulf · Zuytdorp Cliffs · Beaches · Barriers · Sediment transport · Sediment compartments

33.1 Introduction

Western Australia's central west region encompasses the most arid section of the Australian coast with the shoreline extending for 1659 km, between the Murchison River and Giralia at the base of Exmouth Gulf (Fig. 32.1), and from 27.7 to 21.7°S, in the process crossing the Tropic of Capricorn. The coast is a mix of long straight uninterrupted sections such as the Zuytdorp Cliffs and the highly irregular peninsulas and bays of Shark Bay, with the entire coast having a direct length of just 590 km and a crenulation ratio of 2.8. The coast is also a mix of exposed high energy cliffed and reef sections and very sheltered shores including the most extensive seagrass

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meadows in Australia. Its unifying characteristic is however the hot semi-arid to arid desert climate (BSh to BWh) with rainfall decreasing from 350 mm at Kalbarri to 225 mm at Carnarvon and 260 mm at Exmouth. Because of the aridity, this is a lightly developed coast with from south to north towns only located at Shark Bay's Denham (600), the larger Carnarvon (4500) at the mouth of the Gascoyne River, and Exmouth (2500) on the Exmouth Peninsula, together with tourist facilities around Shark Bay and at Gnaraloo, Coral Bay and in the Cape Range National Park.

33.2 Sediments

Beach sediment along the central west coast is typically moderately well-sorted medium sand averaging 62% carbonate (Table 33.1). However, there is considerable longshore and regional variation as indicated in Fig. 33.1, with sand size ranging from fine to coarse and carbonate from 0 to 100%. The considerable variation is an

Table 33.1 Central west region sand characteristics

n	77
Size (mm)	0.44
σ (mm)	0.23
Sorting	0.57
σ sorting	0.33
% carbonate	61.5
σ (%)	34

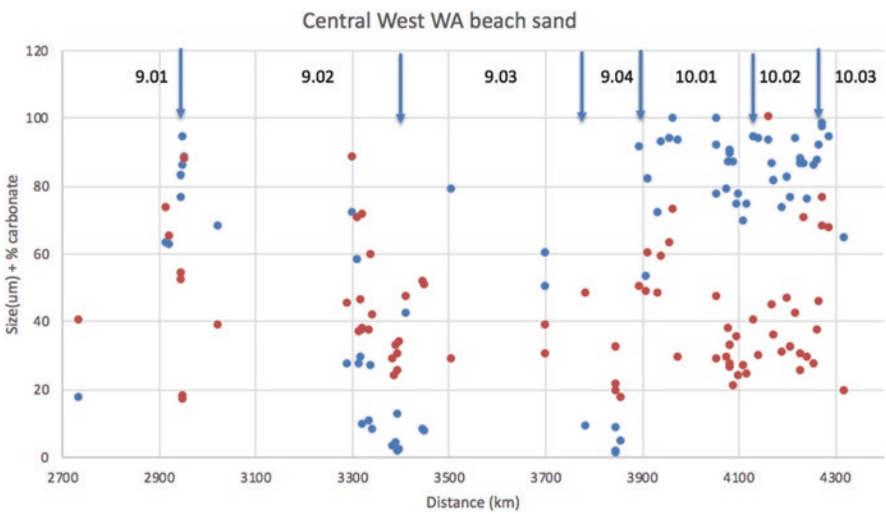

Fig. 33.1 Central west Western Australian region beach sand characteristics (size: red, μm) percent carbonate: blue). Distance clockwise from WA/SA border. Arrows indicated PC boundaries

indication of the range of coastal environments from very exposed to sheltered, sediment sources from limited fluvial to entirely biogenetic, and the many closed sediment cells within Shark Bay. These will be discussed in the PCs and SCs below.

33.3 Coastal Processes

The coast is exposed to the persistent moderate to high southwest swell averaging 2–2.5 m that dominates the open coast as far as North West Cape (Fig. 31.2). The large Shark Bay and Exmouth Gulf are however sheltered from ocean waves and rely on local wind waves and are consequently very low wave TD environments. Tides are micro on the open coast (~1.5 m), range from 1 to 1.8 m in Shark Bay and only reach meso in Exmouth Gulf with 2 m at Point Murat and 2.6 m at Learmonth (Figs. 1.15 and 30.3). Winds are predominately southeast to south at Carnarvon (Fig. 1.7) trending almost exclusively south at Learmonth. The coast is within the region of summer tropical cyclone impact with cyclones occasionally making landfall as far south as Shark Bay (Fig. 1.6a) and bringing strong winds, heavy rain, high seas and storm surges. Strom surges are predicted to reach up to 2 m (Fig. 1.14) and tsunami to 4 m amongst the highest on the Australian coast (Fig. 1.16).

33.4 Beaches

Five hundred beaches occupy 887 km (48%) of the coast, the remainder a mix of the high calcarenite Zuytdorp Cliffs and extensive tidal flats within Shark Bay and Exmouth Gulf, together with extensive calcarenite outcrops along both the open and Shark Bay coasts. The range of beach types and states reflects the range of coastal environments with the usually calcarenite and coral reef-sheltered R-LTT (38% by length) dominating the open coast, with only 3% exposed TBR. Just under half the beaches (239) are located in Shark Bay where the very low waves result in predominately TD beaches all fringed by extensive seagrass meadows. Likewise, the sheltered Exmouth Gulf beaches are all TD. In addition, there are 46 beaches fronted by rock flats or fringing coral reefs (8.5%) (Table 33.2), the latter along the Ningaloo coast. Short (2005) provides a description of all the regions beaches.

33.5 Barriers

The region has 99 barrier systems which extend along 626 km of coast (34%) (Table 33.3). Like the beaches they range considerably in nature and extent. The most extensive are the exposed high energy clifftop dunes along the northern

Table 33.2 Central west WS region beach types and states

BS	BS	No.	%	km	%	Mean (km)	σ (km)
4	TBR	8	1.6	26.8	3.0	3.4	4.0
5	LTT	49	9.8	64.2	7.2	1.3	4.2
6	R	157	31.4	267.2	30.1	1.7	2.0
10	B + RSF	13	2.6	38.7	4.4	3.0	3.1
11	B + SF	201	40.2	365.8	41.2	1.8	2.3
12	B + TSF	26	5.2	37.5	4.2	1.4	0.9
14	R + RF	10	2	37.3	4.2	3.7	3.3
15	R + CF	36	7.2	49.7	5.6	1.4	1.1
		500	100	887.2	100	1.8	–

Table 33.3 Central west Western Australia region and PC barrier dimensions

PC	09.01	09.02	09.03	09.04	10.01	10.02	10.03	CW WA Region
No.	8	15	28	4	14	25	7	101
Total length (km)	134.8	21.7	197.8	47	104.4	149.2	53.9	708.8
Mean min width	2240	50	80	1000	300	180	130	570
Mean max width	6750	400	640	4200	1150	900	400	2060
Mean height (m)	72	7	4	10	18	11	6	19
Area (ha)	53,450	320	4600	21,850	11,500	11,135	1300	104,155
Unstable (ha)	6340	40	70	300	1860	2140	10	10,760
Total volume (M m^3)	10,708	17	197	1818	2190	1845	88	16,863
Unit volume (m^3 m^{-1})	79,436	790	995	42,776	20,974	12,368	1612	23,790

Zuytdorp Cliffs and Dirk Hartog Island (PC:WA09.01); while the very low energy Shark Bay (PCs WA09.02–03) has some of the smallest barriers in Australia. The Gascoyne River delta (PC:WA09.04) has extensive delta and associated deposits including large downdrift regressive and transgressive barriers, with transgressive dunes also dominating the more exposed Quobba-Gnaraloo coast (PC:WA10.01). The reef-sheltered Ningaloo Reef coast (PC:WA10.02) has a mix of regressive and transgressive systems; while the very sheltered Exmouth Gulf shoreline (PC:WA10.03) has limited barrier development. In total the regions barriers extend on average between 0.5 and 2 km inland with a relatively low height of 19 m. They cover an area of 104,155 ha of which 10,760 (10%) is bare and unstable. They have total volume of 16,863 M m^3 deposited at a per metre rate of 23,790 m^3 m^{-1} (Table 33.3). The dimensions of the open coast barriers are typical of the southern coast, with the Zuytdorp Cliffs (WA09.01) being on the higher side, while the small Shark Bay and Exmouth Gulf barriers are one to two orders of magnitude smaller. The barriers are all discussed in more detail in the following SCs.

33.6 Sand Transport

The central west coast is a sediment-rich region exposed to persistent southerly swell, the two combining to maintain a substantial northerly longshore sand transport, part of the system that commences 800 km to the south at Cape Naturaliste. There has been considerable sand transport of carbonate-rich beach and dune sand along the central west coast since the Pliocene. The carbonate sand (~60%) is derived from the shelf and inshore seagrass meadows, while the terrigenous sand (~40%) including quartz together with heavy minerals and garnet (Playford et al. 2013) has been eroded from the Northampton Complex Precambrian rocks and delivered locally by the Murchison and Gascoyne rivers, all combining with sand transported from the south. The sand has been transported northwards in the energetic nearshore and surf zone by the prevailing southerly waves, to be deposited as beaches and then blown inland by the southerly winds as north-trending transgressive dunes (primarily longwalled parabolics Fig. 33.2a). In the south much of this sand has been deposited on the Shark Bay peninsulas (the large Peron and the outer

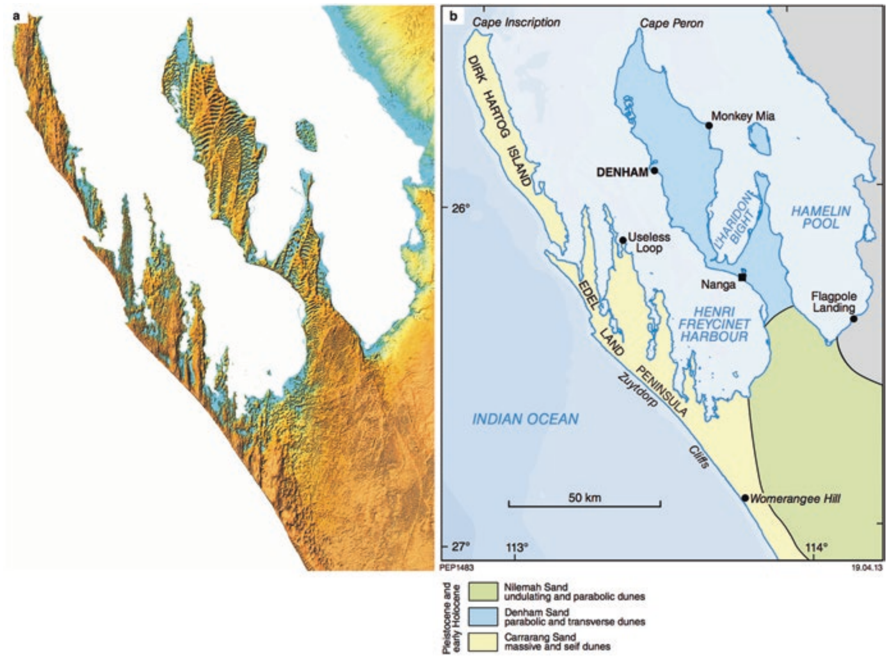

Fig. 33.2 (**a**) Digital elevation model of the Zuytdorp Cliffs, Dirk Hartog Island and Peron Peninsula region highlighting the longwalled parabolic and transverse dune systems; and (**b**) sand dune types in the Shark Bay region, with the Carrarang Sand also known as the Tamala Limestone and the Peron Sandstone underlies the Denham Sand (right). (Both from: Playford et al. 2013, reproduced with permission Geological Survey of Western Australia)

Cararang, Heirisson, Bellarine) and the high Zuytdorp Cliffs and islands (Dirk Hartog, Dorre, Bernier) as the Nilemah Sand, Peron Sandstone (Denham Sand) and Tamala Limestone (Carrarang Sand) (Fig. 33.2b). The Nilemah Sand consist of red sandy calcarenite nearer the coast, grading to quartz further inland, with a 30 km long band of heavy minerals south from Hamelin Pool. The Peron sandstone has been dated at 267.5 ka and 128 ka and consists of partly calcareous red sand, which may have had carbonate leached from the dunes. It is believed it was transported east from Edel Land deposits during lower sea levels. The Tamala Limestone is Pleistocene dune calcarenite which has been dated between 360 and 200 ka (Playford et al. 2013). These deposits rival the southeast Queensland sand islands in age, size, extent and volume, both being on the order of 200 km^3 in volume (Short and Woodroffe 2009). Also, both systems are located at the end of >1000 km long sand transport systems driven up the southeast and southwest coasts, respectively, by Southern Ocean southerly swell, and both occur where there is an inflection in the coast away from the prevailing swell allowing the sand to accumulate in high energy beaches and backing massive dune systems. The dunes represent multiple episodes of highstand sand accumulation as massive transgressive dunes including clifftop dunes, most as parabolic to longwalled parabolic, with each highstand adding another layer of sand. On the Peron Peninsula, there are large transverse dune field sets within the parabolic dunes (Fig. 33.2a). These dunes are interesting in that their spacing is an order of magnitude greater than modern transverse dunes, that is 1500 m versus ~150 m. The origin and nature of these 'oversized' dunes required further investigation. All of these dunes however were likely to the active during drier and winder 'glacial' conditions than today.

The PMT and highstand delivered yet another layer of sand to the outer Zuytdorp Cliffs and islands, with most likely deposited during the early to mid-Holocene, following which the beaches and sand ramps that supplied the dunes were eroded. Sand is most likely continuing to be transported both onshore and alongshore with some supplying the few remaining beaches and active dunes and some reaching South Passage and moving into Shark Bay.

Within Shark Bay sand transport is very limited owing to the low-wave energy and limited to the extensive seagrass feed sand banks and tidal flow into some of the bays. The Gascoyne River is supplying terrigenous sand to its sandy river mouth delta with the sediment being transported northwards into large regressive and then transgressive barriers. All the above is discussed in more detail in the following sections. The central west region contains 7 PCs and 23 SCs (Fig. 33.3; Table 33.4), all of which are discussed in more detail below.

33.7 PC:WA09.01 Zuytdorp Cliffs

The Zuytdorp Cliffs are one of the great depositional features of the Australian coast. They extend continuously northeast from the Murchison River mouth for 176 km to Zuytdorp Point and then for another 34 km north-northeast to Steep

Fig. 33.3 The central west region and its seven PCs extends from the mouth of the Murchison River at Kalbarri to Exmouth Gulf. (Source: Google Earth)

Table 33.4 Central west (Western Australia) region: PCs and SCs

Central West WA[a]	Location	Boundaries	WA beaches[b]	No.	km[c]	Total km
WA09.01.01	Zuytdorp Cliffs	Murchinson R-Nuginjay Spring	WA 1134-1137	4	2734–2751	17
WA09.01.02	Zuytdorp Cliffs	Nuginjay Spring-Steep Pt	WA 1138-1187	50	2751–2945	194
WA09.01.03	Dirk Hartog Is	Steep Pt-C Inscription	–	(7)	–	(82)
WA09.01				*54*		*211*
WA09.02.01	Dirk Hartog Is	Dirk Hartog Is (E)	–	(99)	–	(113)
		Steep Pt-C Bellefin	WA 1188-1205	18	2945–2991	46
WA09.02.02	Shark Bay	C Bellefin-Giraud Pt	WA 1206-1283	78	2991–3164	173
WA09.02.03	Shark Bay	Giraud Pt-Goulet Bluff	WA 1284-1311	28	3164–3302	138
WA09.02.04	Shark Bay	Goulet bluff-C Peron north	WA1312-1367	55	3302–3397	95
WA09.02				*180*		*452*
WA09.03.01	Shark Bay	C Peron north-Monkey Mia	WA 1368-1383	16	3397–3448	51

(continued)

Table 33.4 (continued)

Central West WA[a]	Location	Boundaries	WA beaches[b]	No.	km[c]	Total km
WA09.03.02	Shark Bay	Monkey Mia-Pell Pt	WA 1384-1397	14	3448–3539	91
WA09.03.03	Shark Bay	Pell Pt-Hamelin Pool (S)	WA 1398-1403	6	3539–3613	74
WA09.03.04	Shark Bay	Hamelin Pool (S)-Wooramel R	WA 1404-1423	20	3613–3702	89
WA09.03.05	Shark Bay	Wooramel R-Grey Pt	WA 1424-1426	3	3702–3802	100
WA09.03				*59*		*405*
WA09.04.01	Gascoyne R delta	Grey Pt-Miaboolya	WA 1427-1431	5	3802–3874	72
WA09.04.02		Miaboolya-Pt Quobba	WA 1431-1436	5	3874–3897	23
WA09.04				*10*		*95*
WA10.01.01		Pt Quobba-C Culver	WA1437-1447	11	3897–3930	33
WA10.01.02		C Culver-Gnaraloo	WA 1448-1468	21	3930–3986	56
WA10.01.03		Gnaraloo-Alison Pt	WA 1469-1488	20	3986–4029	43
WA10.1				*52*		*132*
WA10.02.01	Ningaloo Reef	Alison Pt-Pt Maud	WA 1489-1515	27	4029–4078	49
WA10.02.02	Ningaloo Reef	Pt Maud-Pt Cloates	WA 1516-1532	17	4078–4135	57
WA10.02.03	Ningaloo Reef	Pt Cloates-Winderabandi Pt	WA 1533-1539	7	4135–4167	32
WA10.02.04	Ningaloo Reef	Winderabandi Pt-North West C	WA 1540-1602	63	4167–4267	100
WA10.02				*114*		*238*
WA10.03.01	Exmouth Gulf (W)	North West C-Learmonth	WA 1603-1618	16	4267–4313	46
WA10.03.02	Exmouth Gulf (W)	Learmonth-Giralia	WA 1619-1633	15	4313–4393	80
WA10.03				*31*		*126*
WA09–10		Region WA09–10		500		1659 (195)

[a]NCCARF compartment number
[b]ABSAMP beach ID
[c]Clockwise distance from SA/WA state border

Point, the westernmost tip of the Australian continent, with the entire system is known as Edel Land. At Steep Point they break into a series of calcarenite islands (Dirk Hartog, Dorre and Bernier) that extends for another 155 km to Cape Ronsard on Bernier, in all a distance of 365 km. The usually vertical cliffs average between 100 and 150 m in height reaching in places to more than 200 m. They all consist of

Table 33.5 PC:WA09.01 beach types and states

BS	BS	No.	%	km	%	Mean (km)	σ (km)
4	TBR	7	13.0	24.6	43.6	3.5	4.2
5	LTT	46	85.2	31.5	55.9	0.7	1.1
6	R	1	0.3	0.3	0.5	0.3	–
		54	100	56.4	100.0	1.04	–

multiple layers of lithified carbonate-rich dune sand (palaeodunes and palaeosols), with the unconsolidated more recent Holocene sand resting on top as clifftop dunes. This is an exposed high wave energy coast consisting of steep sea cliffs, with cliff debris and extensive intertidal rock platforms at their base and persistent 1–2 m waves breaking heavily on their outer edge. There are 54 beaches in amongst the rocks and platforms with most LTT fronted by rock flats (Table 33.5). The beaches are the scattered remnants of the once more extensive early to mid-Holocene beach systems that supplied the sand ramps to feed the extensive clifftop dunes. Much of this coast is now protected in parks and reserves including the Zuytdorp Conservation and Nature Reserve and the Francois Peron, Dirk Hartog Island and Edel Land (proposed) national parks, while the entire Shark Bay is a marine park. This PC contains three SCs including Dirk Hartog Island.

33.7.1 SC:WA09.01.01 Murchison River–Nuginjay Springs

SC:WA09.01.01 is a short straight 17 km long SC containing the northern shores of the slightly indented Gantheaume Bay between the Murchison River mouth (Figs. 33.4a and 33.5a) and Nuginjay Springs. This coast is part of Murchinson House station and accessible, with permission, via the station. The coast consists of near continuous beaches, backed by calcarenite which slopes inland for a few hundred metres rising to around 150 m, and which mark the beginning of the Zuytdorp Cliffs. The coast faces west-southwest into the prevailing southwest swell which maintains high energy beaches consisting of sections of TBR interrupted by numerous outcrops of sloping beachrock and calcarenite, including boulder fields of beachrock slabs, all of which induce topographic rips. Four beaches occupy 15 km (88%) of the shore, including the 14 km long rip-dominated (TBR) Gantheaume Bay (WA 1135), with the remainder of the shore calcarenite rocks, reefs and flats, all backed by steeply rising calcarenite slopes and in places north-trending dunes climbing the slopes at an acute angle to the shore. The largest active dunes are up to 2 km long and climb to over 100 m elevation (Fig. 33.5b). The dunes are driven by the strong almost unidirectional south to southeast winds that dominate this PC and have a volume of 60 M m^3 (6315 m^3 m^{-1}). The beach sand is a mix of shelf carbonate and Murchison River sand, as indicated by the high proportion of quartz (~80%) and the presence of dark bands of heavy minerals and the pink garnet which is deposited by the swash as a thin surface layer giving the beaches a pink hue.

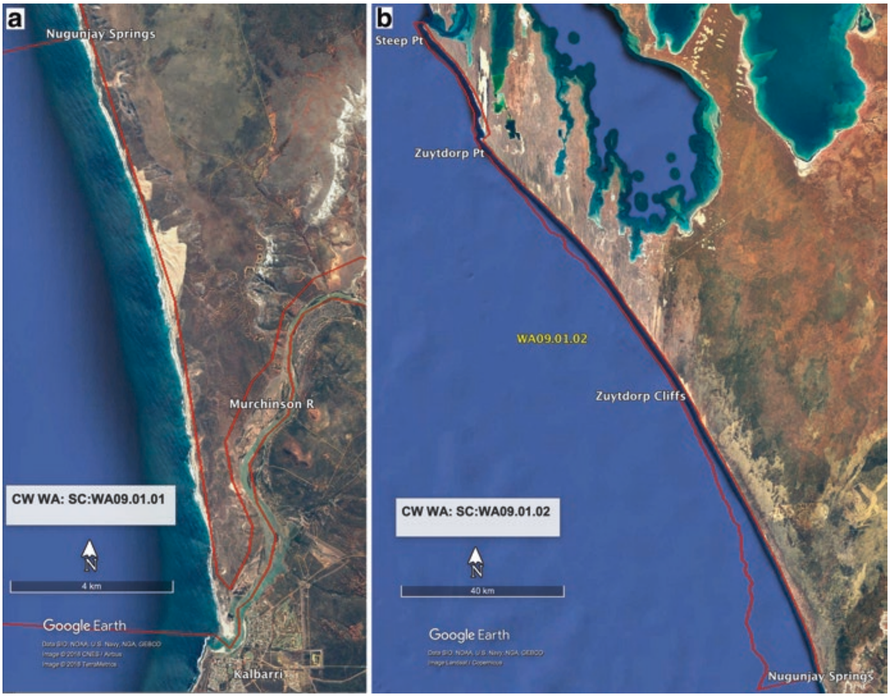

Fig. 33.4 (**a**) SC:WA09.01.01 and (**b**) WA09.01.02 extend from the Murchison River moth at Kalbarri to Steep Point, the westernmost tip of Australia. (Source: Google Earth)

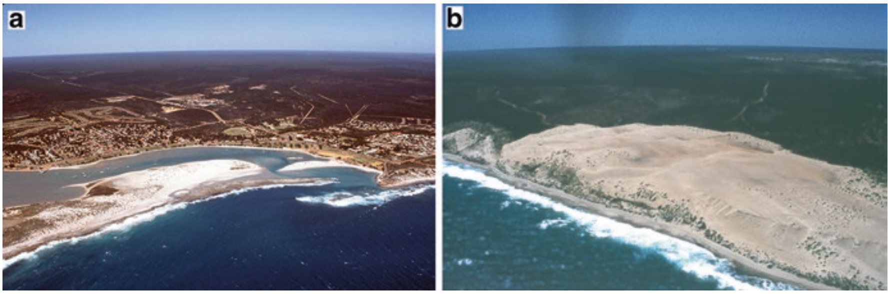

Fig. 33.5 (**a**) Kalbarri and the reef constrained mouth of the Murchison River (WA1135) and (**b**) climbing dunes about 10 km north of the Murchison River (WA 1135). (Photos: AD Short)

33.7.2 SC:WA09.01.02 Nuginjay Springs–Steep Point

SC:WA09.01.02 contains the bulk of the Zuytdorp Cliffs, extending in a very gently north-northwest-trending curve for 161 km from Nuginjay Springs to Zuytdorp Point and then a second curving section for 33 km to Steep Point, with a total shoreline of 194 km (Fig. 33.4b). The coast south of the State barrier fence is part of Murchison House station, while to the north it extends into the Zuytdorp Nature Reserve, Tamala station, and Edel Land National Park (proposed 2019). There are 50 beaches located along the base of the cliffs totalling 42 km in length (22%) (Fig. 33.6a). They are all bordered and interrupted by a combination of calcarenite rocks, bluffs and beachrock, with most sheltered LTT and only six more exposed TBR totalling 11 km in length including the northern Catfish Bay. Many of the beaches are at the base of cliffs and steep slopes and inaccessible. The bulk of the coast is rugged with jagged calcarenite rocks and platforms backed by the steep rising cliffs and slopes, with a 90 km long section between the Zuytdorp wreck site and Zuytdorp Point and 20 km long section between Catfish Bay and Steep Point of continuous cliff rocky coast and no beaches. The beach sand, which has low carbonate at the Murchison, increases in carbonate to 70% by Catfish Bay with the sand moderately well-sorted and medium to coarse (mean = 0.64 mm).

The cliffs are however capped by extensive transgressive dunes, some climbing slopes and some clifftop dunes deposited on top of cliffs up to 260 high. Holocene transgressive and clifftop dunes occupy 125 km (60%) of the cliffs. They occur as small climbing dunes in the south, an extensive 68 km long section of clifftop longwalled parabolics south from Zuytdorp Point and between Zuytdorp Point and Steep Point, with the dunes extending on average ~10 km inland. The dunes cover an area of 53,000 ha and were likely to be active during the late Pleistocene and early Holocene (Playford et al. 2013). At present ~10% are unstable, including the active 34 km long longwalled parabolic that trends due north out of Dulverton Bay (Fig. 33.6b), the longest active parabolic dune in Australia, with older now stable dunes extending for 40 km. The Dulverton dune activity may be related to the fact it is continuing to receive sand from the beach, while the clifftop dune instability may be related to stock grazing since the mid-nineteenth century. The uniformity in direction and extent of the dunes is due to the strong unidirectional south wind coupled with the arid climate. The dunes have a total volume of 16,648 M m^3 and high per metre volume of 84,980 $m^3\ m^{-1}$.

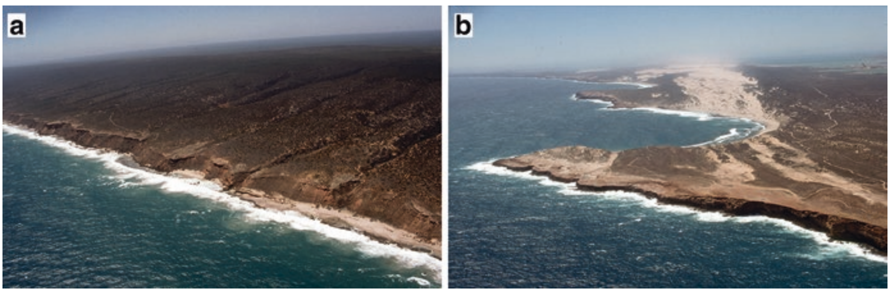

Fig. 33.6 (**a**) Zuytdorp Cliffs 60 km north of the Murchison River (WA 1166-7) and (**b**) Zuytdorp Point and Dulverton Bay with long dunes blowing north out of the bay (WA 1186). (Photos: AD Short)

33.7.3 SCs:WA09.01.03–02.01 Dirk Hartog Island

SCs:WA09.01.03-WA09.02.01 include the western and eastern side of Dirk Hartog Island (Fig. 33.7). The 80 km long island trends north-northwest, with an exposed 99 km long western shoreline and a sheltered 105 km eastern shoreline. The island consists entirely of Pleistocene dune calcarenite (Tamala Limestone). The western shore is a near continuous line of cliffs ranging from 50 to 150 m in height, with all the cliffs capped by clifftop dunes (Fig. 33.8a). The only beaches are in the south inside the sheltered South Passage where they are all fronted by sand flats, the small central exposed Mystery Beach, and in the north between West Point and Cape Inscription where they are all fringed by calcarenite rock flats, with a total of 11 beaches extending along 10 km (10%) of the shore. In contrast the sheltered east

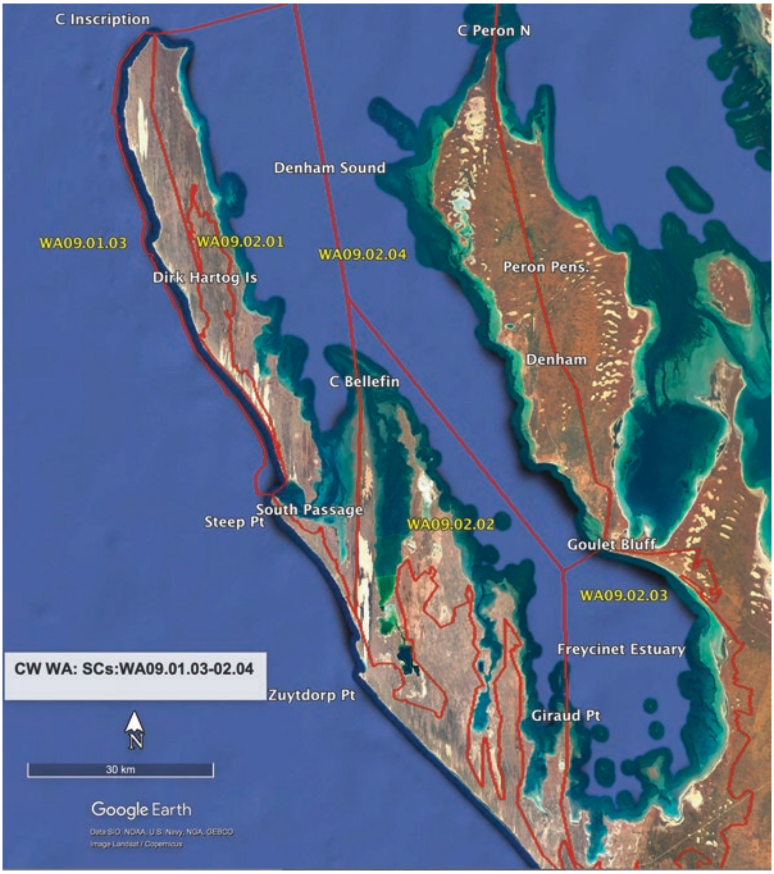

Fig. 33.7 SCs WA09.01.03–02.04 Dirk Hartog Island to Peron Peninsula. (Source: Google Earth)

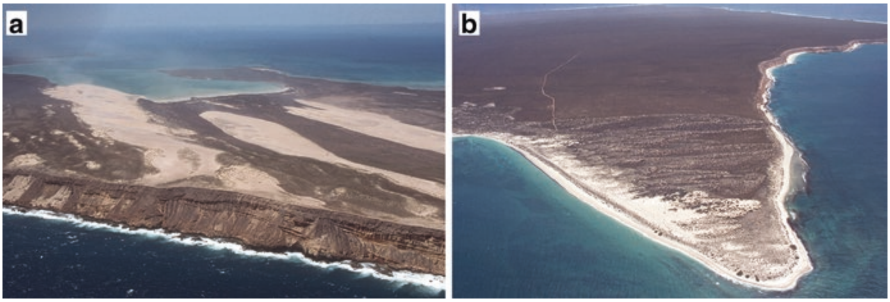

Fig. 33.8 (**a**) Clifftop dunes overpassing Dirk Hartog Island; and (**b**) parabolic dunes moving northwards across Cape Levillain, Dirk Hartog Island. (Photos: AD Short)

coast has 96 near continuous beaches which occupy most of the shore. They range from WD R to TD B + RSF and SF.

The western half of the island is blanketed by a continuous series of clifftop dunes with some extending up to 15 km northwards diagonally across the island and sub-parallel to the coast, while two in the south have reached the eastern shore and migrated up to 2 km out across the sand flats. The dunes cover and area of around 35,000 ha, which assuming they average 20 m in thickness would represent 7000 M m^3 with a per metre volume of 70,000 m^3 m^{-1}, both comparable to the Zuytdorp Cliff dunes in volume. Most of the dunes are stable with about 8% unstable, including the two overpassing dunes. Some of the instability may be a result of stock grazing since the mid-nineteenth century.

The eastern side of the island has one small area of transgressive dunes on southeast-facing Cape Levilian (Fig. 33.8b) and a series of six regressive salient composed of both south-trending recurved spits in Turtle Bay and multiple beach-foredune ridge, including Withnell and Sandy points. These are all located along the northeastern shore of the island and may rely on refracted ocean swell for their formation.

This SC also includes the mainland coast between the southern entrance to Shark Bay at Steep Point and the tip of the Bellefin Prong (peninsula) at Cape Bellefin (Fig. 33.7), a shoreline distance of 46 km. This is a roughly U-shaped, north-facing shoreline facing across South Passage and Blind Strait to Dirk Hartog Island. The beach sand in this section is predominately moderately well to moderately sorted, medium and carbonate-rich (85%). The sand is most likely transported into South Passage by ocean swell and moved by flooding tides into Blind Passage where there is an 80 km^2 flood tide delta. There are 18 beaches along this southern shore which occupy 24 km (52%) of the coast, the remainder low calcarenite bluffs. The beaches along the first 7 km of shore receive low refracted swell through South Passage and are R, while those further in are B + SF with the sand flats ranging from 1 to 3 km in width.

South Passage-Blind Strait appears to be a major conduit for wave- and tide-transported marine sand, the sand reaching as far as Cape Bellefin and its tidal shoals that extend a further 8 km northwards. Its salinity is oceanic (35 $^{o}/_{oo}$) owing to proximity to South Passage. In the past dune sand from the Zuytdorp Cliffs overpassed the cliffs and was deposited along the southern shore of South Passage and western shore of Bellefin Prong. While these areas are backed by parabolic dunes, they are now all well vegetated and stable. The Passage and Strait has therefore acted as a major sink for marine-dune sand; however apart from the beaches and their sand flats and the tidal delta, there are no subaerial barriers or dunes along this coast owing to the sheltered nature of the shore.

33.7.4 PC Overview

The Zuytdorp Cliffs-Dirk Hartog Island is a very exposed predominately cliffed coast that has been evolving throughout the Pleistocene. The PMT has added yet another layer of carbonate-rich dune sand to the 50–200 m high dune calcarenite cliffs. While most of the longwalled parabolic dunes are stable, about 10% are unstable possibly dune to stock activity. This SC contains the longest stretch of calcarenite cliffs in Australia and perhaps the world, the most extensive field of longwalled parabolic dunes in Australia with the longest dunes extending for 40 km and most dunes sitting on top of cliffs 100–150 m high. The Gantheaume Bay beach and climbing dunes (Fig. 33.5b) illustrate how the clifftop dunes evolved, with most of the beaches and sand ramps that supplied the dunes now eroded. Rising sea level will have little impact on this coast, other than reactivate the calcarenite rock platforms and perhaps cause a slight increase in cliff retreat, which based on SA studies should be on the order of 30 mm year^{-1}. The dunes could also be impacted if rainfall declines and wind velocity increases, leading to some dune reactivation. Within South Passage-Blind Strait, the rise in sea level may lead to a reactivation of the flood tide delta leading to an increase in sand transport into the passage, assuming marine sand is available.

33.8 PC:WA09.02 Shark Bay (SW)

PC:WA09.02 occupies the southwestern section of Shark Bay and includes the shoreline of a 280 km long roughly U-shaped embayment that contains Denham Sound in the north between Dirk Hartog Island-Edel Land Peninsula and the Nanga-Peron Peninsula, with a series of smaller elongate north-south bays in the south including Blind Strait, Useless, Boat Haven and Depuch loops and the larger Freycinet Reach and Estuary (Fig. 33.3 and 33.7). It is a highly crenulated 565 km long shoreline with a crenulation ratio of 5.2. Tides are micro, and waves are low locally generated seas, apart from some low swell reaching the western side of Cape Peron. Overall this is a very low energy environment with wide shallow sand banks, averaging 1.3 km in width (σ = 1 km), extending out from most beaches

Table 33.6 PC:WA09.02 beach types and states

BS	BS	No.	%	km	%	Mean (km)	σ (km)
5	LTT	2	1.1	3.2	1.5	1.6	–
6	R	19	10.6	12.5	5.8	0.7	0.6
10	B + RSR	5	2.8	7.5	3.5	1.5	0.6
11	B + SF	152	84.4	191.7	88.3	1.3	1.7
12	B + TSF	2	1.1	2.1	1.0	1.1	–
		180	100	217	100	1.2	–

further lowering wave height. There are 180 predominately TD beaches occupying 217 km (38%) of the shore dominated by the wide sand flats (88%), with a few WD R and LTT on the more exposed shores (Table 33.6).

Shark Bay is a large shallow (<20 m deep) epicontinental sea bordered on the west by the Zuytdorp Cliffs and its extension as the three islands (known as Edel Land), and the mainland to the east, with several north-trending elongate peninsula and islands occupying the southern half of the bay. It has an area of 23,000 km^2 and 1050 km of shoreline. It was declared a World Heritage Area in 1991 in recognition of the large temperate and tropical seagrass meadows and dugong population and its range of salinities which permit stromatolites to grow in the southern hypersaline Hamelin Pool. The combination of a shallow bay with micro-tides and restricted circulation in a hot desert environment has led to the salinity increasing southwards into the bay, from oceanic (35–40°/$_{oo}$) reaching metahaline (40–55°/$_{oo}$) generally south of Cape Peron and hypersaline (55 to >70°/$_{oo}$) in Hamelin Pool (Logan and Cebulski 1970). The bay is also a massive carbonate factory with its extensive seagrass meadows producing epifauna (Fig. 16.8), whose detritus is slowly transported shoreward to build the extensive carbonate sand banks or embankments. An overview of the seagrass systems is provided by Kendrick et al. (2012) and Kilminister et al. (2018). While most sediment is produced in situ, some marine sand is transport by ocean swell into South Passage-Blind Strait and between and around the islands; however the vast bulk is produced and maintained within the bay, making the bay a massive sink for carbonate sediment. The carbonate environment its nature, ecology, embankments and diagenesis has been both intensively and extensively investigated by a range of researchers starting with Logan (1961). He was followed by Logan (1970, 1974), Logan and Cebulski (1970), Logan and Hagan (1970), Logan et al. (1970a, b, 1976), Read (1974a, b) and Wood and Brown (1975); while Playford (1990) and Playford et al. (2013) describe the geology of the bay area, the latter extremely well illustrated.

33.8.1 SC:WA09.02.02 Cape Bellefin–Giraud Point

SC:WA09.02.02 consists of four north-trending peninsulas (Bellefin, Heirisson (Fig. 33.9a), Carrarang and Giraud) up to 50 km in length, separated by three narrow (<5 km) elongated bays (Useless, Boat Haven and Depush) which all narrow to

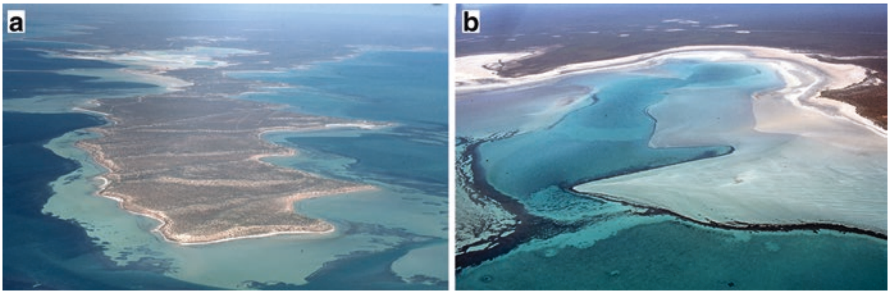

Fig. 33.9 (**a**) View of Cape Heirisson and the Heirisson Prong (peninsula) with its shoreline fringed by sand flats and seagrass meadows (WA 1242-9) and (**b**) view towards Eighteen Mile Well showing extensive carbonate banks in the southeastern corner of Freycinet Estuary (WA 1301). (Photos: AD Short)

the south (Fig. 33.7), with a total shoreline length of 173 km and crenulation ratio of 2.9. The bays are all metahaline, reaching hypersaline in their lower reaches where algal mats grow in the highly saline conditions (Logan 1961) and all part of Shark Bay Marine Park. The southern end of Useless Loop is dammed and used for salt production, the only development in the area apart from Carrarang and Tamala stations and limited camping facilities on the stations and in Edel National Park. The bay shorelines are a mix of some outer beaches in the slightly more exposed locations and sand flats in the lower more sheltered locations, both separated by generally low (<20 m) calcarenite bluffs. The 78 beaches occupy 73 km (42%) of the shore, all are B + SF with seagrass meadows rimming their outer edge. The sand flats average 1.1 km in width and range from 0.3 to 2 km. Sediments within the bays have been supplied in the past by dune overpassing from the Zuytdorp Cliffs and since the PMT from the seagrass meadows and their growing sand flats. Apart from the sand flats and the low shelly beaches, there has been no internal dune development and no barrier formation.

33.8.2 SC:WA09.02.03-04 Giraud Point–Cape Peron North

SC:WA09.02.03-04 incorporates Denham Sound in the north and in the central-south the 80 km long Freycinet Reach and Estuary (Fig. 33.9b) bordered in the west by the four peninsulas and their bays, part of the eastern shore of Edel Land and Dirk Hartog Island in the north and on the east by the western shore of the long Nanga-Peron peninsula (Fig. 33.7), with a shoreline length of 233 km and crenulation ration of 2.1. Then only development on the coast is the town of Denham and some camping areas at Nanga and in the Francois Peron National Park, which occupies the northern half of the peninsula. The 60 km long Nanga Peninsula is covered by red transverse and parabolic sand dunes of the Denham Sand, together with

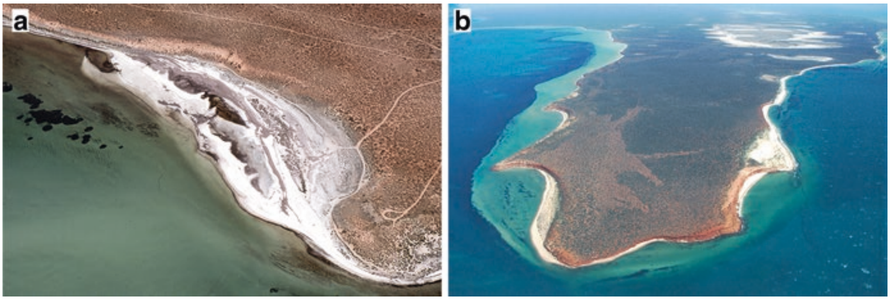

Fig. 33.10 (**a**) North-trending spits on the northern side of Goulet Bluff (WA 1312) and (**b**) Cape Peron and the Peron Peninsula with its big red bluffs (WA 1366-8). (Photos: AD Short)

parabolic and undulating dunes of the Nilemah Sand in the southern part (Fig. 33.2a). The Peron Peninsula is about 75 km long and composed of Peron Sandstone which is almost entirely covered by dune sands of the Denham Sand (Fig. 33.2b), which are regarded as mid-Pleistocene to early Holocene in age (Playford et al. 2013). The bright red sandstone is exposed in bluffs around the edge of the peninsula such as at Cape Peron (Fig. 33.10b). This SC is for the most part a west-facing shore which forms the eastern side of 140 km long south-southeast-trending embayment, which varies in width from 15 to 45 km.

Beach sand along the west shore of the northern Nanga and Peron peninsulas varies considerably in sorting (well to poor), size (fine to very coarse) and carbonate (2–58%, mean = 22%). The low carbonate is typical of the Person Sandstone and capping Denham sands, while the variation in size and sorting is a result of the very low energy environment and high shell content. The shoreline is fronted by near continuous sand flats fringed by seagrass meadows; the flats range up to 5 km in width, averaging 1.5 km (σ = 1.3 km). They are backed by 83 beaches which occupy 121 km (52%) of the shore, the remainder red sandstone bluffs up to 20 m high (Fig. 33.10b). The beaches are primarily B + SF, with a few R beaches in more exposed locations and where the sand flats are absent or vary narrow, including Nanga Bay (WA 1308-10), Whalebone (WA 1322-23) and between Gregory and Cape Peron (WA 1362-1367).

The beaches are backed by 15 Holocene barriers which include foredunes backed by north-trending blufftop dunes extending a few hundred metres inland, all located in lee of more southerly facing salients and regressive beach ridges and north-trending recurved spits, the latter located on the northern side of the many salients. The dunes are driven by the dominant southerly winds, which also generates the low, short seas and wind-driven currents which form the spits, and are indicative of northerly sand transport (Fig. 33.10a). Northerly transport is also occurring on the sand flats as indicated by their general increase in width and extent on the northern side of salient and possibly the series of shoals that extend 12 km north of Cape Peron. The 15 barriers occupy just 22 km (9%) of the coast and range in width from 50–400 m. They have a volume of just 17 M m^3 and a small per metre volume of

790 m^3 m^{-1}, indicative of the low energy environment. They cover an area of 320 ha of which 13% is presently unstable (Table 33.3).

33.8.3 PC Overview

This western side of Shark Bay is a generally very low energy sediment-rich environment, with most of the sand located in wide sand flats (embankments) that typify the shores of Shark Bay. While some marine sand has been transported into South Passage and probably around Dirk Hartog Island, the bulk of the sand is expected to originate in the seagrass meadows from where it is slowly transported onshore to form the extensive sand flats. There is also a contribution from erosion of the Nanga and Peron peninsulas and their capping sand dunes as indicated by the lower carbonate content along their shorelines. The impacts of future climate change in this environment will be related to rising sea level which will increase the tidal prism thereby improving circulation and reducing salinity. The rise will physically 'drown' the flats raising wave energy at the shore and probably lead to localised erosion as well as an increasing in northerly sand transport. The decrease in salinity will have impacts on the salinity-dependent organism.

33.9 PC:WA09.03 Hopeless Reach–Hamelin Pool

PC:WA09.03 is a 125 km long up to 40 km wide south-southeast-trending embayment, bordered by the eastern shores of the Nanga-Peron peninsulas in the west and the mainland in the east, including the Wooramel River delta (Figs. 33.3 and 33.11). The embayment contains the northern Hopeless Reach and southern Lharidon Bight and Hamelin Pool, the two separated by a shallow 50 km wide Faure Sill (Fig. 33.11). This southeastern corner of Shark Bay is the most remote from the ocean and has the highest salinities, with metahaline conditions in Hopeless Reach and hypersaline south of the sill in Lharidon Bight and Hamelin Pool. This is a very low energy environment, with entirely TD beaches in this micro-tidal environment (Table 33.7). Bufarale and Collins (2015) investigated the evolution of the Faure Sill and found that low-stand erosion, was followed by seagrass establishing itself on the sill which

Table 33.7 PC:WA09.03 beach types and states

BS		No.	%	km	%	Mean (km)	σ (km)
10	B + RSF	4	6.8	10	4.7	2.5	4
11	B + SF	33	55.9	138.8	65.8	4.2	3.1
12	B + TSF	12	20.3	24.7	11.7	2.1	1
14	R + RF	10	16.9	37.3	17.7	3.7	3.3
		59	100	210.8	100	3.6	–

initiated bank growth by 8.5-8ka, and then as sea level rose rapidly bank accumulation reached its maximum by 6.8 ka. This was followed by a fall in sea level during the late Holocene infilling of remaining accommodation space.

33.9.1 SCs:WA09.03.01–03 Cape Peron North–Hamelin Pool (S)

SCs:WA09.03.01–03 extend along the eastern shores of the Peron and Nanga peninsulas from Cape Peron to Hamelin Pool (Fig. 33.11), a shoreline distance of 216 km with a crenulation ratio of 1.8. For the most past, this is a very low energy leeward shoreline with the southerly winds blowing off or alongshore and much of the shore fringed by sand flats and in the north seagrass meadows. There is no development on the coast apart from some camping areas in the national park including

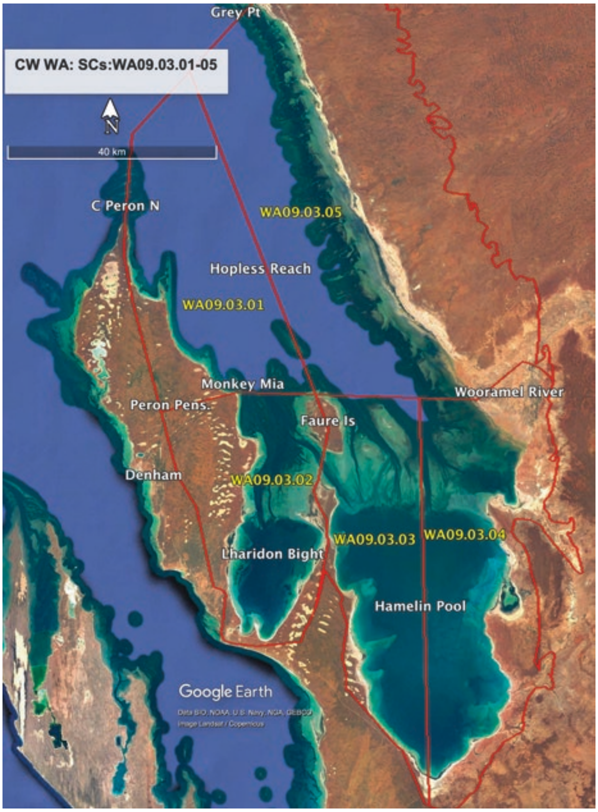

Fig. 33.11 SCs:WA09.03.01-05: Peron Peninsula, Hopeless Reach, Lharidon Bight, Hamelin Pool and the Wooramel Delta. (Source: Google Earth)

the Monkey Mia facilities (Fig. 33.12b) and the boardwalk though the Hamelin Pool stromatolites. The southern section of Lharidon Bight is a sanctuary zone, and all of Hamelin Pool is a marine nature reserve. The beaches along this shore remain relatively low in carbonate (mean = 28%, σ = 29%) but range from 7 to 100%, with the sand moderately well-sorted and medium in size. The coast has 36 beaches occupying 155 km (72%) with generally low red bluffs (<20 m) occupying the remainder. The beaches occur in a series of curving embayments forming near continuous sandy shore, with three beaches more than 10 km in length. They are fronted by sand flats that range in width from 0.5 to 2 km averaging 1.8 km (σ = 1.1 km) and fringed by seagrass meadows. The beaches are predominately B + SF, with some B + RSR around the slightly more exposed Herald Bluff (WA 1378-81). At the base of L'Haridon Bight is the famous Shell Beach (WA 1394) composed of 100% small white cockle shells (*Fragum erygatum*) (Fig. 33.12c). The shell is mined for aggregate, and areas of lithified shell (shellrock) are quarried for building material. At the base of Hamelin Pool are the even more world-famous stromatolites, ancient algal concretions that thrive in the hypersaline environment, that preclude most other organisms.

This coast has series of 19 low energy barrier systems occupying 148 km (69%) of the shore, all consisting of low sandy-shelly beach ridge-recurved spits, most

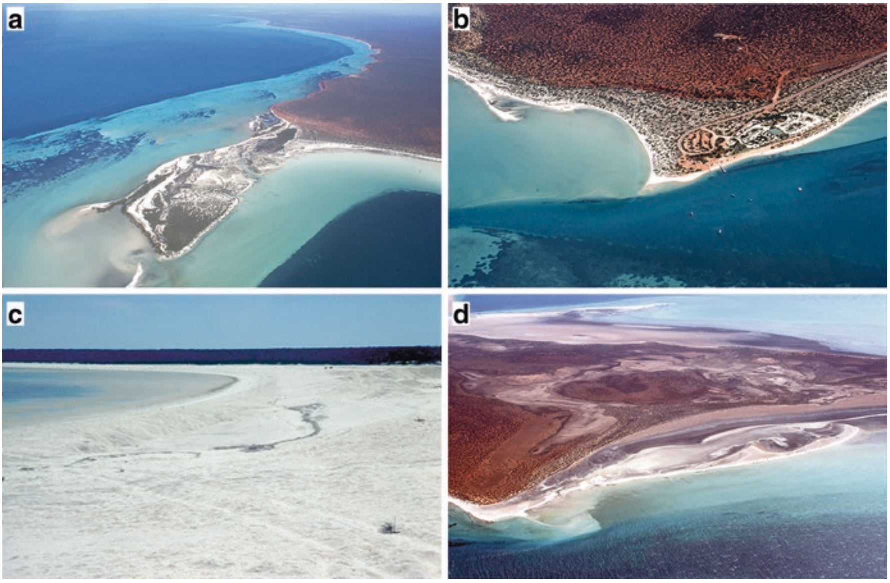

Fig. 33.12 (**a**) Guichenault Point is composed of a series of north-trending spits enclosing mangroves, with the point surrounded by the carbonate banks and seagrass meadows (WA 1375-6); (**b**) the popular Monkey Mia is located on a salient that extends to deeper water where the dolphins emerge (WA 1382-3); (**c**) Shell Beach (WA 1394) at the base of hypersaline Lharidon Bight is composed of 100% cockle shells (*Fragum erugatum*); and (**d**) (WA 1398); a 1.5 km long spit trending northwest from Petit Point. (Photos: AD Short)

trending northwards (Fig. 33.12a, d), and a continuous series on the eastern shore of Lharidon Bight extending for 22 km (WA 1395-6), the final 5 km trending northwest across the sand flats. Some of the ridges are backed by inner higher ridges deposited during the higher (~1 m) mid-Holocene sea level. It is believed the beaches and ridges are only active during strong wind events, particularly those associated with tropical cyclones. Nott (2011) dated a series of inner ridges at the base of Hamelin Pool to reconstruct a record of tropical cyclone events over the past 6 ka. The barriers average from 70–700 m in width, with a total area of 2755 ha and volume of 128 M m^3 and small per metre volume of 862 m^3 m^{-1}.

33.9.2 SCs:WA09.03.04-05 Hamelin Pool (S)–Grey Point

SCs:WA09.03.04-05 commence at the Hamelin Pool stromatolites and extend up the eastern mainland coast to the Wooramel Delta and then onto the base of the Gascoyne delta at Grey Point, a shoreline distance of 189 km (Fig. 33.11). While the coast faces west-southwest into the prevailing winds, this remains a very low energy shore owing to the limited fetch and in Hopeless Reach the shallow sill and wide sand flats. Most of the shore is protected by the Hamelin Pool Marine Nature Reserve and a special purpose and sanctuary zone along most of the coast to the north. The only access and development is at the Hamelin Pool stromatolites and a camping area at Gladstone (WA 1423) where there are the remains of a 300 m long rock jetty (Fig. 33.13b). There are 23 beaches along this coast, 20 in the southern SC south of the Wooramel delta and just 3 all located at the northern end of the second SC. They occupy 55 km (29%) of the coast, the remainder consisting of low bluffs in the south and the delta flats and tidal flats to the north, the latter covered by stunted mangroves owing to the high salinity. The low sand-shelly beaches are fronted by sand flats and tidal sand flats averaging 1 km in width. The southerly wind and waves are driving sand northwards along the coast and have formed a series of embayed beach ridges and north-trending recurved spits, with nine active

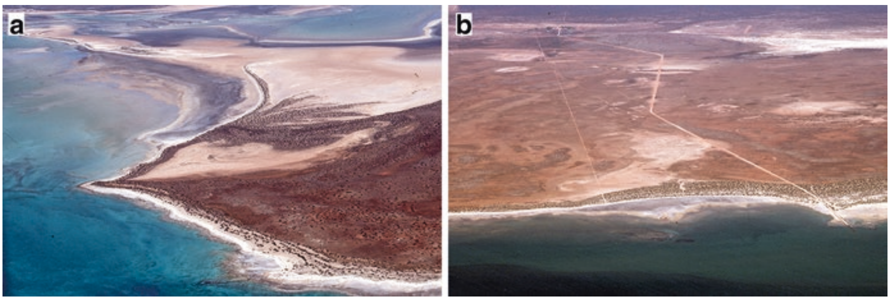

Fig. 33.13 (**a**) A series of recurved spits extending northeast across the salt flats at Yanga Point (WA1414-5) and (**b**) Gladstone beach (WA 1423) and jetty backed by a few low beach ridges. (Photos: AD Short)

systems (Fig. 33.13a) and several raised and inactive systems remnants of the mid-Holocene sea level high, particularly north of the Wooramel delta. The active systems occupy 50 km (26%) of the shore and consist of pockets of beach ridges spit averaging 80–600 m in width, with an area of 1840 ha and volume of just 70 M m^3 (1397 m^3 m^{-1}). North of the Wooramel, there is a 70 km long series of raised inactive beach ridges and spits, many dissected by small tidal creeks and fringed by low mangroves and fronted by 2–4 km wide sand flats then seagrass meadows.

33.9.3 PC Overview

This is an unusual PC in that it is extremely low energy and metahaline to hypersaline, as result of which it contains some rare environmental conditions and ecosystems, which have resulted in the entire shore and bays being protected in the marine park and associated reserves. This has led to it becoming an important and increasingly popular geological-ecological tourist destination, all in the most arid part of the Australian coast. Rising sea level will directly impact all these environments both physically and ecologically. Physically it will raise the water level over the sills and tidal flats thereby increasing wave energy, improving circulation and decreasing salinity. The higher waves will accelerate the northerly sand transport and may lead to localised shoreline erosion, while the decrease in salinity will have impacts on the salinity-dependent organisms. Extreme weather events including heat and freshwater runoff from the Wooramel have already caused defoliation of 1000's km^2 of temperate Shark Bay seagrasses, an issue which will have to be addressed as global temperatures rise (Kilminister et al. 2018). North of the Wooramel delta, decreasing salinity should improve conditions for mangroves and will start to reactivate the raised shorelines.

33.10 PC:WA09.04 The Gascoyne River Delta

The Gascoyne River is the longest river in Western Australia (865 km) and one of the larger rivers in the central and south of western Australia with a catchment of 76,254 km^2 (Table 30.2). Its flow however is highly seasonal, and major flows and floods are dependent on heavy rains from cyclones, monsoon troughs and winter lows. It tends to start flowing in March due to cyclonic rain or May due to southerly winter rain, with usually no flow between September and December. There is however considerable variation in the timing and amount of flow. It has a sediment load of medium to coarse sand with minor gravel and mud (Johnson 1982). The river has a series of abandoned deltas, commencing with a large Miocene paleodelta that extends down to the Wooramel delta, followed by the Quaternary Brown and Boodalia deltas extending 16 km to the south of the modern delta and probably formed at the interglacial high sea level stands 240 ka and 130–120 ka, respectively, while the modern delta extends 30 km north from the mangrove-lined Boodalia delta to Miaboolya (Hocking et al. 1987). The delta sequence indicates that the Gascoyne River has gradually migrated northwars in the Quaternary, possibly due to the prevailing southerly wind waves and winds and northerly longshore transport building north-trending spits and blocking the earlier channels (Hocking et al. 1987). The northerly transport has also supplied sand to build the Miaboolya-Bejaling beach dune systems which blocked the southern end of Lake MacLeod about 5 ka (Hocking et al. 1987). Lustig (1977) reported that Babbage Island at the mouth of the delta had receded 200 m since 1882 and proposed a model whereby the river mouth is deflected southwards on a cycle of 600–1000 years and then breaks through in the north to resume the cycle.

The regional centre of Carnarvon is located on the southern banks of the river mouth (Fig. 33.14) and includes two jetties and some boating facilities and is the only development in this PC. The delta lies 50 km to the lee of Dorre and Bernier islands which afford considerable protection form ocean swell. Ocean wave energy

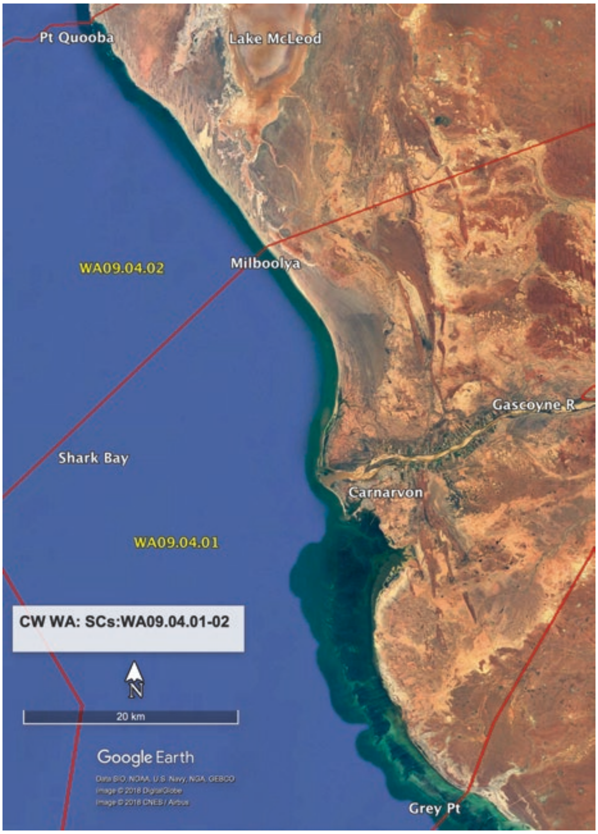

Fig. 33.14 SCs:WA09.04.01–02: the Gascoyne River delta whose sediments are transported north to Miaboolya and Point Quobba and have blocked Lake McLeod. (Source: Google Earth)

Table 33.8 PC:WA09.04 beach types and states

BS	BS	No.	%	km	%	Mean (km)	σ (km)
5	LTT	1	9.1	29.5	53.6	29.5	–
6	R	6	54.5	17	30.9	2.8	2.4
10	B + RSR	2	18.2	7	12.7	3.5	–
12	B + TSF	2	18.2	1.5	2.7	1.5	–
		11	100	55	100	5.0	–

is very low on the southern side of the delta at Point Grey where mangroves fringe the shore. Wave height slowly increases northwards, with beaches and spits forming at the river mouth and more continuous low energy beaches north to Miaboolya, which is in line with the northern end of the islands, with higher energy waves and beaches further north. In all 11 longer beaches occupy 55 km (68%) of the shore, with mangroves and tidal flats dominating the south, the sandy spits at the river mouth and a near continuous beach between the river mouth and Point Quobba, the latter transitioning from LTT in the south to rip-dominated TBR, including many reef-induced rips (Table 33.8).

33.10.1 SC:WA09.04.01 Grey Point–Miaboolya

SC:WA09.04.01 encompasses the Gascoyne delta and its adjacent shorelines (Fig. 33.14). It is 72 km in length extending from Point Grey, the southern limit of the Boodalia delta to Miaboolya the northern end of the modern delta's regressive foredune ridge plain, with the sandy river mouth in the centre (Fig. 33.15b, c). The nature of the delta reflects the gradual northerly increase in ocean wave height. The sheltered southern side of the delta is lined by mangroves and fronted by the 7 km wide Gascoyne flats which are covered in seagrass meadows (Fig. 33.15a). The river deposits its coarse bedload on the river mouth bars which are reworked by low ocean swell. On the southern side of the mouth is a 5 km long curving spit (WA 1428), backed by a 1.5 km wide series of former spits which narrow inland. Most of the sand is however transported north from the river mouth as a series of north migrating spits (WA 1429-30) which link to the main beach about 8 km to the north. They are backed by a 1 km wide band of former spits and then the multiple sandy channels and supratidal flats of the lower deltaic plain. North of the merging area, the beach (WA 1431) runs continuously for 15 km to the north and then northwest. It is backed by a shallow 5 km wide Miaboolya embayment that has been filled with a series of up to 40 low beach-foredune ridges (Fig. 33.15c) which narrow to the northern end of the embayment. Some of the outer ridges have been reactivated as blowouts, with blowout-parabolic activity also increasing to the northern SC boundary.

The beaches north of the river mouth reflect their fluvial origin. They are very well-sorted fine to medium quartz-rich sand with just 4% carbonate (Fig. 33.1). The

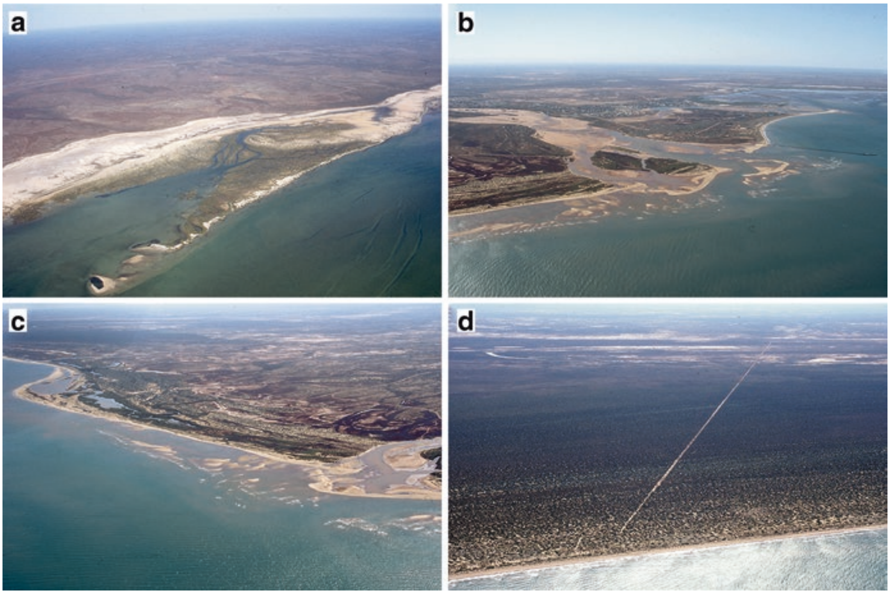

Fig. 33.15 (**a**) A low discontinuous north-trending spit enclosing low mangroves at New Beach (WA 1424); (**b**) view south across the Gascoyne River mouth and its river mouth sand bars (WA 1428); (**c**) view north from the Gascoyne mouth showing the northwards migrating sand spits and backing regressive spits (WA 1429-30); and (**d**) the Miaboolya regressive foredune ridge plain (WA 1431). (Photos: AD Short)

coarser river mouth sand combines with the waves to form R beaches around the river mouth spits. As the sand fines downdrift along Miaboolya beach, the waves maintain a wide flat LTT, which as wave energy increases northwards transforms to TBR along the northern end of the beach. The transition in wave energy and beach states is also reflected in the barriers, with low spits and beach-foredune ridges in the south (Fig. 33.15c, d), which as wave energy increases begin to be reworked by blowout-parabolics (Fig. 33.16a, b), the transgressive dunes increasing in size and extent northwards in parallel with increasing wave energy. The northern end of the regressive plain shows clear evidence of episodes of dune transgression followed by shoreline regression on at least three occasions, including at present. In all this SC has five longer beaches occupying 42.5 km (63%) of the shore, with the southern mangroves and tidal flats making up the remainder. They grade from B + RSF and SF in the south (Fig. 33.14a, b) to R-LTT on the river mouth spits, to LTT and then TBR northwards.

The beaches are in turn backed by the large Gascoyne River delta, with its sand reworked and transported by the waves to form a series of barrier systems which grade from river mouth spits to the regressive Miaboolya (Fig. 33.15a) and to the northern dune transgression. The river mouth spits and the large Miaboolya barrier extend along the northern 34 km of the shore and have a volume of 718 M m^3 with a per metre volume of 21,117 $m^3\ m^{-1}$.

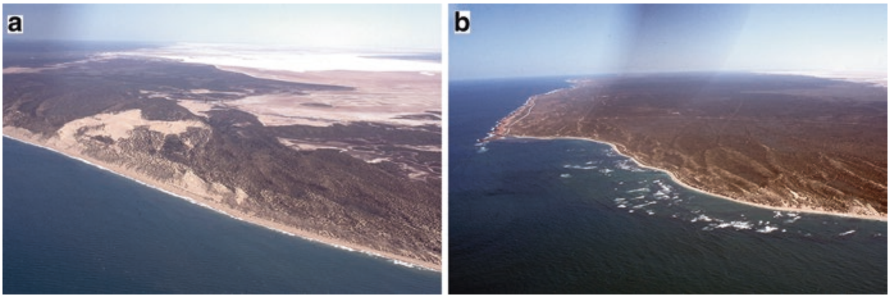

Fig. 33.16 (**a**) Northern Miaboolya beach (WA 1431) and the transgressive Bejaling dunes which blocked the entrance to Lake McLeod ~5 ka and (**b**) fringing calcarenite reefs and vegetated parabolic dunes east of Point Quobba (WA 1435). (Photos: AD Short)

33.10.2 SC:WA09.04.02 Miaboolya–Point Quobba

SC:WA09.04.02 is a continuation of the Gascoyne sediment system, commencing at the northern end of Miaboolya-Bejaling beach and trending northwest to the calcarenite bluffs of Point Quobba, a distance of 23 km (Fig. 33.14). This is an increasingly more exposed shoreline facing directly into the southwest waves and southerly winds. Six essentially continuous beaches occupy all the shore. The southern 15 km long beach is TBR, with beachrock beginning to outcropping in the surf zone towards the north. The northern four beaches become sheltered in lee of beachrock reefs which extends from the shoreline to several hundred metres offshore, forming a lagoon on the south side of Point Quobba (Fig. 33.15b). The reefs result in low waves and R conditions at the shore together with many reef-controlled rip channels. The higher energy beach conditions is reflected in the backing barrier systems which is entirely composed of parabolic to longwalled parabolic dunes extending up to 6 km inland and rising to between 10 and 20 m and in the south blocking the southern entrance to Lake Macleod. The dunes extend along the entire SC and have a total and per metre volume of 1100 M m^3 and 47,826 m^3 m^{-1}. The northern 5 km of the dunes have had the earlier major episode of transgression, followed by stability and slight shoreline regression, with the present shoreline backed by active dunes along a 10 km long central section of the beaches. Whether this instability is natural or induced by introduced stock and animals is uncertain.

33.10.3 PC Overview

This PC contains one of Australia's larger deltaic systems, the Gascoyne. The sand-rich river enters the northern end of Shark Bay just as refracted ocean swell begins to reach the shore providing sufficient energy to generate northerly longshore sand transport, as migratory river mouth spits and then along the long Miaboolya beach.

The sand has been deposited to the north in the river mouth spits, the 6 km wide Miaboolya regressive plain and in the north, as wave energy increases, as massive transgressive dunes. In all 1818 M m^3 of barrier sand have been deposited in the system, much derived from the river. However, while sand in the south is quartz-rich (~95%), by Point Quobba it is carbonate-rich (<10% quartz), implying there has also been a component of marine sand that increases northwards along Bejaling beach (WA 1431-2) towards Point Quobba. Based on the total barrier volume of 1818 M m^3 (Table 33.3) deposited over the past 7 ka, this would imply alongshore transport rates from the delta on the order of 250,000 m^3 $year^{-1}$, which is on the high side for the level of wave energy, particularly in the south. However, given that the marine component increases northwards, the actual rate could be less but still on the order of ~100,000 m^3 $year^{-1}$. The actual marine versus fluvial contribution and rate of longshore transport remains to be resolved.

This is a dynamic PC with intermittent river floods and pulse supply of sand to the mouth, where persistent southerly seas and swell move the sand northwards, to be deposited as regressive ridges and further north transported by southerly wind into the transgressive dunes, only some of which are presently active. Rising sea level will lead to a slight increase in wave height, particularly in the south which will increase longshore sand transport. Inundation of the lower reaches of the river and lower deltaic plain will however open up accommodation space which could see a reduction in sediment supply to the shore. It could also initiate shoreline recession which could in turn lead to dune instability. Also change in rainfall and wind velocity will also impact dune stability.

33.11 PC:WA10.01 Point Quobba to Alison Point

PC:WA10.01 is a 132 km long section of coast that trends roughly north and then north-northeast from Point Quobba to Alison Point (Fig. 33.3). The entire coast is backed by pastoral leases and some tourist-camping facilities on the properties. The underlying geology consists of a series of dissected anticlinal limestone domes separated by low-lying areas filled with Pleistocene marine and aeolian sands (Hocking et al. 1987). The largest dome is the northern Cape Range (PC:WA10.02) which is about 100 km long and 20 km wide, rising to a maximum of 315 m. The limestone forms the coastal zone along this PC, with 130 km long Lake Macleod part of a sunkland that was closed to the sea about 5 ka. Hocking identified three dune provinces: an older dissected field (Exmouth Sandstone) that flanks the Rough Range and southeast side of the Cape Range; a younger 120–130 ka Bundera terrace deposits on the west side of the Cape Range; and the modern unlithified Holocene transgressive dune field. Kendrick et al. (1991) investigated the tectonic stability of this region and concluded it has been uplifted >100 m since the Late Cenozoic. However, Pleistocene highstands have reached near present sea level a number of times, indicating present stability. The shoreline is dominated by limestone bluffs and cliffs in places blanketed by dune calcarenite together with calcarenite reefs and

Table 33.9 PC:WA10.01 beach types and states

BS	BS	No.	%	km	%	Mean (km)	σ (km)
4	TBR	1	1.9	2.2	2.8	2.2	–
6	R	52	98.1	75.3	97.2	1.5	1.4
		53	100	77.5	100	1.5	1.4

beachrock, with the cliffs ranging from 10 to100 m high. In amongst the rocky shores are 53 generally embayed beaches occupying 77.5 km (59%) of the coast. The beaches generally face west and are well exposed to the prevailing southwest swell and seas. However, the headlands, rocks and reefs substantially lower waves at the shore resulting in a dominance of sheltered R beaches (97%), many located behind intertidal rock flats and just one TBR (WA 1451) (Table 33.9). However, there are numerous rock- and reef-induced rips associated with the sheltered beaches. The beaches are composed of sand which varies considerably longshore ranging from fine to coarse and 50 to 100% carbonate (Fig. 33.1). Transgressive dunes, including clifftop dunes, back all the slightly south-facing section of coast south of Gnaraloo, with the coast to the north trending north-northeast resulting in a lee shore with no coastal dunes. The dunes have a volume of 2190 M m^3 (20,974 m^3 m^{-1}) indicative of the high energy nature of the coast. This PC contains three SCs which are discussed below.

33.11.1 SC:WA10.01.01 Point Quobba–Cape Culver

SC:WA10.01.01 is a straight section of coast that faces due east between Point Quobba and Point Culver (Figs. 33.17a and 33.18a), a distance of 33 km. The coast is predominately rocky with both limestone and calcarenite bluffs and calcarenite rocks, platforms and reefs littering the shore, with the first 10 km north to Quobba station entirely calcarenite bluffs less than 20 m high. North of the station, there are 11 R beaches all located to the rear of platforms and occupying just 9 km (27%) of the shore. Beach sands are well to moderately well-sorted medium sand, with carbonate ranging from 53 to 82%. A series of longwalled parabolic dunes have blown out of the 1.5 km long beach that extend southeast from Point Quobba and migrated parallel to the coast in band ranging from a few hundred metre to 2 km wide, between 16 Mile and 5 Mile Well, with a second band of dunes beginning between 5 and 9 Mile wells and extending 2–3 km inland where they interfinger the north-south longitudinal 'glacial' desert dunes. The coastal dunes have a volume of 1000 M m^3 (35,714 m^3 m^{-1}). They are now cut off from their former sand sources and largely stable, with some unstable dunes in the 5–9 Mile Well area, possibly as a result of stock grazing and pests.

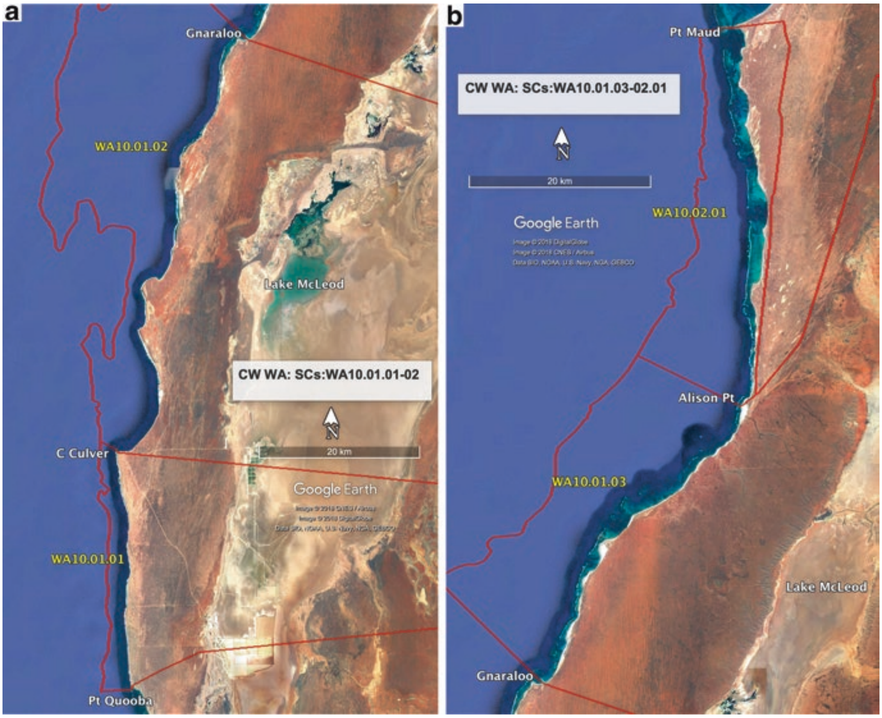

Fig. 33.17 (**a**) SCs:WA10.01.01-02 and (**b**) SCs:WA10.02.03-02.01. (Source: Google Earth)

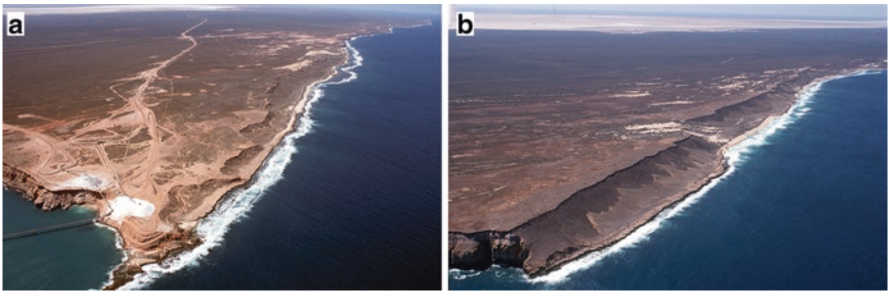

Fig. 33.18 (**a**) View south from Point Culver showing the 70 m high bluffs, beach (WA1446) and calcarenite reefs and (**b**) eighty metre high cliffs north of Red Bluff with an active climbing dune ramp and clifftop dune (WAS1450-1). (Photos: AD Short)

33.11.2 SC:WA10.01.02 Cape Culver–Gnaraloo

SC:WA10.01.02 is a 56 km long section of coast between the protruding Point Culver and Gnaraloo (Fig. 33.17a). There is a 600 m long jetty at Point Culver for loading the Lake Macleod gypsum and a small community of surfers at Red Bluff;

otherwise apart from access roads and tracks there is no development on the coast. The shoreline is a mix of limestone bluffs and cliffs rising to as high as 100 m but most between 10 and 20 m, including a 15 km long cliffed section between 17 Mile Well and Red Bluff which averages 90–100 m. Most of the coast is fringed by rock platforms at the base of the cliffs and fringing calcarenite reefs, some encrusted with coral. There are however 21 beaches occupying 30 km (54%) of the shore, all are R beaches and located at the base of the bluffs and fronted by intertidal platforms and reefs of variable width but which reach 1 km at Gnaraloo. High waves do however break on the reefs, and platforms generating some well known surf breaks and a number topographic rips. The beaches are composed of carbonate-rich (mean = 90%) moderately well-sorted medium sand (Fig. 33.1). The coast trends north to north-northeast, leaving only a few sections to face more southerly into the prevailing winds. As a result transgressive dunes only occur in lee of the more southerly facing beaches including the northern Red Bluff beach (WA1448–51) where dunes are actively climbing the 80 m high cliffs (Fig. 33.18b) and behind the west-facing beaches (WA 1454-46). Both areas have transgressive dunes extending respectively 5 and 10 km northwards, with the dunes having a volume of 1080 M m^3 (30,000 m^3 m^{-1}).

33.11.3 SC:WA10.01.03 Gnaraloo–Alison Point

SC:WA10.01.03 commences in the curving Gnaraloo bay (Fig. 33.19a) and trends north-northeast and then northeast for 43 km to the 20 m high dune-capped Alison Point which marks the beginning of the Ningaloo fringing coral reef system (Fig. 33.17b). Then only development on the coast is Gnaraloo station and beach-front camping facilities. Owing to the orientation of the coast and near continuous fringing calcarenite/coral reefs, this is a sheltered lee coast (Fig. 33.19b), with the low hinterland (~20 m) consisting of north-south-trending longitudinal desert dunes. Near continuous beaches occupy most of the shore, with 20 beaches extending along 39 km (91%) of the coast, the remainder made up of low calcarenite

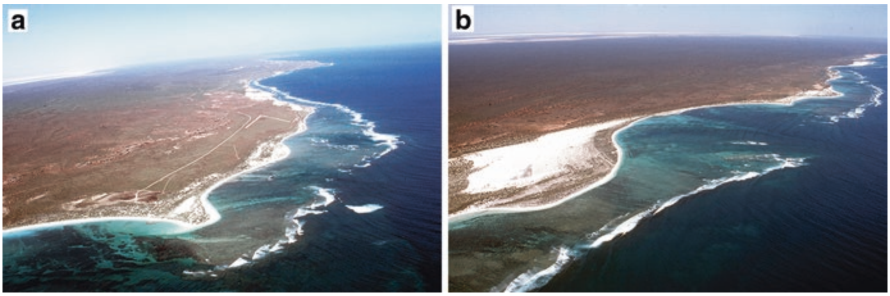

Fig. 33.19 (**a**) Fringing coral reefs extending south of Gnaraloo Bay (WA1 1467-9) and (**b**) fringing coral reefs at Cape Farquhar and gap at Seventeen Mile bore (WA 1472-4). (Photos: AD Short)

bluffs, with four small usually closed streams reaching the shore along the northern 12 km. All the beaches are R, some located in lee of the reefs with a 0.1–1.5 km wide lagoon between the reefs and beach, while others are in lee of deeper reefs, with waves averaging <1 m at the shore. The presence of the discontinuous reefs and sheltered shore has resulted in the development of a series of ten salients in lee of the reefs, with embayments in lee of the gaps, through which flow large reef-controlled rips. The salients tend to be composed of north-trending foredune ridges similar to the type described by Sanderson and Eliot (1996, 1999) on the Cervantes coast. As the salient have built seawards, their southern shores have become more orientated into the southerly wind resulting in low to moderate dune instability and active dunes moving up to 2 km northwards and partly burying the foredune ridges. The salients occupy 40 km of the shore and have a volume of 110 M m^3 (2715 m^3 m^{-1}) an order of magnitude less than the adjoining more exposed southern SCs.

33.11.4 PC Overview

This is a generally exposed high energy section of coast exposed to the persistent southwest swell and seas and periodic strong southerly winds. The high degree of carbonate indicates that it does not receive sand from the Gascoyne River; rather it has shelf and reef-derived marine sediments. Like most of the southwest coast, it appears that most onshore sediment transport took place accompanying the PMT assisted by strong south winds which combined deposited beaches, built sand ramps and deposited transgressive dunes including clifftop dunes. Most of these beaches have gone leaving sheltered remnants in lee of platforms and reefs, as have the ramps, though there is one of the few active, perhaps recently reactivated, on the coast north of Red Bluff (Fig. 33.18a). As some of the coast trends more to the east and becomes more sheltered the dunes are replaced by regressive salients. It appears sand is continuing to move both onshore and longshore along the coast, particularly along the more sandy northern SC (WA10.01.03); however the rates are unknown.

Rising sea level will increase water depth over the platforms and reefs thereby increasing breaker wave height which should accelerate erosion of the calcarenite and limestone bluffs and cliffs and accelerate longshore sand transport, which could lead to localised beach erosion. Beach erosion could in turn lead to some dune reactivation, which would also depend on future wind and rainfall conditions.

33.12 PC:WA10.02 Ningaloo Reef

PC:WA10.02 incorporates the 238 km long Ningaloo reef coast between Alison Point and North West Cape at the tip of the Exmouth Peninsula, the northern section of which is located in Cape Range National Park (Fig. 33.3). This is a hot desert coast, the most arid on the Australian coast, with the aridity in part responsible for

Table 33.10 PC:WA10.02 beach types and states

BS	BS	No.	%	km	%	Mean (km)	σ (km)
6	R	79	69.3	162.3	79.7	2.1	2.3
11	B + SF	3	2.6	0.6	0.3	0.2	–
15	R + CF	32	28.1	40.8	20.0	1.3	1.1
		114	100	203.7	100	1.8	–

coral reefs growing to the shore. The reefs are the longest fringing reef system in Australia and the most poleward fringing reefs in the world. Their presence is due to the Leeuwin Current delivering warm tropical Indian Ocean water down the coast, coupled with a suitable inshore platform for growth and the absence of terrigenous runoff and sediments to adversely impact the reefs, as occurs on the humid Queensland coast. The nature of the reef communities, habitats and substrates is described by Cassata and Collins (2008). The coast trends essentially due north for 138 km to Winderabandi Point and then turns and trends relatively straight to the north-northeast for 100 km to North West Cape. It is an exposed west-facing coast which receives the southwest swell and westerly seas. The moderate to occasionally high swell however breaks on the outer reefs, with generally low waves (<0.5 m) at the shore. The low inshore wave height is reflected in the predominance of sheltered R beaches (89%) together with a few sand flats and 32 beaches fringed by coral reefs (Table 33.10). Beach sediment is predominately carbonate-rich (mean = 85%), moderately well-sorted, medium sand (mean = 0.41 mm) with the reefs and reef flats acting as sources of the carbonate-rich material, while the terrigenous component is ultimately derived from the backing coastal range. There is however considerable longshore variation in both size and carbonate (Fig. 33.1) indicative of the limited longshore sand transport and numerous closed salients. There are 25 barrier systems along the coast which can be divided into those south of Winderabandi Point which have a more westerly orientation including embayments with southwest-facing shores and those north of the point with trends north-northeast. The more south-facing section of the southern shore are backed by transgressive dune systems extending a few kilometre northwards, while the barrier to the north is a mix of regressive salient and some more recent small to moderate dune instability on the southern side of the salients. The barriers occupy 149 km (63%) of the shore and have a total volume of 1845 M m^3 (12,368 m^3 m^{-1}) (Table 33.3). The PC contains four SCs which are discussed below.

33.12.1 SC:WA10.02.01 Alison Point–Point Maud

SC:WA10.02.01 commences at Alison Point and trends northwards for 49 km to the protruding Point Maud (Figs. 33.17b and 33.20c), with several embayments largely bordered by regressive salients in between and the entire coast fringed by coral reefs which lie an average of 1.3 km offshore. The reefs are closest to shore (~0.3 km) in

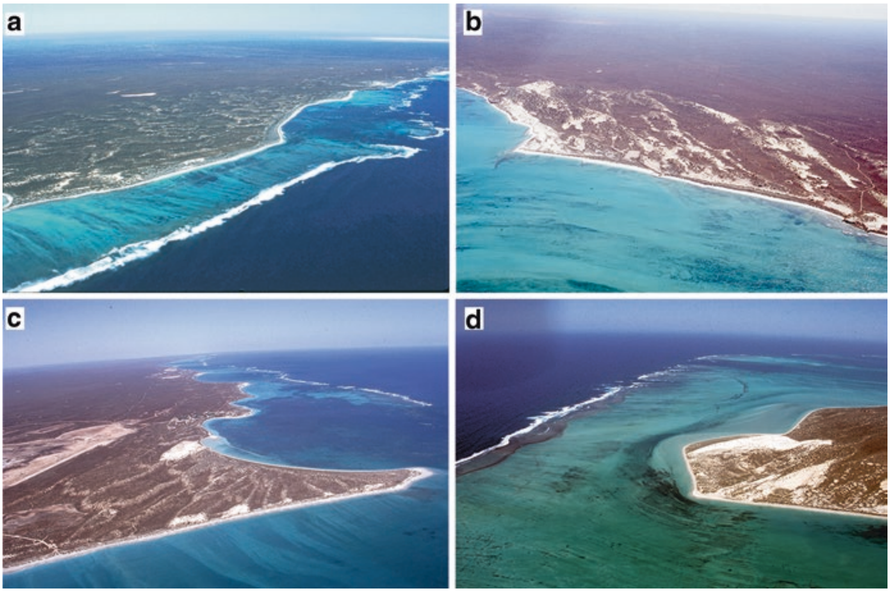

Fig. 33.20 (**a**) View south from Pelican Point of the fringing reefs and reef-sheltered beaches (WA 1493-5); (**b**) partly stable north-trending parabolic dunes at Point Anderson (WA 1504-6); (**c**) the protruding Point Maud salient with parabolic dunes and Coral Bay and reefs to south (WA 1515–6); and (**d**) the tip of Point Cloates and its fringing reef (WA 1532-3). (Photos: AD Short)

the south but lie 2 km offshore north of Pelican Point, with a shallow lagoon between the reefs and the shore. There are however gaps in the reefs, known as 'passages', and the variation in wave breaking between the shallow reefs and deeper gaps leads to variable wave attenuation and refraction and consequently spatial variation in wave height and direction at the shore. This has led to the formation of salients, with sheltered protruding forelands in lee of the reefs and more exposed embayments in lee of the gaps. Cassata and Collins (2008) also found that there is a strong correlation between reef morphology and wave- and tide-driven energy gradients. Sediments range from medium to coarse, the latter predominately coral rubble, with carbonate ranging from 77 to 99%. Beaches occupy 44 km (90%) of the shore with boundaries formed by the salients and section of low bluffs. The beaches average 1.9 km in length (σ = 1.9 km) and are all R. There are four barrier systems, each located on a protruding more southerly facing section of shore (Pelican Point (Fig. 33.20a), South Passage, Fourteen Mile Camp and Coral Bay (N)), with each consisting of north-northeast-trending nested parabolic to longwalled parabolics extending up to 3 km inland (Fig. 33.20b). They cover an area of 2950 ha of which 13% is presently unstable. They have a volume of 565 M m^3 and a per metre volume of 15,188 $m^3\ m^{-1}$. The dunes were probably deposited in the early to mid-Holocene when both sea level and inshore wave height were higher, the latter before the reef reached their present level. This would have been followed by stability, with the present level on instability possibly a result of stock grazing and pests. The small but popular tourist community of Coral Bay is located in the embayment that extends 2.5 km south from Point Maud (Fig. 33.20c).

33.12.2 SC:WA10.02.02 Point Maud–Point Cloates

SC:WA10.02.02 consists of essentially one long embayment bounded by the protruding boundary points (Maud and Cloates) located 44 km apart, with a curving 57 km shoreline in between (Fig 33.21a). The two points lie in lee of reefs, with the embayment containing two 15 km long reef sections separated by 3–6 km wide gaps. The southern shore trends northeast and then north and only curves round to trend north-northwest and finally west in the north. The beach sand is carbonate-rich (mean = 83%), fine to medium and moderately well sorted. Seventeen sheltered R beaches occupy 47 km (82%) of the shore. The beaches average 2.8 km in length and include the 15 km long beach (WA 1532) in lee of Black Rock Passage. The beaches are backed by two regressive barriers in the south starting with the curving 8 km long Point Maud regressive foredune which reaches 0.8 km in width and grades northwards into active and stable parabolics (Fig. 33.20c); and the Bateman Bay barrier has 100 m wide regressive foredunes which are backed by older stable parabolics extending up to 400 m northwards. In the northern section are two more south-facing shores both backed by larger transgressive systems at Twin Hill and the 15 km of coast south from Point Cloates (Fig. 33.20d), which has parabolics extending up to 4 km inland. The barriers have a total length of 43.5 km (76%), a

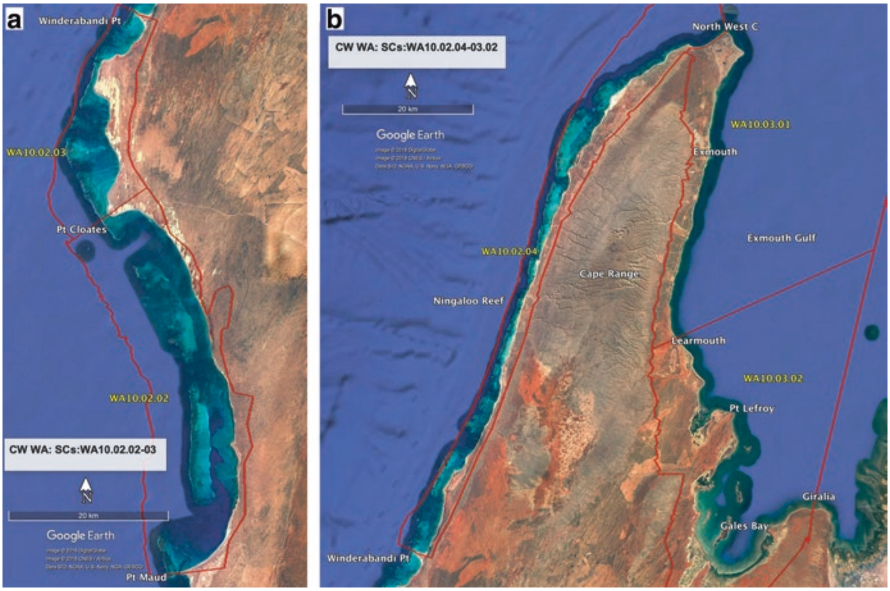

Fig. 33.21 (**a**) SCs WA10.02.02-03 and (**b**) WA10.02.04-03.02. (Source: Google Earth)

volume of 928 M m^3 and per metre volume of 21,322 $m^3\ m^{-1}$, 77% of this in the larger Point Cloates system. They cover an area of 5100 ha of which 15% is presently unstable.

33.12.3 SC:WA10.02.03 Point Cloates–Winderabandi Point

SA:WA10.02.03 bulges westwards as the most westerly section of the Exmouth Peninsula. It extends for 32 km between the stubby Point Cloates (Figs. 33.21a and 33.22a) past Point Billie to the pointed Winderabandi Point (Fig. 33.22b), with three curving embayments in between including Norwegian and Lefroy Bays, each located to the lee of gaps in the reef, which lies 6 km off the embayments. The previously low bedrock slopes become steep bluffs north from Beacon Point and parallel the coast rising to heights of 100–130 m within a kilometre of the coast, with the Cape Range National Park commencing just north of Point Cloates. The beach sands are high in carbonate (~95%) but vary in size (medium to coarse). This is a sandy shore with seven sheltered R beaches occupying the entire shoreline, separated by the salients and inflections. There are essentially two barrier systems in this section, first commencing south of Beacon Point and extending for 12 km northwards to the rear of Norwegian bay where it links with the Point Edgar dunes and the second smaller Winderabandi regressive-transgressive salient, which extends 1.8 km into the lagoon (Fig. 33.22b). The barriers occupy 16 km of the shore, primarily south for Point Edgar, and have a volume and per metre volume of 270 M m^3 and 16,875 $m^3\ m^{-1}$, with 38% of their 1850 ha presently unstable.

33.12.4 SC:WA10.02.04 Winderabandi Point–North West Cape

SC:WA10.02.04 is a 100 km long SC backed by the steep slopes of the Cape Range which parallel the entire shore as far as Vlaming Point (Fig. 33.20b), rising to a 100–150 m high heavily dissected plateau (Fig. 33.22b). The entire coast up to

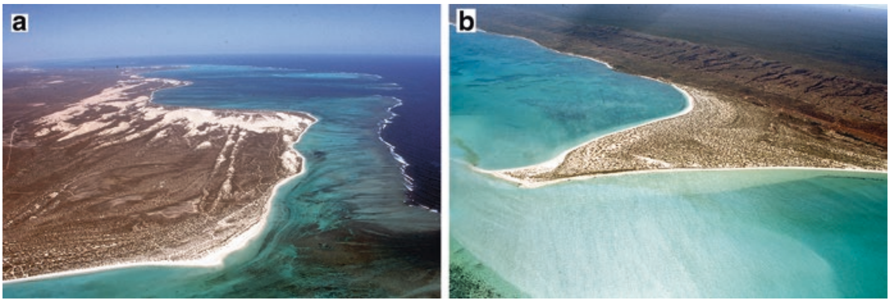

Fig. 33.22 (**a**) View south to Point Cloates (WA 1337-8) and (**b**) the protruding Winderabandi Point (WA 1539-40). (Photos: AD Short)

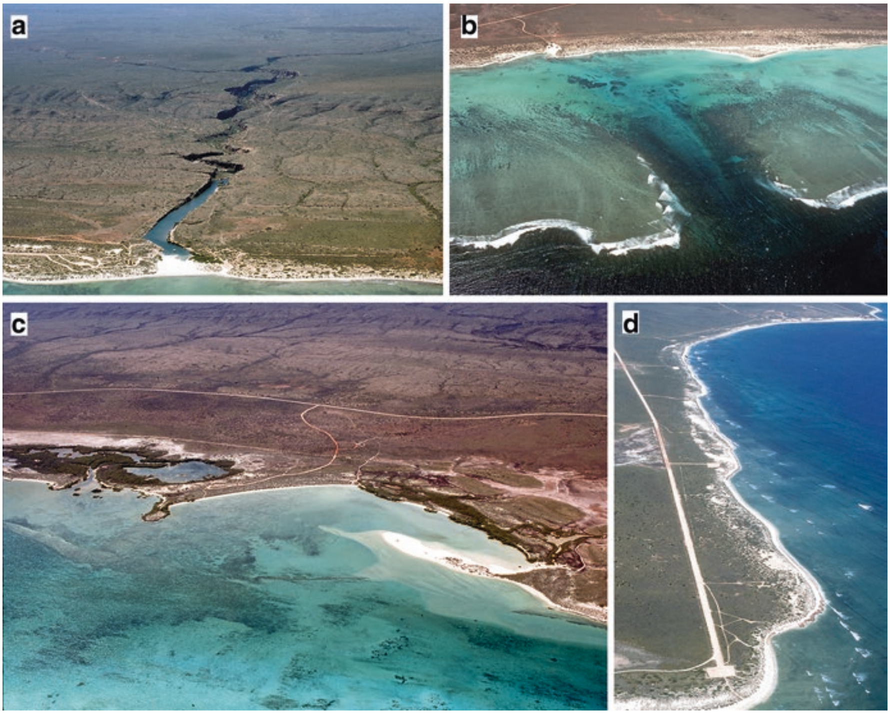

Fig. 33.23 (**a**) Yardie Creek flows through a deep gorge to reach the coast (WA1553-4); (**b**) Pilgonaman Bay is located in lee of a major gap in the fringing reef (WA 1561-4); (**c**) mangrove-lined Mangrove Bay is sheltered by a north-trending spit (WA 1581); and (**d**) view southwest from North West Cape (WA 1600). (Photos: AD Short)

Vlaming Point is contained in the Cape Range National Park. A series of steep creeks (Yardie (Fig 33.23a), Pilgonaman (Fig. 33.23b), Bloodwood, Tulki, RAAF, Milyering, Mangrove (Fig 33.23c), and Tantabiddi) drain the range and flow to the shore where they deposit coarse creek mouth bars. The creeks are usually blocked and only flow following heavy rain. They have however supplied terrigenous sediment to the shore and shelf since the Miocene. On the seaward side, the coast is paralleled by the fringing reef which lies between 0.3 and 4 km offshore averaging 1.7 km ($\sigma = 1$ km), with the continuous shallow lagoon in between. There are however numerous gaps (passages) in the reef leading to the formation of a range of salients of varying size and shapes depending on the nature of the reef gaps and degree of wave refraction and attenuation. There are 63 beaches extending along 82 km (82%) of the shore. They are a mix of sheltered R (49%), R + CF averaging 50 m in width (49%) and three B + SF in Mangrove Bay. The beach sediment is moderately well-sorted medium sand averaging 85% carbonate ($\sigma = 5\%$). There are 15 small barriers along this lee coast occupying 52.5 km (52.5%) of the shore. Each has developed as a regressive salient in lee of the reefs. However, as their northern, more south-facing shore has become more exposed to the predominately southerly wind, most have been partly or entirely blanketed with north-trending transgressive dunes. The barrier, however, remains small with a total volume of just 83 M m^3 and a small per metre volume of 1580 m^3 m^{-1}, both an order of smaller than the southern more exposed SCs. However, 24% of their 1235 ha area is presently unstable.

33.12.5 PC Overview

This PC is in some ways unique – the longest fringing coral reef in Australia – and also transitional, between the micro-tidal high energy southwest swell and strong southerly winds that extends from Cape Leeuwin to North West Cape to the low energy meso-tidal shores of Exmouth Gulf, north of which are the low waves and increasingly higher tides of the Pilbara region. In itself the PC has an interesting morphodynamics related to the energetic waves, strong southerly winds, the fringing reef and palaeo-stream channels, and the variation in shoreline orientation. When the PMT flooded the lagoon area and prior to the reefs reaching their present state, the shoreline was very likely more energetic than today, transporting sands northwards and building beaches and on south-facing shores supplied sand to north-trending transgressive dunes. As the reefs grew vertically and sea level fell, wave attenuation, refraction and diffraction over the shoaler reefs and through the gaps between the reefs modulated wave height and direction along the shore. This led to the formation of regressive shoreline salients, which increasingly interrupted and in places blocked the longshore sand transport, forming numerous smaller TCs. As the salients regressed seawards, they developed more south-facing shores on their southern side which exposed these shores to the southerly winds, leading to second phase dune transgression over the regressive ridges, in turn leading to salient overpassing. It is likely sand is still being transported northwards by waves across the lagoon and along the shore, both interrupted by the passages and salients, together with dune overpassing on many of the salient. The rates are however expected to be small on the order of perhaps 1000–10,000 m^3 $year^{-1}$.

Taebi et al. (2011) investigated wave breaking and currents within the lagoon and predicted that a rise in sea level will reduce wave dissipation over the reefs leading to an increase in breaker wave height at the shore, at the same time as reducing wave-driven currents. This will not only physically impact the lagoon bed and shoreline, but as Cassata and Collins (2008) found, the reef morphology is tied to wave- and tide-driven circulation, and it too will respond to the changing hydrodynamics.

33.13 PC:WA10.03 Western Exmouth Gulf

At North West Cape (Fig. 33.23d), the 2700 km long exposed and generally high energy south-central west WA coast turns abruptly to the southeast and then trends south into Exmouth Gulf (Fig. 33.3) as a very low energy east-facing shore,

Table 33.11 PC:WA10.03 beach types and states

BS	BS	No.	%	km	%	Mean (km)	σ (km)
10	B + RSR	2	6.5	14.2	20.7	7.1	–
11	B + SF	13	41.9	34.7	50.5	2.7	1.5
12	B + TSF	12	38.7	10.9	15.8	0.9	0.5
15	R + CF	4	12.9	8.9	13.0	2.2	1.3
		31	100	68.7	100	2.2	1.9

beginning the transition to the low energy TD Pilbara region. The sheltered shore has seen the development of Exmouth initially to service the North West Cape radio facility but now more to service the fishing fleet and growing tourist industry.

This PC contains the eastern shore of Exmouth Peninsula south from North West Cape and the southern shore as far as Giralia, the division and province boundary. It is a low-wave energy meso-tidal shore with tides increasing into the gulf from 2 m at Point Murat to 2.4 m at Exmouth and 2.6 m at Learmonth. The southerly winds blow off and alongshore, and easterly winds are restricted to a maximum fetch of 40 km across the shallow gulf. In contrast to the western side of the peninsula, there are no fringing reefs, except in the very north. The coast consists of a narrow (1–2 km) outwash plain feed by numerous small, usually dry braided streams flowing out of the Cape Range to the shore where they have deposited small protruding deltas. However, beach sands remain carbonate rich (mean = 89%), though it decreases to 64% by Learmonth. The sand is moderately well-sorted and varies in size from fine to coarse (Fig. 33.1).

The combination of slightly higher tides and very low waves result in TD ranging from B + RSF to B + TF, together with four beaches fringed by coral reefs between the northern North West Cape and Point Murat (Table 33.11). The low wave energy is also reflected in the small barrier systems with just seven barriers occupying 54 km (43%), all consisting of low foredunes grading to south-trending spits in the south. They have a low total volume and per metre volume of just 88 M m^3 and 1612 m^3 m^{-1}, respectively (Table 33.3). The PC contains two SCs which are discussed below.

33.13.1 SC:WA10.03.01 North West Cape-Learmonth

SC:WA10.03.01 commences at North West Cape, the northern tip of the Exmouth Peninsula, and trends southeast for 5 km to Point Murat where it turns and begins the long southerly trend into Exmouth Gulf, with the SC boundary at Learmonth 41 km to the south (Fig. 33.21b). This is a sheltered east-facing shore backed by the narrow outwash plan and the Cape Range and facing out across the shallow 40 km wide gulf. The shoreline is a near continuous low sandy beaches backed by a few low foredunes and just one area of small dune transgression on the southeast-facing side of Point Murat (Fig. 33.24a). A few usually dry creeks reach the shore where they are blocked by berms for most of the year (Fig. 33.24b). At Exmouth a boat harbour was built in the mid-1990s, and its curving attached breakwaters extend 700 m into the gulf, with a small groyne located towards their bases to trap sand moving both north and south along the shore, with more sand trapped on the northern side.

There are 16 beaches occupying 42 km (91%) of the shore. In the north scattered fringing reefs extend along the first 9 km of shoreline around Point Murat. The remaining beaches are all TD and a mix of B + RSF on the more exposed beaches north from Exmouth, the ridges generated by easterly wind waves, and B + SF to the south. Low regressive barriers extend essentially along the entire shore range in width from 100–500 m and are generally less than 10 m high. They have low volumes of 55 M m^3 (1162 m^3 m^{-1}) as typical of such an environment. Sand appears to be moving around North Wert Cape and Point Murat and down the east coast as indicated by the southward deflection of the creek that drains the Point Murat salt flats, the accumulation of sand on the northern side of the boat harbour, and the generally southerly deflection of the several creeks south of Exmouth. Rates are however expected to be low. Base on the ~100,000 m^3 trapped on the northern side of the marina breakwater, this would represent southerly longshore transport on the order of ~5000 m^3 $year^{-1}$.

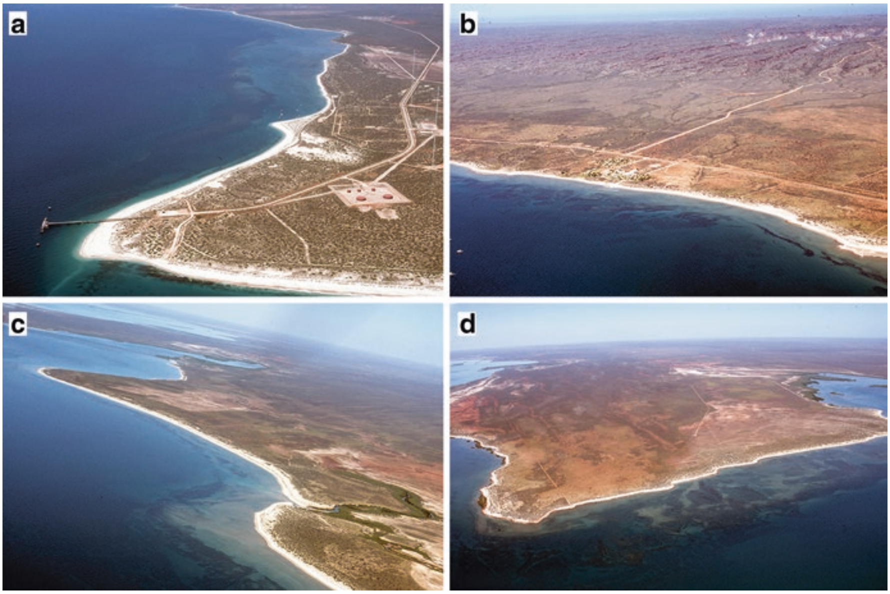

Fig. 33.24 (**a**) Point Murat, its jetty and salients extending to the south (WA 1604-5); (**b**) Qualing Pool beach (WA 1616) the 'pool' referring to the usually blocked creek mouth; (**c**) view south from Learmonth towards the Bay of Rest (WA 1619–20); and (**d**) the northern shore of the Point Lefroy peninsula (WA 1624-6). (Photos: AD Short)

33.13.2 SC:WA10.03.02 Learmonth–Giralia

SC:WA10.03.02 continues south from Learmonth to the base of the gulf at Gales Bay and includes the V-shaped Bay of Rest, the Point Lefroy peninsula (Fig. 33.24d) and the U-shaped Gales Bay and finally terminates at Giralia on the trip of the Sandalwood Peninsula (Fig. 33.21b), a total shoreline distance of 80 km, with a crenulation ratio of 2.4. Wave energy decreases southwards into the gulf as tide range continuous to increase reaching 2.6 m at Learmonth. Beach sand is lower in carbonate (64%) at Learmonth, and 15 beaches occupy just 19 km (19%) of the shore, the remainder predominately the mangrove-lined Bay of Rest and Gales bays, with the beaches restricted to the Learmonth coast and the tip of the two peninsulas. The beaches are all TD B + SF at Learmonth and B + TSF further south. There is a considerable evidence of southerly sand transport into the southern gulf, with the small Learmonth jetty-groyne trapping sand on its northern side and the Learmonth beach consisting of a 2 km long south-trending regressive spit, together with a series of spits trending south along the eastern shores of the Bay of Rest and Gales Bay (Fig. 33.24c). There are three regressive beach-foredune ridge-spit systems extending 12 km south of Learmonth and 10 km south of Lefroy Point and along the top of the Sandalwood Peninsula at Giralia. They range in width from 100–800 m, the widening due to recurves. They extend along 24 km of the shore (30%) and have a total volume of just 16 M m^3 and low per metre volume of 682 m^3 m^{-1}. May et al. (2017, 2018) investigated the nature and origin of these systems which are described in Chapter 3 (Sect. 3.4.3)

33.13.3 PC Overview

The western shore of Exmouth Gulf is low energy, TD and composed of continuous sandy beaches for 62 km south to Heron Point. Sand is slowly moving down these beaches at rates of a perhaps a few 1000 m^3 $year^{-1}$, very likely decreasing to the south as waves decrease. The northern SC is an open compartment with some of the sand contributing to the shoreline regression, while the southern SC is the ultimate sink for these sediments. Rising sea level will increase water depth in the gulf leading to a slight increase in wave height at the shore and thereby accelerate the southerly longshore sand transport. It will also impact the southern tide-dependent mangroves and seagrass communities and inundate the lower reaches of the normally dry creeks and the Point Murat salt flats.

33.14 Regional Overview

The central west WA coast has a high energy deepwater wave climate that slowly decreases northwards and a highly variable inshore wave climate owing to extensive open coast calcarenite reefs and in the north fringing coral reefs, together with the presence of two large very sheltered embayments, Shark Bay and Exmouth Gulf. As a consequence, it has largely sheltered lower energy WD beaches (R and LTT 37%) on the open coast grading to TD (50%) in the largely micro-tidal bays, together with R + CF (6%) along Ningaloo Reef (Table 33.2). Beach sands are also highly variable in size and carbonate content, the latter while usually high decreases in parts of Shark Bay and around the Gascoyne River mouth and southwards in to Exmouth Gulf. Longshore sand transport is severely constrained by the physical presence of reefs together with their lowering of inshore wave height and the salients they induce. There are potentially high rates in the nearshore along the Zuytdorp Cliffs and north from the Gascoyne delta, but elsewhere they are constrained on the open coast, while the bays and their tributary embayments act as sediment sinks.

The impacts of climate change along this coast are as variable as the coast itself. The high cliffs will be little affected apart from a slight increase in cliff erosion owing to increased water depth over the basal platforms and reefs. The calcarenite and coral reef-sheltered open coast will have increasing water depth over the reefs, leading to higher inshore waves and decreasing wave refraction, which will impact the entire inshore, raising wave height and beach states and accelerating sand transport, as well as impacting coral reef morphology on the Ningaloo coast. In addition, the higher wave will potentially erode the foredunes which could reactivate the backing transgressive dunes, while any change in southerly wind velocity and rainfall will also impact the extensive dune systems. Within the bays the rising sea level will have a dramatic impact both physically and ecologically. Physically water will be deeper over the Shark Bay sand banks, sills and flats and the Exmouth Gulf sand flats, allowing higher waves to reach the shore which will impact shoreline stability and sand transport. Ecologically the tide-dependent seagrass and mangroves will need to shift to shoaler water, while the salinity-dependent southern Shark Bay environments may experience reduced salinity as the deeper bay water and greater tidal prism will improve circulation.

Finally, sea water temperature is rising around the Australian coast, and any rise along the central west coast could see the coral reefs beginning to extend south of Alison Point. If this is the case, it would have a direct impact on the shoreline through its impact on wave transformation across the reefs, as occurs along the Ningaloo coast. The warmer water should also impact the tropical cyclones that move down and over the coast, possibly leading to more intense cyclones with higher waves, greater storm surges and higher rainfall.

References

Bufarale G, Collins LB (2015) Stratigraphic architecture and evolution of a barrier seagrass bank in the mid-late Holocene, Shark Bay, Australia. Mar Geol 359:1–21

Cassata L, Collins LB (2008) Coral reef communities, habitats, and substrates in and near Sanctuary Zones of Ningaloo Marine Park. J Coast Res 24:139–151

Hocking RM, Moors HT, van de Graaff WJR (1987) Geology of the Carnarvon Basin Western Australia. Geol. Survey Western Australia, Bulletin 133, 289 p plus maps

Johnson DP (1982) Sedimentary facies of an arid zone delta: Gascoyne Delta, Western Australia. J Sediment Petrol 52:547–563

Kendrick GW, Wyrwoll KH, Szabo BJ (1991) Pliocene–Pleistocene coastal events and history along the western margin of Australia. Quat Sci Rev 10:419–439

Kendrick GA, Fourqurean JW, Fraser MW, Heithaus MR, Jackson G, Friedman K, Hallac D (2012) Science behind management of Shark Bay and Florida Bay, two P-limited subtropical systems with different climatology and human pressures. Mar Freshw Res 63:941–951

Kilminister K, Hovey R, Waycott M, Kendrock GA (2018) Seagrasses of southern and south-western Australia. In: Larkum AWD, Kendrick GA, Ralph PHJ (eds) Seagrasses of Australia: structure, ecology and conservation. Springer, Cham, pp 61–92

Logan BW (1961) Cryptozoon and associated stromatolites from the recent, Shark Bay, Western Australia. J Geol 69:517–533

Logan BW (1970) Carbonate sedimentation and environments, Shark Bay, Western Australia. Am Assoc Petroleun Geol, Mem 13:1–38

Logan BW (1974) Inventory of diagenesis in Holocene-Recent carbonate sediments, Shark Bay, Western Australia. In: Logan BW, Read JF, Hogan GM, Hoffman P, Brown RG, Woods PG, Gebelein CD (eds) Evolution and diagenesis of quaternary carbonate sequences, Shark Bay, Western Australia. American Association of Petroleum Geologists, Tulsa, pp 195–248

Logan BW, Cebulski DE (1970) Sedimentary environments of Shark Bay, Western Australia. In: Logan BW et al (eds) Carbonate sedimentation and environments, Shark Bay, Western Australia, Mem13. American Association of Petroleum Geologists, Tulsa

Logan BW, Hagan GM (1970) Calcrete deposits and quaternary sediments of Hamelin Basin, Shark Bay, Western Australia. In: Logan BW et al (eds) Carbonate sedimentation and environments, Shark Bay, Western Australia, Mem13. American Association of Petroleum Geologists, Tulsa

Logan BW, Read JF, Davies GR (1970a) History of carbonate sedimentation, Quaternary Epoch, Shark Bay, Western Australia. In: Logan BW et al (eds) Carbonate sedimentation and environments, Shark Bay, Western Australia, Mem13. American Association of Petroleum Geologists, Tulsa, pp 38–85

Logan BW, Read JF, Hogan GM, Hoffman P, Brown RG, Woods P, Gebelein CD (1970b) Evolution and diagenesis of Quaternary carbonate sequences, Shark Bay, Western Australia. American Association of Petroleum Geologists, Tulsa

Logan BW, Brown RG, Quilty PG (1976) Carbonate sediments of the west coast of Western Australia. In: 25th international geological congress, Sydney

Lustig TL (1977) Aeolian-induced cyclic meandering of an ephemeral deltaic river mouth. In: 3rd Australian conference on coastal and ocean engineering, pp 233–239

May SM, Brill D, Leopold M, Callow JN, Engel M, Scheffers A, Opitz S, Norpoth M, Brückner H (2017) Chronostratigraphy and geomorphology of washover fans in the Exmouth gulf (NW Australia) – a record of tropical cyclone activity during the late Holocene. Quat Sci Rev 169:65–85. https://doi.org/10.1016/j.margeo.2017.03.005

May SM, Gelhausen H, Brill D, Callow JN, Engel M, Opitz S, Scheffers A, Joannes-Boyau R, Leopold M, Brückner H (2018) Chenier-type ridges in Giralia Bay (Exmouth gulf, Western Australia) - processes, chronostratigraphy, and significance for recording past tropical cyclones. Mar Geol 396:186–204. https://doi.org/10.1016/j.margeo.2017.03.005

Nott J (2011) A 6000 year tropical cyclone record from Western Australia. Quaternary Sci Rev 30:73–722

Playford PE (1990) Geology of the Shark Bay area, Western Australia. In: Berry PF, Bradshaw SD, Wilson BR (eds) Research in Shark Bay. Western Australian Museum, Perth, pp 13–31

Playford PE, Cockbain AE, Berry PF, Roberts AP, Haines PW, Brooke BP (2013) The geology of Shark Bay: geological survey Western Australia. Bulletin 146, 281p

Read JF (1974a) Carbonate bank and wave built platform sedimentation, Edel province, Shark Bay, Western Australia. In: Logan BW, Read JF, Hogan GM, Hoffman P, Brown RG, Woods P, Gebelein CD (eds) Evolution and diagenesis of Quaternary carbonate sequences, Shark Bay, Western Australia. American Association of Petroleum Geologists, Tulsa, pp 1–60

Read JF (1974b) Calcrete deposits and Quaternary sediments, Edel Province, Shark Bay, Western Australia. In: Logan BW, Read JF, Hogan GM, Hoffman P, Brown RG, Woods P, Gebelein CD (eds) Evolution and diagenesis of quaternary carbonate sequences, Shark Bay, Western Australia. American Association of Petroleum Geologists, Tulsa, pp 250–282

Sanderson PG, Eliot I (1996) Shoreline salients, cuspate forelands and tombolos on the coast of Western Australia. J Coast Res 12:761–773

Sanderson PG, Eliot I (1999) Compartmentalisation of beachface sediments along the southwestern coast of Australia. Mar Geol 162:145–164

Short AD (2005) Beaches of the Western Australian Coast: Eucla to Roebuck Bay. Sydney University Press, Sydney, 433 p

Short AD, Woodroffe CD (2009) The coast of Australia. Cambridge University Press, Melbourne, 288 p

Taebi S, Lowe R, Pattiaratchi C, Ivey G, Symonds G (2011) The response of the wave-driven circulation at Ningaloo Reef, Western Australia, to a rise in mean sea level. In: 20th Australasian coastal ocean engineer conference, pp 706–711

Woods PJ, Brown RJ (1975) Carbonate sedimentation in an arid zone tidal flat, Nilemah embayment, Shark Bay, Western Australia. In: Ginsburg RN (ed) Tidal deposits: a casebook of recent examples and fossil counterparts. Springer, New York, pp 223–232

Chapter 34
The Australian Coast: Review and Overview

Abstract Half the Australian coast consists of beaches and barrier systems composed of sediments that can be grouped into a hierarchy of coastal sediment compartments. This book has investigated the nature of the beaches, barriers and their sediment compartments around the entire coast. In this concluding chapter, the beaches are reviewed beginning with the controls on their spatial distribution and temporal variability, finishing with an overview of their status. This is followed by a review of the types of barrier and their distribution around Australia including the regional variation in their sediment characteristics and implications for sediment transport. The future impacts of climate change are considered including the impact of rising sea level and changing waves and tide regimes. Finally, as this book is based on the role of sediment compartments, it finished with a list of what is required to investigate a compartment and predict future shoreline changes.

Keywords Australian coast · Beaches · Barriers · Sediment compartments · Climate change impacts

34.1 Introduction

This book has examined the nature of the entire Australian coast using the framework of coastal sediment compartments in a descending hierarchy from province through to division, region, and primary (PC) and secondary compartments (SC). Using this approach, the coast is divided into 2 provinces, 23 regions, 102 PCs and 354 SCs (listed in Appendix 34.1). At each of these levels, the book has examined the coastal processes and sediments, beach and barrier systems and nature and role of sediment transport in forming much of the coast. In this concluding chapter, the results presented in the previous 33 chapters are collated and summarised in order to provide an overview of the beaches, barriers, sediments and sediment compartments for entire coast. The aim is to provide an insight into the nature and behaviour of the coast based on the nature and distribution of beach and barrier systems, their sediment characteristics and the rates of supply, and volume of sediment at the

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division and regional level. It will also summarise the present status of the coast and its potential response to the impacts of climate change.

The chapter will particularly focus on the variation in the nature and behaviour of the coast in response to the changing coastal processes, using the beaches as an indicator of the relative contribution of waves and tides, and barriers as indicators of longer-term shoreline response to these and other processes combined with sediment supply. The beach systems which occupy half the coast provide an ideal insight into the processes acting on the coast. *Beaches* are wave-deposited accumulations of sediment (usually sand but also cobbles and boulders) at the shore. They represent the interaction of waves, tide and sand and will range from WD to TD as wave-tide conditions change and can consequently be classified into WD, TM and TD beach types (see Chap. 1.6). Likewise, the *barrier* systems represent the long-term integral of these processes including wind and biota and can range from tidal flats and cheniers to massive transgressive dunes, also reflecting the availability and delivery of sediment to the coast. Once sediment is delivered to a beach, the waves, together with wind and coastal vegetation, will determine its arrangement at and beyond the coast, which can range from stable well-vegetated regressive systems (cheniers, beach ridges, foredune ridges) through to a range of transgressive dune systems (blowouts, parabolics, longwalled parabolics, transverse dunes and dune sheets) including clifftop dunes. Likewise, rates of sand supply can range from 0.1 to 10 $m^3\ m^{-1}\ year^{-1}$ and total volume from 10s to 100,000 s $m^3\ m^{-1}$, with both the rates and volume dependent primarily on wave energy. To build any of these features, sand is required, which means both a source and transport mechanism to deliver it to the shore. As sand supply is a dynamic system, the shoreline is also dynamic responding to changes in the rate of supply, which may be positive, balanced or negative leading, respectively, to shoreline accretion, stability or recession. It is the nature of this supply and its sources, volume, transport mechanisms, transport rates and the variation in all of these through time that is at the core of the sediment compartment approach. A *sediment compartment* is a section of coast with well-defined boundaries that shares a common source of sand that may be transported to and/or through the compartment. The compartment can range in size from a single closed embayed beach to 100 s km of open coast, while its boundaries may be open, leaky or closed to sand transport.

34.2 Australian Beach Systems: Spatial Distribution

The range of WD, TM and TD beaches and their nature are described in Chap. 1.6.1, and the type, number and extent of beaches in each region, PC and many SCs are presented in their respective Chaps. 3 to 33. This section will summarise the type and extent of the beach systems on a State by State basis using the results of Short (2006) and a provincial and regional basis as presented in this book. Fig. 1.20 illustrates the distribution of WD, TM and TD beaches around the Australian coast, and Table 34.1 summarises these data into provincial beach types only, while Table 34.2

Table 34.1 Percentage of beach type (number and length) by province

		WD	TM	TD	R/C	Total
Northern	Number	3.5	21	57	18.4	100
Northern	Length	4	37	50	8.9	100
Southern	Number	78.4	2.5	15.4	3.7	100
Southern	Length	78	2.5	18	1.8	100

Table 34.2 Provincial beach states by (a) number and (b) length. **Bold** indicates dominant-modal states

Northern province (number and length)																
Beach state	1 D	2 LBT	3 RBB	4 TBR	5 LTT	6 R	7 R+LTT	8 R+LTR	9 UD	10 B+RSF	11 B+SF	12 B+TSF	13 B+TMF	14 R+RF	15 R+CF	Total
number	0	0	0	14	27	122	**648**	173	172	300	**1410**	735	248	**653**	221	4723
%	0	0	0	0.3	0.6	2.6	13.7	3.7	3.6	6.4	29.9	15.6	5.3	13.8	4.7	100
length (km)	0	0	0	45	47	154	**1043**	588	636	819	**1391**	552	281	**452**	91	6100
%	0	0	0	0.7	0.8	2.5	17.1	9.6	10.4	13.4	22.8	9.1	4.6	7.4	1.5	100
Southern province (number and length)																
beach state	1 D	2 LBT	3 RBB	4 TBR	5 LTT	6 R	7 R+LTT	8 R+LTR	9 UD	10 B+RSF	11 B+SF	12 B+TSF	13 B+TMF	14 R+RF	15 R+CF	Total
number	14	8	286	1099	939	**2459**	111	27	15	127	**689**	128	0	**193**	36	6131
%	0.2	0.1	4.7	17.9	15.3	40.1	1.8	0.4	0.2	2.1	11.2	2.1	0.0	3.1	0.6	100
length (km)	291	5	801	**2472**	1325	1756	110	66	36	190	**1062**	262	0	112	50	8539
%	3.4	0.1	9.4	29.0	15.5	20.6	1.3	0.8	0.4	2.2	12.4	3.1	0.0	1.3	0.6	100

lists the 15 beach states, their number and length in the northern and southern province. Table 1.3 shows just the same data for each State/Territory and Table 34.3 for each of the 23 regions presented in this book.

The distribution of beach types shows a clear relationship to province, State and region. Starting at a provincial level, Table 34.1 shows the northern province with its meso- to mega-tides, and low to moderate waves are dominated in length by TM and TD (37 and 50%), followed by rock and coral flats (RF/CF, 9%) with just 4% WD. In contrast the southern province with its micro-tides and moderate to high waves is dominated by WD (78%), except in sheltered meso-tidal areas where TD (18%) and TM (2.5%) occur. Table 34.2 provides further insight into the provincial distribution of beaches showing the number and length of each of the 15 beach states in both provinces. As expected the northern province is dominated by the modal TD B + SF (23% by length), followed by TM R + LTT (17%) and TD B + RSF (13%), while the few WD beaches are primarily low energy R (2.5%). The southern province is dominated by the WD R by number (40%); however these average just 0.7 km in length, while the longer TBR (2.2 km) dominate by length (29%). These are followed by the R (21%), LTT (15.5%) and then the TD B + SF (12%). The overall dominance of lower energy WD and the presence of the TM and TD beaches are an indication of the amount of wave sheltering both on the open coast when the R and LTT tend to occur and at a broader level on the sheltered meso-tidal northern Tasmanian coast, SA gulfs and Shark Bay where most of the TM and TD occur.

Table 34.3 Regional beach states by (a) number and (b) length. **Bold** indicates dominant-modal states

a) NUMBER	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
	D	LBT	RBB	TBR	LTT	R	R+LTT	R+LTR	UD	B+RSF	B+SF	B+TSF	B+TMF	R+RF	R+CF	
1 Pilbara						28	61		62	14	**140**	**153**	8	**90**	17	573
2 W Kimberley						12	18	3	6	14	**377**	**390**	106	**144**	148	1218
3 Western NT							26	1	9	5	32	9	**25**	**29**		136
4 N Arnhem							80	35		38	**309**	80	61	**233**	33	869
5 E Arnhem				14	27	60	7	7			**90**	15	17	**106**		343
6 Southern Gulf										**49**	17	7	3	5		81
7 W Cape York						7	20	19		19	**49**	20	9	4		147
8 E Cape York						14	**237**	64	30	135	**249**	46	19	42	23	859
9 Central Qld						1	**199**	44	65	26	**147**	15				497
10 Central east			17	**145**	59	51	8			1	17	1				299
11 South NSW			49	**183**	**114**	**181**										527
12 Gippsland			**26**	**38**	22	21										107
13 E Tasmania				67	**112**	**323**				31	29					565
14 W Tasmania				**128**	64	242										434
15 N Tasmania	2		6	3	3	7	**60**	27	15	4	29	2		**146**		304
16 C Victoria			52	**123**	**118**	**212**				34	20	26		4		589
17 Southern SA		3	31	66	47	**140**										287
18 SA Gulfs				31	98	**248**	35			22	**252**	48				734
19 W Eyre Pen.	12	5	20	94	55	**278**	7			22	121	24				638
20 Nullabor			7	13	**24**	**16**					2			4		66
21 Southern WA			78	**170**	**120**	**169**	1				2	1		24		565
22 SW WA				30	54	**414**					16			2		516
23 Central WA				8	49	**157**				13	201	26		10	36	500
Total (km)	14	8	286	1113	966	2581	759	200	187	427	2099	863	248	846	92	10689
%	0.1	0.1	2.7	10.4	9.0	24.1	7.1	1.9	1.7	4.0	19.6	8.1	2.3	7.9	0.9	100.0

b) LENGTH (km)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
	D	LBT	RBB	TBR	LTT	R	R+LTT	R+LTR	UD	B+RSF	B+SF	B+TSF	B+TMF	R+RF	R+CF	
1 Pilbara						84	41		341	9	**217**	**221**	16	109	4	1042
2 W Kimberely						4	14	7	9	7	98	**145**	74	57	38	453
3 Western NT							52	5	47	11	**59**	7	**78**	37		296
4 N Arnhem							129	50		86	**315**	58	35	**125**	35	833
5 E Arnhem				45	47	36	1	7			**101**	13	21	**103**		374
6 Southern Gulf										**242**	62	17	23	2		346
7 W Cape York						8.3	**206**	**223**		91	**160**	17	34	3.3		743
8 E Cape York						1.5	**388**	173	67	**257**	209	60		16	14	1243
9 Central Qld						21	**212**	123	**172**	116	**170**	15				827
10 Central east			138	**608**	153	56	7.5			0.4	37	8.5				1008
11 South NSW			128	**266**	61	53										508
12 Gippsland			**175**	92	61	25										352
13 E Tasmania				**112**	**106**	**135**				12	17			0.6		383
14 W Tasmania				**148**	30	70										247
15 N Tasmania	6		10	3	2.8	1	**54**	**66**	36	5	30	5		**55**		273
16 C Victoria			64	**264**	79	94				70	15	31		3.5		621
17 Southern SA	**227**		70	**109**	41	70										517
18 SA Gulfs				43	**130**	**192**	43			26	**429**	167				1029
19 W Eyre Pen.	59	5.4	81	**163**	**43**	120	3			39	**113**	14				640
20 Nullabor			11	140	**315**	13					4			1.8		484
21 Southern WA			123	**431**	123	79	2.8				1			14		773
22 SW WA				66	117	**581**					51			1		815
23 Central WA				27	64	**267**				39	**366**	38		37	50	887
Total (km)	291	5	801	2517	1372	1910	1153	654	672	1009	2453	814	281	564	141	14639
%	2	0	5	17	9	13	8	4	5	7	17	6	2	4	1	100

Short (2006) presents the distribution of beach types/states on a State by State basis (Table 1.3). The only solely northern state (NT) is dominated by TM and TD beaches (75% by length); those that straddle the north and south (WA and QLD) have a mix of WD, TM and TD. In contrast all the solely southern states (NSW, VIC, TAS and SA) are dominated by WD, with NSW exclusively WD. Finally, the regional distribution (Table 34.3) provides more detail on the spatial occurrence of beach types/states around the coast. The nine northern regions are all dominated by TM and TD states, with the only significant number of WD beaches occurring along the exposed eastern coast of Arnhem Land which faces across the Gulf of Carpentaria. In the south the 14 regions are all dominated by WD, with the only significant areas of TM-TD beaches occurring in the southeast TAS bays (E Tasmania), along the sheltered meso-tidal northern TAS coast, in Port Phillip Bay (central-western VIC), in the sheltered meso-tidal SA gulfs, in some large western Eyre Peninsula bays, and finally in the central west's Shark Bay. These distributions also show a clear relationship to prevailing wave (Fig. 1.12a) and tide (Fig. 1.15) conditions, with WD beaches spread primarily around the more exposed micro-tidal southern states and TM and TD beaches located around the northern coast with its lower waves and meso- through mega-tides.

Nyberg and Howell (2016) undertook a global assessment of shoreline characteristics (sand versus rock) and dominant process (waves, tides, fluvial). They derived a figure of 28% of the world's coast as depositional (sand-mud) of which 62% are WD, 35% TD and 3% fluvial-dominated beaches. In Australia their results compare favourably with Short (2006) results (Table 34.3), with the comparison illustrated in Fig. 34.1.

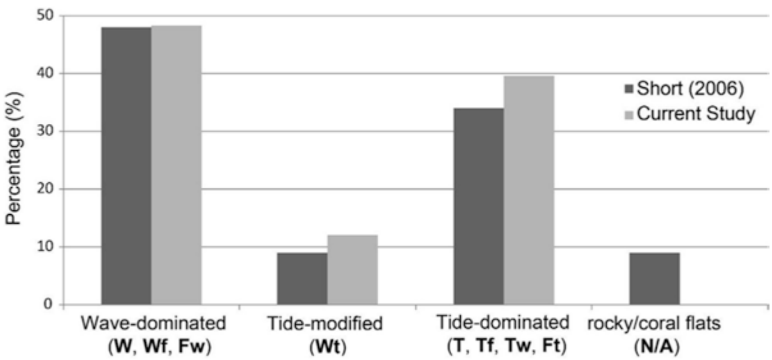

Fig. 34.1 Comparison of beach data presented in Table 34.1 (Short 2006), with Nyberg and Howell's (2016) classification of Australian beach types. (Source: Nyberg and Howell 2016, reproduced with permission of Elsevier)

34.3 Large-Scale Spatial Controls on Beaches

While beaches are simple entities shaped by waves and tide, a number of factors control their location, length, type and state including geological control and Pleistocene inheritance.

34.3.1 Geological Control

In working around the coast to produce this book, two factors became evident with regard to the nature and type of beaches, one which controls location and extent of the beaches and the second which controls their type and state. The average Australian beach is just 1.37 km in length (Table 34.3) with most bordered and even surrounded by some form of bedrock including reefs, rock, points, headlands and capes, what is called geological control (Short 2010a). *Geological control* refers to the impact of the surrounding geology (bedrock and sediments) on coastal processes; while *geological inheritance* refers to the pre-existing geology (bedrock and sediments. Both the inheritance and control are a product of two factors, first the PMT and present highstand of the sea which flooded thousands of coastal valleys and embayments coming to rest in many areas against moderate to steep terrain which occupies ~50% of the coast and provides limited accommodation space for beaches, as illustrated by much of the southern NSW coast, southern TAS and areas like the Nullarbor, as well as the presence of pre-existing Pleistocene sediments. Second, is the prevalence of calcarenite across the southern and up the west coast where former sandy beaches and dunes now remain as resilient calcarenite reefs, islets, rocks, bluffs and cliffs thereby impacing wave shoaling processes and limiting and controlling accommodation space as well as providing hard boundaries. The bedrock, calcarenite and other pre-existing coastal deposits therefore control location of beaches through provision of accommodation space and length through provision of boundaries, and influence beach state and shape through their impact on wave attenuation, diffraction and refraction. It is no coincidence that Australia's three longest beaches, all >200 km in length, each occur along sedimentary basins free of bedrock.

Beach type is controlled by the combination of waves and tides as quantified by the RTR. Tides around Australia are predominately meso-mega in the north and micro, with some meso, in the south, whereas deepwater waves (H_o) are low in the north and moderate to high in the south. However, RTR depends on breaker height (H_b), and this is controlled by wave attenuation and refraction, which in turn depends on shoreface and shelf topography that is controlled by the coastal geology and in places the ecology. For this reason, the moderate to high energy southern coast has a high proportion of sheltered R and LTT beaches and a minority of exposed TBR-D beach systems. This is because the high deepwater waves are attenuated as they cross the nearshore shelf and are refracted around headland and obstacles to ultimately arrive and break at the shore. The amount of attenuation can range from 0 to 100%. Coasts with steep, narrow shelfs like the NSW coast receive most of their deepwater wave energy (Wright 1976) on exposed beaches and are dominated my moderate to high energy WD beaches, whereas coasts with shallow reef-dominated shelfs, like the southwest WA shelf, attenuate much of their high deepwater wave energy to deliver low waves at the shore and consequently maintain lower energy beach states on an otherwise high energy coast. In extreme cases the waves are so low that even in micro-tidal locations TD beach can prevail, such as the southeast TAS bays and in Shark Bay. As Short (2010a) found, the overall impact of geological inheritance around the Australian coast is to generate shorter, more crenulate, lower energy beach systems.

34.3.2 Pleistocene Highstands and Inheritance

Pleistocene sea-level highstands have reached at or close to present sea level on multiple occasions during the Quaternary (Murray-Wallace and Belperio 1991). At each highstand shelf sands are reworked onshore to be deposited as beaches, barriers, flood tide deltas and SSB's. While some of this material is eroded during the subsequent lowstands, it means that each highstand progressively infills the available accommodation space, leaving less space for sediment deposition during the next highstand. Consequently, around the tectonically stable Australian coast during the PMT and subsequent stillstand, there have been local and regional limits on accommodation space, with some sand unable to be deposited onshore as there was no space available. A good example is to compare SA's Coorong coastal plain and western Eyre Peninsula. The southern Coorong plain is being uplifted at 0.07 mm year^{-1}, meaning that at each highstand, the pervious highstand barrier has been elevated several meters and 'shifted inland' thereby providing accommodation space for the next barrier. In this way dozens of barriers have been deposited across the 350 km plain, including 20 barriers across the 90 km wide Pleistocene coastal plain which rises inland to 60 m at Naracoorte (Murray-Wallace 2018). On the neighbouring tectonically stable Kangaroo Island and Eyre Peninsula, each highstand has been confronted with the previous highstand barrier deposits, which have also been lithified to dune calcarenite and form calcarenite reefs, cliffs and bluffs. The only accommodation space available is in front of or on top of the Pleistocene barrier. On exposed high energy coasts where abundant sand accompanied the PMT, it was deposited as beaches leading to sand ramps to the top of the cliffs from which clifftop dunes moved inland. Most of the beaches and ramps were subsequently eroded, some being deposited as SSB's, leaving the dunes stranded on top of the cliffs. The end result is stacked sequences of highstand dune layers reaching in places to 250 m in elevation, but usually between 50 and 100 m and containing 10+ layers of dune sand/palaeosols, each representing a sea-level highstand. This process has led to the formation of the massive 360 km long Zuytdorp Cliffs, the southeast QLD sand islands (Fraser to North Stradbroke) and the numerous cliffed and stacked Pleistocene barriers located along the southern coast, as illustrated in Fig. 34.2. Along the southeast coast it has resulted in the deposition of clifftop dunes on top of exposed bedrock cliffs, such as part of the Sydney coast.

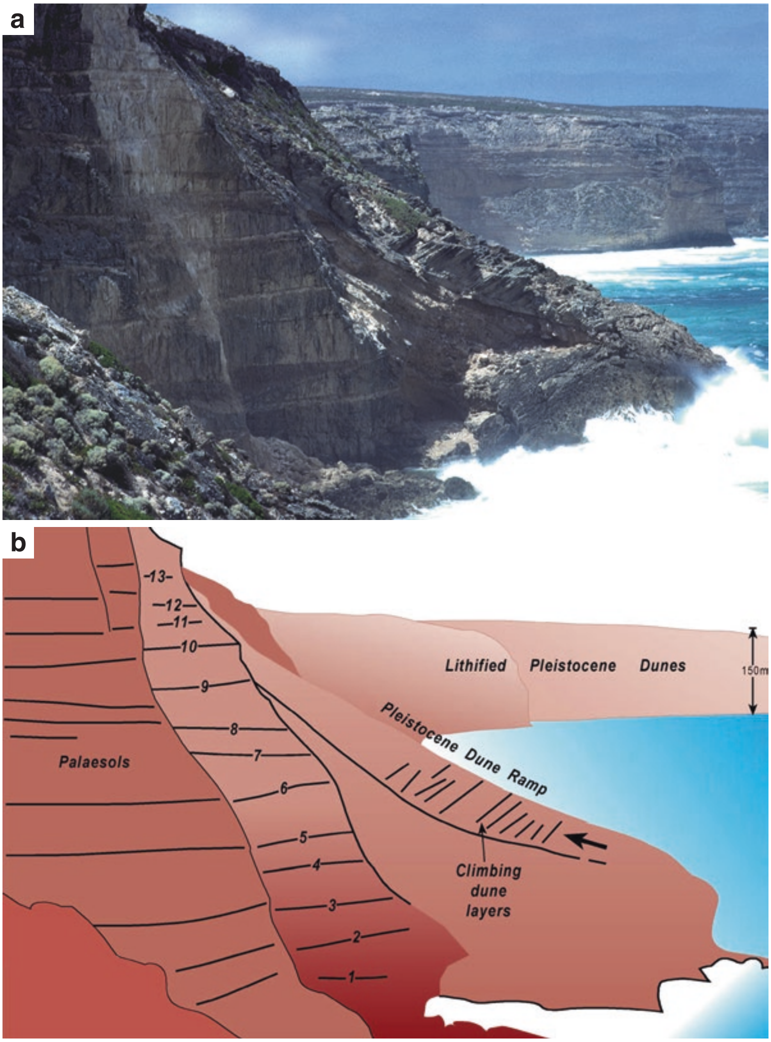

Fig. 34.2 Stacked Pleistocene dune calcarenite with 13 palaeosols and a lithified sand ramp rising 150 m at Groper Bay, southern Eyre Peninsula. (Source: Short and Woodroffe 2009)

34.3.3 Secondary Temporal Controls on Beaches

While geological inheritance exerts a primary control on beach location, extent and state, a number of other factors, which can vary through time, also exert regional controls on beach systems. These include the Holocene sea-level highstand; growth of fringing coral reefs and carbonate banks/sand flats; changes in the rates of sand supply to the shore; and the infilling of embayments.

Sea Level The PMT around much of Australia reached an elevation 1–2 m above present sea level between 7 and 6 ka, followed by a fall in sea level (Fig. 1.42) at regionally variables times and rates to the present level (Murray-Wallace and Woodroffe 2014). This implies that at the highstand, sea level was 1–2 m higher and the nearshore 1–2 m deeper resulting in less depth-dependent wave attenuation and refraction, leading to higher waves at the shore and potentially higher energy beach types/states, while the subsequent fall in sea level lead to lower energy states. The net result is a mid-Holocene higher energy window with a reduction in breaker wave energy accompanying the fall in sea level.

Coral Reefs Coral reefs fringe much of the northern Australian coast and shelf. They represent a recent addition to the coast growing upwards as sea level rose. Coral reefs accrete at a rate between 0.3 and 0.8 mm year^{-1} (Hopley et al. 2007), while during the PMT, sea level was rising at between 1 and 2 mm year^{-1}. While some reefs were able to keep up with the rising sea level, others had to catch up, with a delay in their reaching the surface (Woodroffe 2007). During this period the coast to the lee of the deeper 'catching up' reefs was exposed to less wave attenuation over the reefs and higher waves at the shore, what Hopley (1983) referred to on the GBR as the mid-Holocene 'high energy window'. A similar high energy window is expected to have occurred around northern Australia's other coral reef environments. As the reefs caught up and reached sea-level wave breaking, attenuation and refraction increased, causing wave energy to decline leading to lower energy beaches in their lee and a transition from mid-Holocene higher to late Holocene lower energy coastal systems.

Carbonate Sand Flats Southern and Western Australia's temperate carbonate province has acted as the major source of beach and dune sand for these coasts. In the sheltered section of the coast such as the SA gulfs and western Eyre Peninsula bays and Shark Bay, the extensive seagrass meadows provide a habitat for a range of epifauna whose detritus is transported shorewards to be deposited in the sub- to intertidal zone and slowly build carbonate banks whose surface is manifested as intertidal sand flats (Fig. 16.8). Studies in northern Spencer Gulf by Belperio et al. (1984, 1988) found that the carbonate banks had to 'catch up' following the PMT and only reached present sea level between 4 and 5 ka, while Burne (1982) and Short et al. (1989) both found that the gulf sand flats only emerged sufficiently to allow beach ridges to be deposited in their high tide zone between 4 and 3 ka. This implies it took 3000–4000 years for the carbonate banks to accrete and in the process decrease the water depth from ~5 m to ~0 m. The SA sand flats average 1 km in width and in Shark Bay 1–1.5 km so that their accretion resulted substantial shoaling of the intertidal zone leading to wave attenuation and significantly lower waves at the shore. Consequently, these regions like the coasts in lee of coral reefs, also experienced a mid-Holocene high energy window which was gradually closed as the banks aggraded and extended.

Sediment Supply Coastal sediments require a source and a transport mechanism to deliver it to and along the coast. Most sand around the Australian coast was transported onshore from the shelf and longshore by waves, with the rate of transport proportional to the wave energy which can range from <0.1 m^3 m^{-1} $year^{-1}$ to >10 m^3 m^{-1} $year^{-1}$ (Short 2010b). In the coastal zone, sediment sources can be terrestrial delivered directly by rivers and cliff erosion or via the shelf where they are deposited at lower sea levels; or they may be carbonate and produced by epifauna on the shelf or in shoaler seagrass meadows and coral reef ecosystems. The source will also have texture that can vary in size, sorting, composition and colour. Waves tend to winnow and sort the material and around Australia deliver primarily reasonably well-sorted fine to medium quartz-carbonate sand to the coast. The source will have a certain volume which can be finite size or an ongoing supply. The rate at which it is transported to and along the coast will increase basically at the square of wave height; likewise the depth from which it can be transported will increase with rising wave height, ranging from a few meters to as a much as 70 m depth of the high energy southern shelf. All this means that on high energy coasts, large volumes of sand can be transported from deeper water at high rates to and along the coast, while low waves can only transport sand from shallow water at low rates. It is no surprise then that the greatest accumulations of sand on the coast are all in high wave environments, assisted regional by strong onshore winds, while the lowest rates occur in sheltered environments with low to very low waves. The impact of the locally and regional variable sand volume and rate of supply will be discussed below in relation to barrier systems.

Embayment Infilling As sediment is supplied to the Australian coast, it is deposited in usually small (<1.5 km long) beach barrier systems. If it is an embayed system, this may lead to shoreline regression as the beach progrades seawards gradually filling the embayment-accommodation space. As the shoreface moves seawards, it is also usually moving into deeper water, and as it fills the embayment, the shoreline often straightens owing to a decreased wave refraction. As a consequence, many embayed systems progressed from inner lower energy more crenulated beach systems to outer, straighter, higher energy systems, as described by Oliver et al. (2017b, 2018), which may result in a change in beach state and barrier form.

34.3.4 Status of Australian Beaches

While the above details the nature and extent of Australia's beaches, it does not provide information on the status in terms of whether the beaches are prograding, stable or receding. Unfortunately, in Australia, there are just a handful of beaches that have been monitored for a sufficiently long period (decades) to provide accurate information on decadal scale shoreline trends (e.g. Eliot and Travers 2011; McLean and Thom 2018; Short et al. 2014).

However, new technology utilising satellite imagery can detect shoreline position and decadal-scale changes on a global scale (Fig. 34.3a; Luijendijk et al. 2018). In Australia the satellite detection estimated that 52% of the coast was sand, which compares favourably to the actual 49%, and that nationwide the beaches were stable with an average rate of change −0.20 m year^{-1}, within the projects 'stable' range of ±0.5 m year^{-1}. The project assessed shoreline trends at 0.5 km interval around the entire Australian coast including many islands, estuaries and bays. It detects the shoreline position along each transect from each satellite image and plots the shoreline position at each transect to generate a shoreline trend over a 32-year period (1984–2016). The project's website (http://shorelinemonitor.deltares.nl) provides a map of the world with the ability to zoom in on any section of coast and any individual transect. Each transect is colour-coded from red (erosion) to yellow (stable) to green (accretion), with the length of the transect marker indicating the amount of change. At a glance it is possible to see individual and longshore trends. A time series plot of individual trends is available by clicking on the trend line, which provides a plot of each shoreline position between 1984 and 2016 and a trend line of best fit.

Most of the Australian coast is labelled as stable (Fig. 34.3b), i.e. within the ±0.5 m year^{-1} change, a status which this author agrees with. The few erosion hotspots (>0.5 m year^{-1}) are generally located along dynamics sections of coast, with the three erosion locations indicated on Fig. 34.3a: the macro-tidal Pardoo embayment (Fig. 4.18c) on the Pilbara coast, the West Alligator River mouth in Arnhem Land and the Fly River mouth in New Guinea. Based on a comparison of the 1968 aerial photograph and 2018 Google Earth image, the Pardoo embayment shoreline is actually stable, and the 1 km wide tidal flats have apparently been misinterpreted by the algorithm, while the West Alligator and Fly River are dynamic river mouths. The one green accretion hotspot is associated with the wide mud flats and mangroves of Roebuck Bay, which has been misclassified as beach. By zooming in on the actual transects, most lesser erosion areas are associated with migratory spits in northern Australian and with delta mouths, with the largest Queensland erosion area associated with the very dynamic Burdekin River delta (see Sect. 14.9) and its northward migrating sand spits which generate both substantial erosion and accretion. The vast majority of the beaches, even high energy southern coast beaches, are labelled as stable.

The results of this project must be viewed as a global overpass, and any use of individual transects must be combined with local knowledge or alternative data to verify its accuracy. Nonetheless use of satellite imagery for shoreline detection is the way of the future providing a potentially accurate low-cost way of providing shoreline trends for any of Australia's or the world beaches back to the 1980s. Research undertaken at the UNSW Water Research Laboratory (Vos et al. 2018) found a close correlation between satellite-derived shorelines and surveyed shorelines on Australian and other global beaches. Likewise, Loehr et al. (2018) have used satellite imagery to derive topography and shallow water bathymetry out to 30 m water depth, which will greatly facilitate the mapping of compartment seabeds. Another new and developing site is the Australian government's National

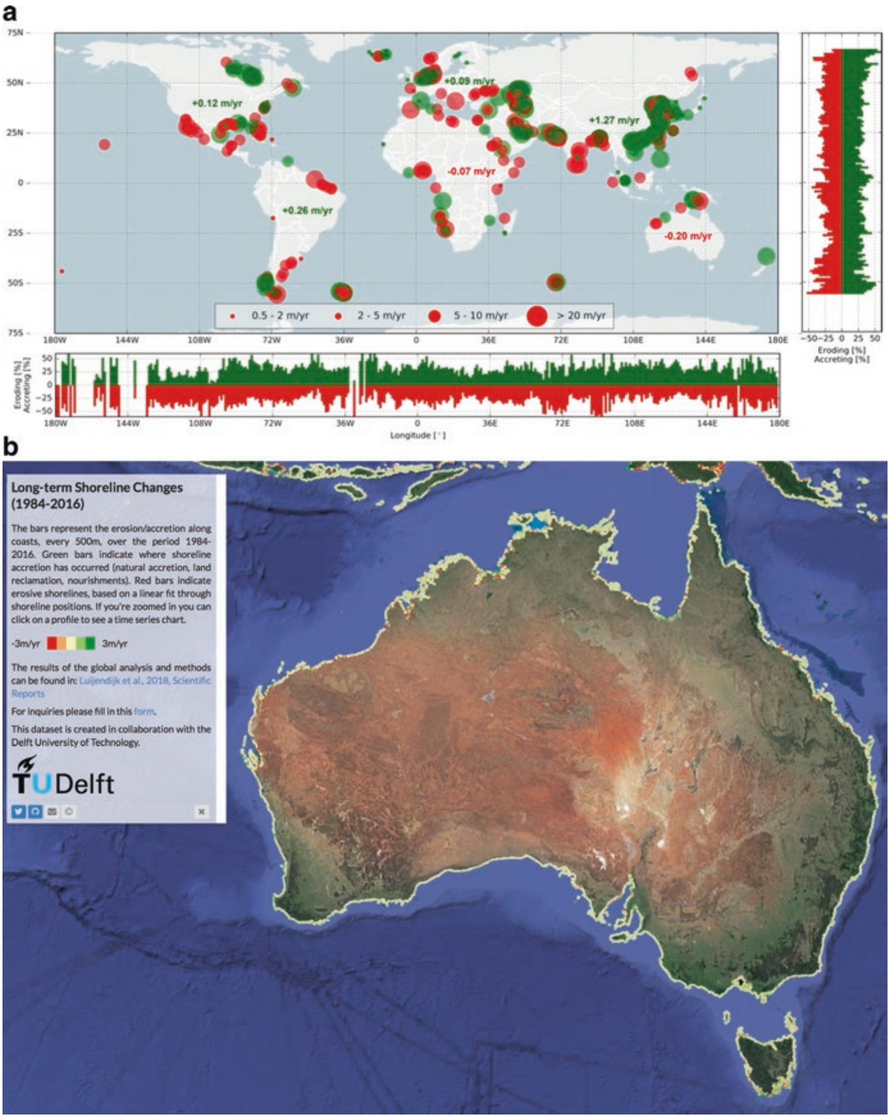

Fig. 34.3 (**a**) Status of the world's beaches by latitude, longitude and regional hotspots (red, erosion; green, accretion) (from Luijendijk et al. 2018, reproduced with permission of Creative Commons Attribution 4.0 International Licence) and (**b**) the Australian coast (yellow, stable). (From: http://shorelinemonitor.deltares.nl)

Map website (https://nationalmap.gov.au/about.htmlAustralian coast status). This provides a range of information about the entire coast, based on satellite imagery. The coastal attributes include: sand areas (predominately beaches and dunes), intertidal extent (predominately tidal flats), saline coastal flats (supratidal flats), mangrove canopy, land subject to fluvial and marine inundation and an intertidal digital elevation model. This is a new and exciting area of research that will offer considerable insight into the nature of Australia's coastal systems and ultimately the behaviour of all Australian beaches since the 1980s and which will enable quantification of this critical component of the sediment compartment approach to the study of shoreline behaviour.

While satellite technology indicates that most Australian beaches are stable, based on the information in this book, it is also opportune to provide a very general overview of beaches in the northern and southern provinces. In the north are the low waves and high tides of the northern province, a province that also receives considerable terrigenous sediment supply to its many river mouths, often delivered in pulses by periodic floods. Depending on location, the sediment feeds into generally north-trending longshore transport systems, driven by low-to-moderate trade wind waves and currents, and in place strong tidal currents. The transport is however interrupted by numerous creeks, inlets, changes in orientation and rocky shore and headlands resulting in a spatially and temporally variable sediment supply. While the coast in general has a positive sediment supply and is prograding, the dynamic river and creek months and north-trending sediment generate considerable decadal scale shoreline oscillation in the process. This natural oscillation in response to variation in inlet dynamics and longshore sand transport is apparent along much of the GBR sheltered east QLD coast as well as the western Cape York Peninsula coast, and along much of the largely undeveloped NT and Pilbara coasts. The northern sedimentary coasts have generally low elevation dynamic shorelines exposed to both longshore transport, river and creek mouth dynamics and low lying coastal plains, which are prone to inundation by river flooding and tropical cyclone storm surge. It is Australia's most hazardous coast, which however because of generally low level of development, apart from east QLD, has generally low risk.

The southern province in contrast has generally higher waves and microtides and an abundance of largely shelf-supplied quartz and carbonate sediment, with longshore transport restricted to the east and west coasts. The central east region (Sandy Cape-Cape Hawke) is dominated by northerly sand transport with volume increasing northward to peak at ~0.5 M m^3 yr^{-1} in southeast QLD. The increasing volume is in part supplied by erosion and recession of Holocene and Pleistocene beaches and barriers. The remainder of the southeast division (Cape Hawke-South East Cape, TAS), and all of the Great Southern division, is exposed to the high Southern Ocean swell, with predominately on-offshore transport, and embayed swash-aligned coast with limited longshore transport. This an exposed coast which received huge volumes of shelf-supplied sediment during and following the PMT, much of which has been exhausted and in places reclaimed by massive coastal erosion. The extent of the former beaches is indicated by the hundreds of kilometres of clifftop dunes that occur around much of this coast, and off the NSW coast the SSBs supplied from this erosion. What is left are generally resilient remnants of once larger systems, existing in a state of dynamic equilibrium to slow recession and whose stability today depends on their current sediment budget.

The southwest division is exposed to persistent southwest swell which drives northerly sand transport. However, unlike the east coast, it is compromised by the inshore calcarenite reefs, and in the north fringing coral reefs, which substantially lower waves at the shore and interrupt the rates and volume of transport.

Australian beach systems have been in a dynamic state since sea-level first came to rest around its present elevation ~7 ka. In southern NSW, half of the coastal hotspots are located on such systems where property was allowed to be developed, on generally stable beaches, but within the hazardous dynamic zone. The same applies to many of the more than 700 Tasmania properties exposed to high risk erosion, and the open South Australian and south West Australian coasts. The South Australian gulfs are lower energy but experience longshore transport which in the Adelaide region is driving the shoreline instability, coupled with past property encroachment into the hazard zone. All of the above shoreline behaviour has been occurring for at least hundreds to, in some cases, thousands of years. There is no evidence to date of rising sea level generating accelerated recession. What has happened in the past 100 years is human encroachment into these dynamic systems with development occurring within the beach hazard zone (e.g. Gold Coast, Wamberal, Collaroy), along shores exposed to dynamic pulses of longshore transport (e.g. east Queensland, Adelaide, Lacapede Bay, Geographe Bay), on dynamic estuarine flood tide delta shorelines (Jimmys, Snapperman, Silver, Surfside) and in some cases built structures to interrupt and/or diminish the sediment budget (e.g. Tweed River entrance, northeastern Port Phillip, Dutton Way, Port Geographe, Cooke Point). The vast majority of the so-called coastal 'hotspots' around the coast are therefore a result on human activity and poor planning that has allowed development within the coastal hazard zone, dynamic zones that continue to behave as they have been doing for centuries to millennium.

34.4 Barrier Systems

While beaches are relatively simply entities, barrier systems while supplied by waves also rely on wind and vegetation, as well as the hinterland topography and variable sediment supply. Beaches tend to maintain their type/state as sea level and sediment supply vary; they simply move seawards or landwards. Barriers represent the time integral of the beach system, combined with the surrounding environment which will include climate and vegetation and more recently human modification. Like beaches they are also impacted by the same geological control, the nature of and availability of accommodation space, temporal changes in sea level, the growth of coral reefs and carbonate banks and the vagaries of sediment supply. However, their response to these factors and the surrounding environments is far more complex leading to considerable variation in their nature and evolution.

There are 2539 barrier systems located around the Australian coast occupying 12,841 km (43%) of the coast and thereby comprising a substantial portion of Australia's coastal environments. The barriers cover an area of 22,200 km^2 of which 2742 km^2 (12.3%) is presently unstable. They have a total Holocene volume of 280,519 M m^3 which represents 21,846 m^3 m^{-1}, and if we assume it has been delivered continuously over the past 6000 years, the average rate is 3.6 $m^3\ m^{-1}\ year^{-1}$. The first overview of Australia's barrier systems was provided by Short (2010b) who divided the Australian coast into 17 'provinces' based on their barrier type and dimensions. The 23 regions described in this book overlay the 17 'provinces'. The preceding Chaps. (3–33) have discussed in more detail the beaches and barriers in each of the 23 regions and their 102 PCs and 354 SCs. In this assessment the seven divisions are used to provide an overview of the spatial variation in Australian barrier systems, followed by a review of the distribution of barrier types around the coast.

The size and extent of the barrier systems indicates their importance to Australia's coastal landscape. However, Table 34.4 also shows the considerable variation in the regional dimensions of these systems, which range in area and volume by two orders of magnitude and rate of supply by one order. This range hints to the considerable variation in barrier size, area, volume and type around the coast, which are discussed below from a divisional and then regional perspective.

34.4.1 Divisional Barrier Characteristics

The forgoing chapters provide an introduction to each division and a description of the coastal processes, waves, beaches and barriers for each region, PC and SC. This section briefly reviews the barrier dimensions in each of the seven divisions.

The *northwest division* contains the 2338 km long Pilbara region, a hot arid to semi-arid region of meso- to mega-tides, low waves and predominately offshore winds. Sediment is periodically supplied from both the several river systems draining the Pilbara which only flow following heavy cyclonic rains and from carbonate production on the shelf and inner seagrass meadows, with 50% of the beach sand carbonate in origin (Table 4.6). Sediment transport is predominately north to northeast driven by southerly waves and flooding tides, with rates on the order of a few 10,000 s $m^3\ year^{-1}$, and manifest in numerous north-trending spits and deflected creek and river mouths. Beaches occupy 1078 km (46%) and barriers 983 km (42%) of the coast and have an area of 863 km^2 of which 13% is presently unstable. The barriers have a volume of 9901 M m^3 which represents a moderate 10,072 $m^3\ m^{-1}$ (Table 34.4).

The *Kimberley-Territory division* is the lowest energy and most sheltered of the divisions and includes the rugged Kimberley coast and generally leeward western NT and north Arnhem Land regions. Tides are meso to mega, waves very low to moderate and the trade winds off- to alongshore. The 7190 km long coast is the longest of the northern divisions and second longest of all seven divisions. However, it has just 1638 km of beaches (23% of coast) and 1107 km of barriers (15%) both the lowest percentage of all the divisions. While a number of moderate to large rivers supply abundant sediment to the coast, little of this is deposited onshore. The paucity of wave and wind deposited sediments is a result not of a lack of sediment but a combination of lack of accommodation space on the rugged Kimberley coast,

Table 34.4 Regional and divisional barrier dimensions. For PC dimensions see Appendix 34.2 and the relevant chapters

No.	Region		Barrier	Barriers	Barriers		Barriers	Barriers	Holocene rate/meter
					Unstable	% unstable	Volume	Per meter	
		n	Length	Ha	Ha	%	M m³	m³ m⁻¹	m³ m⁻¹ year⁻¹
	Northwest reg/div	171	983	86,342	11,460	13.3	9901	10,072	1.7
2	W Kimberley	255	278	8447	718	8.5	511.5	1840	0.3
3	W NT	58	257	21,190	310	1.5	677	2636	0.4
4	N Arnhem	211	572	21,618	1384	6.4	831	1452	0.2
	Kimb-NT div.	524	1107	51,255	2412	4.7	2019.5	1905	0.3
5	E Arnhem	101	343	24,506	2582	10.5	4253	12,399	2.1
6	S gulf	30	427	88,265	2100	2.4	4500	10,539	1.8
7	W Cape York	46	669	188,705	1188	0.6	9675	14,462	2.4
	Gulf carp div.	177	1439	301,476	5870	1.9	18,428	12,806	2.1
8	E Cape York	231	1124	215,374	27,127	12.6	18,473	16,435	2.7
9	Central QLD	183	674	97,556	1319	1.4	15,342	22,763	3.8
	Northeast div.	414	1798	312,930	28,446	9.1	33,815	18,897	3.1
10	Central east	108	1084	290,965	20,747	7.1	35,278	32,544	5.4
11	South NSW	199	473	50,758	5074	10.0	6825	14,429	2.4
12	Gippsland	40	344	38,342	15,627	40.8	4436	12,895	2.1
13	E Tasmania	130	347	11,432	831	7.3	911	2625	0.4
	Southeast div.	477	2248	391,497	42,279	10.7	47,450	21,108	3.5
14	W Tasmania	88	228	34,556	4294	12.4	6585	28,887	7.3
15	N Tasmania	108	310	21,500	4187	19.5	3426	11,052	1.8
16	Central-west VIC	73	263	82,063	8857	10.8	7780	29582	4.9
17	Southern SA	73	263	82,063	8857	10.8	7780	29,582	4.9
18	SA gulfs	99	625	29,686	2240	7.5	2769	4430	0.7
19	W Eyre pen.	85	568	88,145	36,445	41.3	20,245	35,643	5.9
20	Nullarbor	17	523	233,460	17,350	7.4	16,705	31,941	5.3
21	South WA	122	859	209,194	41,845	20.0	41,352	48,140	8.0
	Great southern div.	618	3855	807,860	141,742	17.5	120,019	31,133	5.2
22	Southwest WA	57	702	166,504	31,302	18.8	31,373	44,691	7.4
23	Central WA	101	709	104,155	10,760	10.3	17,513	24,701	4.1
	Southwest div.	158	1411	270,659	42,062	15.5	48,886	34,656	5.8
	Australia total	2539	12,841	2,222,019	274,271	12.3	280,519	21,846	3.6

the generally low to very low wave energy to transport sediment onshore and lack onshore wind to transfer it to dune systems. As a consequence, on this terrigenous sediment-rich coast, 60% of the Kimberley beach sand, 42% of the western NT sand and 50% of the north Arnhem Land beach sand are carbonate in origin. In total the division has 512 km^2 of barrier of which 4.7% are unstable, with a total volume of 2019 M m^3 and a very low per meter volume of 1905 m^3 m^{-1} (Table 34.4), both the lowest of the divisions. Longshore sand transport is extremely limited on the rugged

Kimberley coast with northerly transport on the western NT and variable transport on the northern Arnhem Land coast both at rates expected to be on the order of 100 s to a few 1000 m^3 $year^{-1}$.

The U-shaped *Gulf of Carpentaria division* has a 2697 km long coast containing the exposed east Arnhem Land, the low energy southern Gulf and leeward western Cape York Peninsula regions. The gulf has a monsoonal climate which delivers a large number of rivers and streams to the coast and a relatively high terrigenous sediment supply at both low- and highstands of sea level. The higher terrigenous supply is reflected in the proportion of carbonate dropping from 51% in east Arnhem Land to 38% in the southern gulf to 22% along the western Cape York Peninsula. Beaches also occupy 1557 km (57%) and barriers 1439 km (53%) of this sediment-rich gulf. There is sufficient wave energy to build substantial regressive barrier along the leeward southern Gulf and western cape shores, while there are massive trade wind-driven transgressive dunes on the more exposed parts of the east Arnhem Land coast including on Groote Eylandt. The nature, size and extent of the barrier systems are a product of the abundant sand supply, low to moderate wave energy, high winds on exposed shores and a low gradient accommodating shoreline. The barriers have an area of 3014 km^2 of which just 2% is unstable, total volume of 18,428 M m^3 and per meter volume of 12,806 m^3 m^{-1} (Table 34.4), both an order of magnitude greater than its western neighbouring division. On the western peninsula, maximum northerly sand transport rates are expected to be on the order of a few 10,000 m^3 $year^{-1}$.

The *northeast division* contains the eastern Cape York Peninsula and central QLD regions with a total length of 4205 km. The coast contains 2091 km of beaches (50% of coast) and 1798 km of barriers (43%); the 50–50 breakdown in sedimentary versus rocky is indicative of the mix along the entire coast of rocky shore and long bays and embayments, including a few large sheltered bays in lee of prominent capes. The southeast trades deliver a low to moderate energy wave climate and onshore winds to a meso- through mega-tidal shoreline. The beaches are mix ranging from low energy TD to higher energy TM beaches. The humid climate has supplied terrigenous sediment via numerous small through large rivers and deltas which together with abundant shelf quartz and limited carbonate sources (5–20%) has enabled the development of barrier systems ranging from sheltered regressive (chenier-beach ridge-foredune ridge) through to massive transgressive barriers. The barriers have an area of 3129 km^2, of which 9% is unstable. They have a volume of 33,816 M m^3 and per meter volume of 18,897 m^3 m^{-1} (Table 34.4), both the highest in the northern province and larger than some of the southern province regional systems. All this reflects a low through moderate energy windward coast with an abundant sediment supply, assisted by sections of northerly longshore transport, which is usually on the order of a few 10,000 s m^3 $year^{-1}$.

The 4446 km long *southeast division* extends from Sandy Cape on Fraser Island to the southern tip of TAS at South East Cape and contains the central east, southern NSW, Gippsland and east TAS regions. This division is unified by its east to southeast orientation, moderate to occasional high waves, micro-tides and shelf sediment supply, with most of the numerous rivers and streams discharging their bedload into estuaries. The energetic wave climate in combination with the PMT has supplied large volumes of quartz-rich shelf sand to the coast, and the predominately southerly waves have transported it northwards to an ultimate sink at Fraser Island and beyond, at rates which on the exposed northern NSW-southeast QLD are an Australian maximum of ~500,000 m^3 $year^{-1}$, though considerably less further down the coast. Sediments are predominately well-sorted fine to medium quartz with carbonate ranging from a low 2% in the north to 19% in southern NSW and east TAS. The open coast beach systems are exclusively WD, with TD located in sheltered bays, particularly in southeast TAS. The beaches occupy 2191 km (49%) of the coast and the barriers 2248 km (51%). The barriers cover an area of 3915 km^2 of which 11% is presently unstable. They have volume of 47,450 M m^3 and a reasonably high divisional per meter volume of 21,108 m^3 m^{-1} (Table 34.4). The wind regime however shifts from onshore southeast in the north to long- to offshore southwest and then offshore west in the south, a shift reflected in the southward gradation in barrier type, size and volume. Beginning in the north is Australia's largest barriers and transgressive dune systems, the southeast Queensland sand islands occupying 400 km of the northern region. The barriers then decrease progressively southwards in type, area, volume and per meter volume, with NSW having just three substantial transgressive systems (Myall Lakes, Kurnell and Wreck Bay) and Gippsland the one large Cape Howe system, while eastern TAS has generally small regressive barriers and just the one small Peron transgressive dune system.

The *great southern division* is the longest (8055 km) and most exposed, with the highest energy beaches and largest barrier systems. The long coast is unified by its generally southerly orientation into the prevailing moderate to high southwest waves and strong onshore west through south winds, together with micro-tides on the open coast. It also has areas of significant sheltering and meso-tides in northern Tasmania, the SA gulfs, the western Eyre Peninsula bays and the Roe Plains section of the Nullarbor region. In all it contains eight regions: west and north TAS, central-western VIC, southern SA, the SA gulfs, western Eyre Peninsula, the Nullarbor and southern WA. The climate is humid in TAS, grading to Mediterranean along the southern mainland and to semi-arid in the Bight, with limited terrigenous sediment supplied at low sea level. Beach sediment are quartz-rich in the more humid western and north Tasmania (15–30% carbonate) and southern WA (20%), with carbonate content increasing across central-western Victoria from 28 to 78%, averaging 70% in southern SA, 50% in the SA gulfs, 90% across the high energy western Eyre and then dropping to 50% on the Nullarbor. The open coast is dominated by higher energy WD beaches, with TM-TD in the sheltered meso-tidal regions. On the open coast, there is a dominance of onshore transport from the shelf, while in the bays and gulfs, there is considerable local onshore transport for seagrass meadows together with longshore transport. There are 4672 km of beaches occupying 58% of coast and 3836 km of barriers (48%), with the remainder of the coast rocky including extensive calcarenite sections on the mainland. The barriers have an area of 8079 km^2 of which 17.5% is unstable, the highest of all the divisions. The larger barriers are located along the southwest-facing swash-aligned beaches on the western Eyre and southern WA coast. The division barriers have a total volume of

120,019 M m^3 and a high per meter volume of 31,133 m^3 m^{-1} (Table 34.4), a product of the abundant shelf carbonate sediment, high waves and strong onshore winds. Sand transport is predominately onshore and into the dunes, with longshore transport mainly restricted to southeast TAS, Westernport-Port Phillip, the SA gulfs (up to 40–60,000 m^3 year^{-1}) and the western Eyre Peninsula bays.

The *southwest division* commences in the humid southwest WA region and trends north into the semi-arid to arid central west WA region, with a total coastline of 2575 km. This is a fairly straight and continuous low gradient west-facing coast, exposed to a moderate to high deepwater wave climate much of which is attenuated by inshore calcarenite reefs. It is also exposed to strong southerly winds. These two combine with the micro-tides to maintain predominately lower energy WD beaches on the open coast and TD in the large Shark Bay and Exmouth Gulf. The shelf and inshore seagrass meadows supply abundant carbonate material with beaches and averaging 70% carbonate. There are 2575 km of beaches occupying 66% of the coast, the highest proportion of the divisions and 1326 km of barriers (51%). The barriers cover an area of 2707 km^2 of which 15.5% is presently unstable. They have a volume of 48,886 M m^3 with a high per meter volume of 34,656 m^3 m^{-1}, the latter the highest of the divisions (Table 34.4). The high volume is a product of the abundant shelf sediment and inner seagrass meadows with waves to transport it shorewards, together with long sections of northerly transport, at highly variable rates, but reaching a maximum of at least 100,000 m^3 year^{-1}. The waves have built some substantial regressive barrier systems, and the strong southerly winds have developed massive transgressive dunes extending inland and northwards over the readily accessible low gradient accommodation space.

34.4.2 Regional Barrier Types and Dimensions

The range of coastal dune systems and barrier types found around the Australian coast are presented in Sect. 1.6.4. Short (1988a) and Hesp and Short (1999) found, Australian barrier systems show a strong relation with wave energy, with increasing energy ranging from very low energy cheniers through to moderate energy regressive systems to high energy transgressive systems (Fig. 34.4). At the same time, the rate of sand supply to the barrier and their volume increases exponentially with increasing wave energy. This implies that low energy systems such as cheniers and beach ridges receive low rates and volume of sand and develop slowly and many are relatively young and still evolving, whereas at the other extreme high energy systems receive large volumes of sand, evolved rapidly (early- mid-Holocene), and many rapidly exhaust their large sand supply and begin receding, as illustrated by the hundreds of kilometres of stranded mid-Holocene clifftop dunes, particularly around southern Australia.

The lowest energy depositional shorelines around Australia are the sheltered and very low energy *tidal flats* (A, Fig. 34.4; Fig. 34.5a). These receive very low rates of sediment supply (<1 m^3 year^{-1}) and evolve slowly usually taking a few thousand

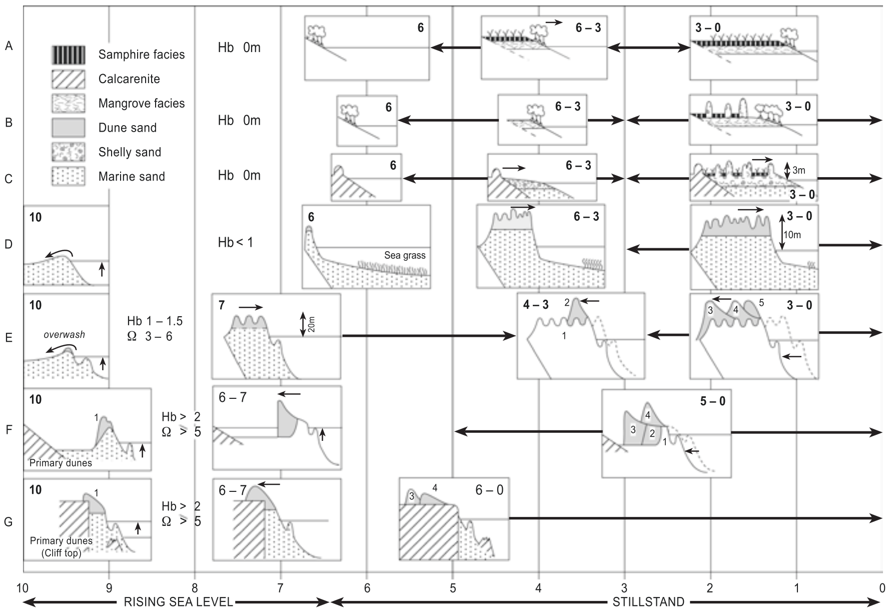

Fig. 34.4 Australian barrier types (A–G) set in relation to wave energy (H_b) and their evolution during the past 10 ka (10–0) (From: Hesp and Short 1999, based on Short 1988a). A, tidal flats (no barrier); B, cheniers; C, beach ridges; D, foredune ridges; E, secondary dune transgression; F, primary dune transgression; G, clifftop dunes

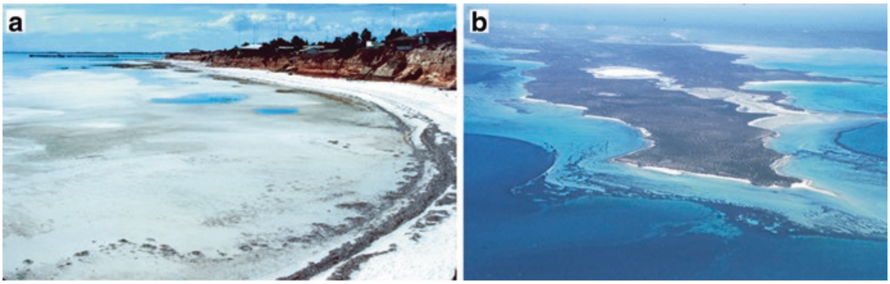

Fig. 34.5 (**a**) Intertidal sand flats at Sim Cove (SA 512), Spencer Gulf, and (**b**) extensive carbonate banks and seagrass meadows surround Giraud Point (WA 1284–7), Shark Bay. (Photos: AD Short)

years to aggrade to sea level and form extensive intertidal sand flats as shown in Spencer Gulf (Belperio et al. 1984, 1988) and Shark Bay (Fig. 34.5b; Logan 1970; Logan et al. 1970).

Chenier and *beach ridge* systems (B and C, Fig. 34.4) develop on high tide tidal flats and must await aggradation of the tidal flats before the usually coarse shelly ridges can be deposited on top of the flats (Fig. 34.6c), the ridges often composed of carbonate detritus and sand derived from the flats. Cheniers across northern Australia consequently date predominately from 3 ka (Lees 1992), in Batemans Bay from

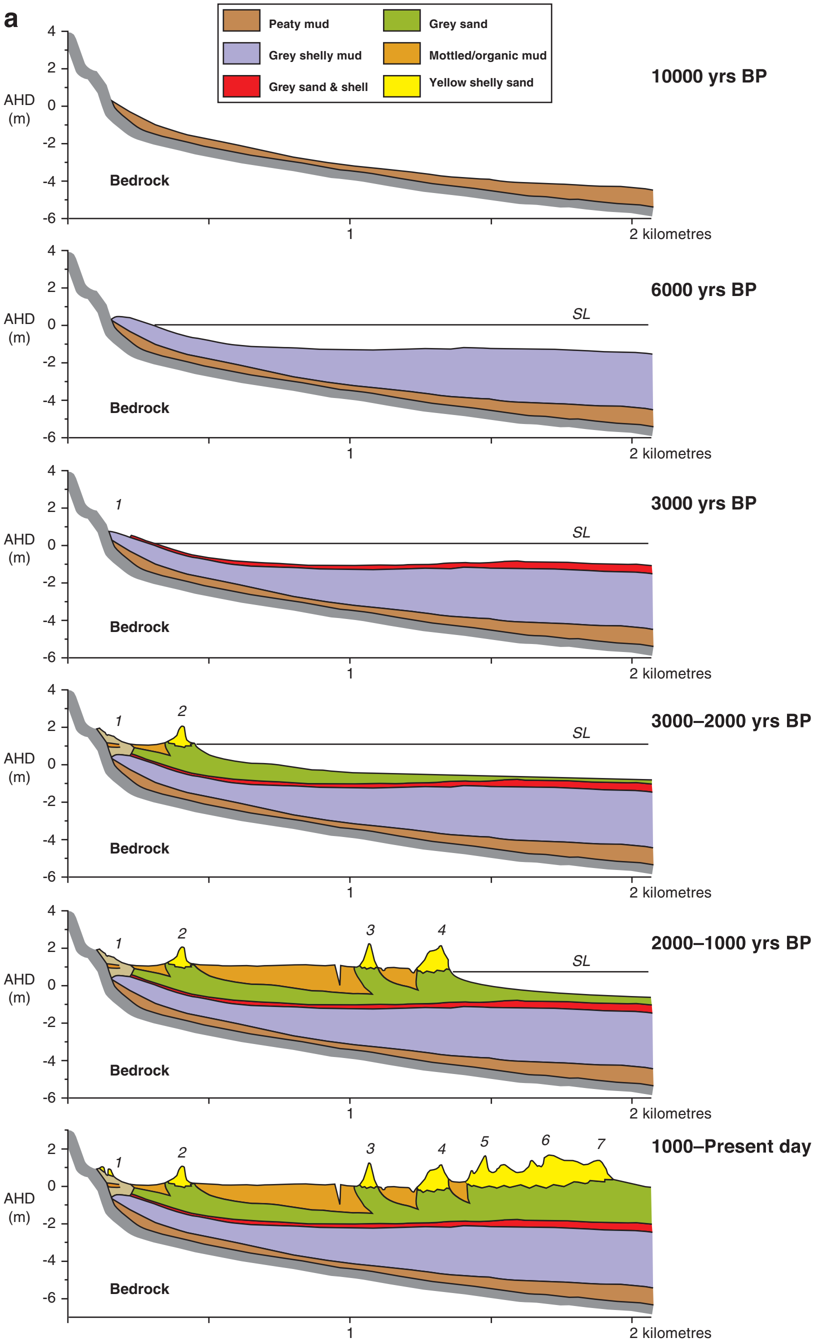

Fig. 34.6 (**a**) Holocene evolution of Cullendulla Creek chenier-beach ridge plain (NSW 531) (based on Lewis 1976), (**b**) aerial view of the outer Cullendulla Creek beach ridges 3 to 7, and (**c**) cheniers and mangrove-lined mud flats at Point Parker, southern Gulf of Carpentaria. (Photos: AD Short)

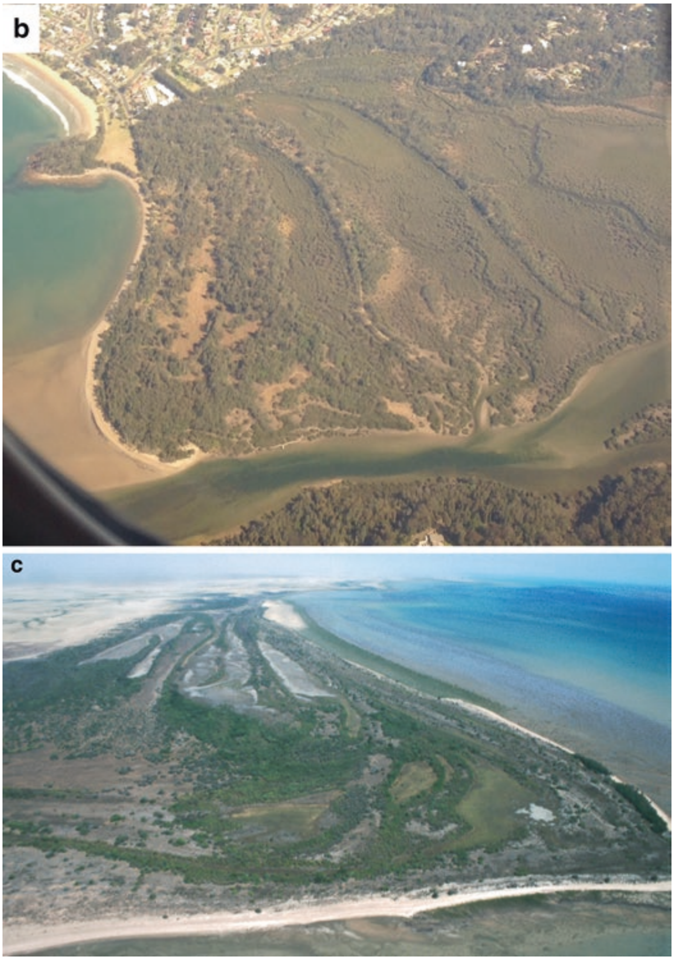

Fig. 34.6 (continued)

2.5 ka (Thom et al. 1986), and in the SA gulfs from 3 ka (Burne 1982; Short et al. 1989) and elsewhere in SA from 4 ka (Short et al. 1989). They also accumulate low volumes of sand (100s–1000s $m^3\ m^{-1}$) at very low rates of supply (0.1–1.0 $m^3\ m^{-1}\ year^{-1}$) (Table 34.4). Figure 34.6a shows how Cullendulla Creek aggraded between 10 and 3 ka before the first chenier was deposited at 3 ka, with outer beach ridges (Fig. 34.6b) following between 2 and 0 ka.

Regressive foredune ridge systems (D, Fig. 34.4) develop on usually moderate energy coasts with a positive sand supply. There are numerous such systems around the entire Australian coast. Those that have been dated includes Cungulla (Nott et al. 2015), Cowley Beach (Nott et al. 2009), Flinders Beach (Gontz et al. 2014), Fens (Thom et al. 1992), Stockton (Thom et al. 1992), Kurnell (Roy and Crawford 1979), Callala (Oliver and Woodroffe 2016), Bengello (Oliver et al. 2015), Pedro

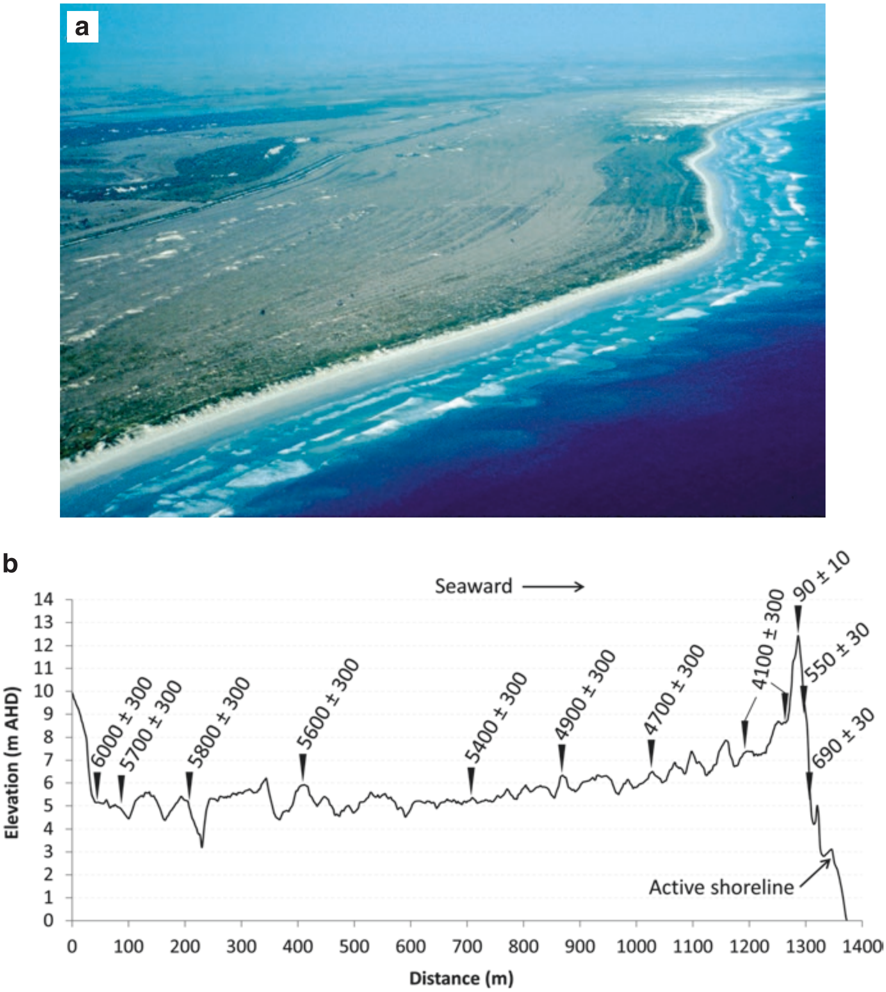

Fig. 34.7 (**a**) Part of the 5 km wide Rivoli Bay regressive barrier containing ~80 foredune ridges and (**b**) section across the Pedro foredune ridges showing their OSL dates (Source: Oliver et al. 2017b). (Photo: AD Short)

(Fig. 34.7b; Oliver et al. 2017b), Merimbula (Thom et al. 1978), Twofold Bay (Oliver et al. 2017a), Disaster Bay (Thom et al. 1981), Rivoli Bay (Fig. 37.7a; Oliver et al. in press), Guichen Bay (Murray-Wallace et al. 2002), Lefevre Peninsula (Harvey and Bowman 1987) and Rockingham (Searle et al. 1988). Their volumes usually range up to 50,000 m^3 m^{-1}, received at rates up to 8 m^3 m^{-1} $year^{-1}$.

Secondary dune transgression (E, Fig. 34.4) was first defined by Davies (1973) who identified two distinct stages in the evolution of some barriers. The occurrence of secondary dunes implies an initial period of shoreline regression, usually as foredune ridges, followed by a period of instability and dune transgression (Fig. 34.8) usually sourcing sand from reworking the outer foredune ridges while burying the

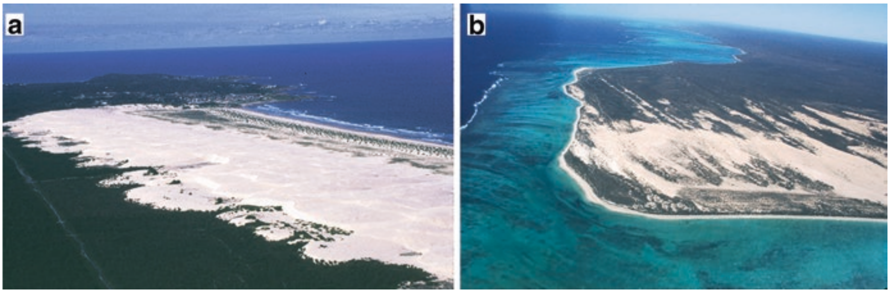

Fig. 34.8 (**a**) Transgressive dunes <500 years old advancing over 5000-year-old foredune ridges at Stockton Bight (NSW 239), the system dated by Thom et al. (1992), and (**b**) the Norwegian Bay (WA 1536) cuspate foreland showing active transgressive dunes blanketing a regressive foredune ridge plain with the exhumed ridges visible in the foreground and part of Ningaloo reef to the left. (Photos: AD Short)

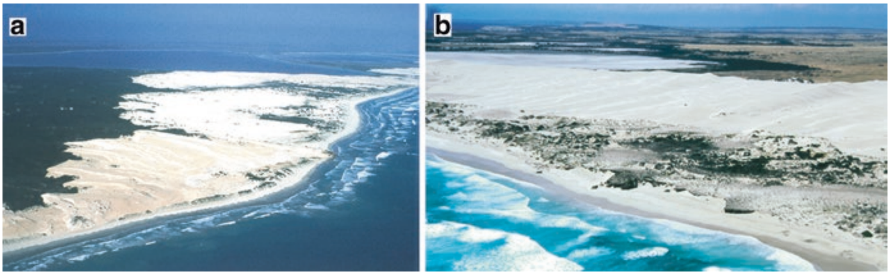

Fig. 34.9 Areas of primary dune transgression at the (**a**) massive Nine Mile Sandhill (SA 90) and (**b**) Picnic Beach (SA 984). (Photos: AD Short)

inner ridges. Secondary transgression to occur in areas of moderate to high wave energy, where the initial sand source has been exhausted, leading to shoreline stability which exposes the stable shoreline to ongoing wave attack resulting in shoreline recession which leads to dune instability. They also require strong onshore winds to initiate and maintain the dune transgression. Secondary dune systems are common around the coast but have only been dated in the Myall Lakes (Fig. 34.8b) and Stockton Bight (Fig. 34.8a; Thom et al. 1992), Kurnell (Sydney) (Roy and Crawford 1979) and Coorong (Short and Hesp 1984). As higher energy systems, they can have large volumes of sand supplied with volumes up to 100,000 $m^3 m^{-1}$, received at rates up to 15 $m^3 m^{-1} year^{-1}$.

Primary dune transgression and *clifftop dunes* (F and G, Fig. 34.4) are only found on the most exposed highest energy section of the coast exposed to high waves and strong onshore winds (Fig. 34.9). Primary dune transgression accompanied the PMT with the dunes moving inland ahead of the rising sea level. Primary dune transgression occurs commonly around much of the coast in exposed locations, particularly along parts of the east QLD, NSW, east VIC, west TAS, much of SA and the south and central west of WA. Only a few of these systems have been dated, with most dating early to mid-Holocene. The systems and their earliest dates include Cape St Lambert (5 ka) (Lees et al. 1992), Arnhem Land (9.5–6.8 ka) and Groote Eylandt (5.7 ka) (Lees 2006), Cape Flattery (8–7 ka) (Pye and Switsur 1981; Pye 1982), Moreton Island (9.3–7.5 ka) (Lees 2006; Brooke et al. 2015), Seal Rocks (7 ka) (Thom et al. 1992), Canunda (8–5.5 ka) (Ohmori et al. 1987) and the Nullarbor cliffs (7.6 ka) (Table 29.7). These systems have potentially very large volumes and the highest rates of sand supply. As higher energy systems, they can have volumes up to 100,000–200,000 $m^3 m^{-1}$, received at rates up to 30 $m^3 m^{-1} year^{-1}$.

Some of the highest volume and most extensive dunes are associated with clifftop dunes, all of which are primary dunes (Fig. 34.10). Where these have been dated, they tend to be the oldest dunes (early to mid-Holocene), in part because they are in a location to be well preserved and not inundated by sea level nor eroded and/or reworked like dunes backing a receding sandy shoreline. Only a few areas of clifftop dunes have been dated. These include Kurnell (10 ka) (Roy and Crawford 1979; Hesp 1993), Marley (9.7–5.2 ka) (Pye and Bowman 1984) and SA Nullarbor (7.6 ka) (Table 29.7). Their volumes and rates are comparable to the above primary dunes.

As Fig. 34.4 indicates, there are both spatial and temporal controls on barrier form and evolution. The spatial controls are, as discussed above, primarily related to the level of wave energy, whereas the temporal controls are more related to sediment supply.

Other temporal controls on barrier formation relate to temporal changes in wave energy. As discussed above for beaches in areas of fringing and barrier coral reefs and carbonate banks, there was often a mid-Holocene high energy wave window that was closed as both the reefs and banks aggraded to sea level and thereby attenuated and lowered breaker wave height in the process. In some areas this process coupled with a higher mid-Holocene sea level leads to the formation of primary dune transgression during the high energy period, followed by barrier regression during the ensuring lower waves and lower sea level, as illustrated in Fig. 34.11.

A final process to modify breaker wave height is for the shoreline to prograde seawards into more exposed locations which occurs when usually embayed beaches prograde seawards into a more exposed higher energy position as documented by

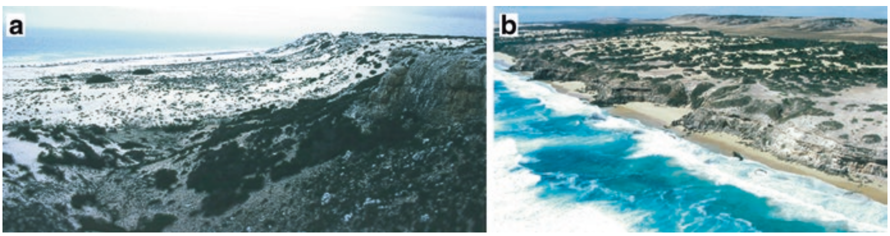

Fig. 34.10 (**a**) The Merdayerrah Sandpatch (SA 1454) is one of the few areas of active sand ramps and clifftop dunes, and (b) clifftop dunes on 30 m high calcarenite cliffs at the northern end of Convention Beach, with remnant beaches at their base (SA 979-982). (Photos: AD Short)

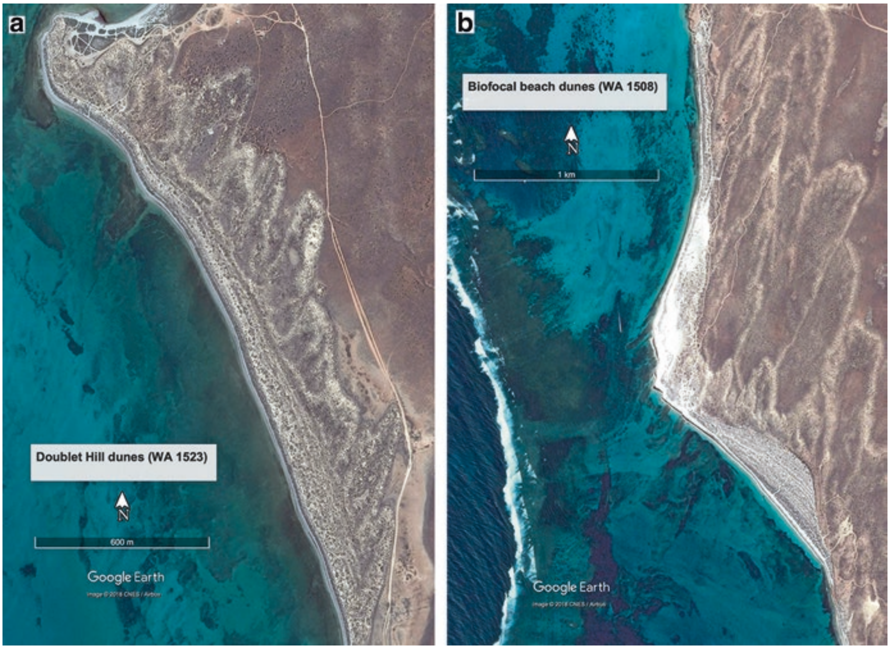

Fig. 34.11 (**a**) The Doublet Hill dunes (WA 1523) have inner north-trending parabolics and outer regressive foredune ridges; and (**b**) the Bifocal Beach (WA 1508) foredune ridge plain is backed by stable longwalled parabolics extending up to 2.5 km to the north. Both locations are located in lee of Ningaloo reef which has lowered breaker wave height as the reef aggraded to sea level and the lagoon infilled with sediments. (Source: Google Earth)

Oliver et al. (2017b) for Pedro Beach (NSW 567). In contrast when beaches recede, they may retreat into a lower energy location, as occurs when beaches retreat behind rock or calcarenite reefs which then protect the backing shoreline as illustrated in Fig. 30.12a and c and Fig. 34.12.

34.5 Regional Barrier Systems and Sediment Supply

Table 34.4 listed the 23 Australian coastal regions and their gross barrier dimensions and volumes. Appendix 34.2 provides the same data for 97 of the PCs, with the chapters providing addition data on the PC and SC barriers systems. While the regional data represents the aggradation of numerous individual barrier systems, they do provide a first approximation of the regional variation in barrier area, stability, volume and rate of supply. The most meaningful figures are the volume per meter of beach and the sediment supply, as these are comparable between individual barriers, SCs, PCs and regions. The smallest barrier volumes (<2000 M m^3,

Fig. 34.12 At least two episodes of massive now very stable transgressive dunes behind Sandfly beach, King Island (KI 53), were probably active when the shoreline was further west and exposed to higher waves, which now break on rock reefs, with lower energy beaches to their lee. (Source: Google Earth)

<2000 $m^3\ m^{-1}$) occur along the Kimberley, western NT and north Arnhem Land coasts (Table 34.4). Each is a low energy lee coasts with meso- to mega-tides and low energy TM and TD beach systems dominated by B + SF and B + TSF (Table 34.3). The small usually low (<5 m) regressive barrier systems are typically up to a few 100 m wide and composed of a mix of ~50% carbonate material derived from fringing coral reefs and local carbonate production with ~50% terrigenous quartz. While each region has a number of rivers supplying abundant sediment to the coast, the low waves are unable to transport large quantities shorewards to supply the barriers.

The next area of low barrier volumes are the low wave energy SA gulfs (2769 M m^3, 4430 $m^3\ m^{-1}$) and leeward eastern Tasmania (911 M m^3, 2635 $m^3\ m^{-1}$) (Table 34.4). The gulfs have low waves and meso-tides and a mix of low energy WD R and LTT, together with TD B + SF (Table 34.3), and while there is abundant carbonate sand on the SA tidal flats, the waves are only able to transport very small amount to build beaches and beach-foredune ridges <10 m high and up to several hundred meters wide. In east Tasmania waves are moderate and beaches a mix of similar low energy WD and TD. The almost total absence of dune transgression owing to predominately offshore winds precludes the development of larger barriers. This region also includes the extensive very sheltered southeast bays with TD beaches and very limited beach and barrier development.

A number of regions have moderate-sized barriers (10,000–20,000 m^3 m^{-1}) reaching elevation of 5–20 m and width from a few hundred meters to several kilometres. In the northern province, these include the northwest of WA (9901 M m^3, 10,072 m^3 m^{-1}), the entire Gulf of Carpentaria (4000–1000 M m^3, 10,000–14,000 m^3 m^{-1}) and eastern Cape York Peninsula (18,473 M m^3, 16,435 m^3 m^{-1}) (Table 34.4), all low to at best moderate energy coasts with predominately TD beaches (B + RSF and B + SF, Table 34.3) with eastern Cape York Peninsula also having substantial TM R + LTT and the largest volumes. In the southern province, they include the leeward southern NSW (6825 M m^3, 14,429 m^3 m^{-1}), Gippsland (4436 M m^3, 12,895 m^3 m^{-1}) and northern TAS (3426 M m^3, 11,053 m^3 m^{-1}) each a moderate to occasionally high energy with a range of low to moderate energy WD beaches together with TM and TD in northern TAS, but all are predominately leeward coasts with dune transgression limited to where beaches are orientated into the onshore southwest through westerly winds as on south-facing NSW barriers, Cape Howe in Gippsland and parts of northern TAS western coast.

The larger barrier systems with between 20,000 and 35,000 m^3 m^{-1} contain one northern province region, namely, central QLD (15,342 M m^3, 22,763 m^3 m^{-1}), which is exposed to strong trade winds which provide low to moderate waves and a combination of TM and TD beaches which have supplied enough sand for the trades to develop a number of massive transgressive dune systems. The other larger systems are located around the southern coast and include the central east (35,278 M m^3, 32,544 m^3 m^{-1}), W TAS (6585 M m^3, 28,887 m3 m^{-1}), central-western VIC (7780 M m^3, 29,582 m^3 m^{-1}), the Nullarbor (16,705 M m^3, 31,941 m^3 m^{-1}) and the central west of WA (17,513 M m^3, 24,701 m^3 m^{-1}) (Table 34.4). These are all exposed moderate to high energy coasts and dominated low to moderate energy WD beaches (Table 34.3) but include extensive low energy sections of shore in the case of the Nullarbor and central west WA which also contains the TD Shark Bay. They each have a combination of extensive transgressive dune systems as well as regressive barriers and smaller systems. They range considerably in height (averaging 10–30 m) and in width from a few hundred up to several kilometres, with some extending tens of kilometres inland.

Finally, the four largest regions with between 35,000 and 50,000 m^3 m^{-1} are southern SA (21,141 M m^3, 44,136 m^3 m^{-1}), the western Eyre Peninsula (20,245 M m^3, 35,643 m^3 m^{-1}) and southern (41,352 M m^3, 48,140 m^3 m^{-1}) and southwest (31,373 M m^3, 44,691 m^3 m^{-1}) WA (Table 34.4). All are exposed to high waves and strong onshore winds, feed by an abundance of shelf carbonate across the south and west. Their beach systems range through the WD spectrum with the largest barriers associated with the southern WA region which also has the highest energy beach systems in Australia (Table 34.3) and a series of longer beaches aligned to the southwest winds and waves. Their barrier systems are dominated by massive and extensive transgressive dune systems and in places extensive clifftop dunes. The dunes range in average height from 15 and 40 m and extend on average several hundred meters to a few kilometres inland. Not surprisingly, all the largest barrier systems are located in the southern province an area of high waves, strong west through south winds and in places abundant shelf sediment.

The average rate of sand supply during the past 6000 years is provided purely as indicator assuming a constant and continuous supply required to build the volumes. However, as discussed throughout the book, the rate of supply is neither uniform nor continuous, with some of higher energy systems in particular exhausting their supply by the mid-Holocene, while the lower energy systems are expected to have a more continuous, albeit low, rate of supply. Then rate does however indicate the average volume required to supply the various barrier systems over a period of 6000 years.

The above discussion on barrier location, size and volumes is summarised in Fig. 34.13a–e which illustrates the data provided in Table 34.4. Starting at Fig. 34.13a, the most extensive barrier systems based on area (>100,000 ha) are generally found in regions exposed to strong onshore winds including the trade wind exposed east QLD coast (regions 8–10) peaking in the high energy southeast QLD sand islands (region 10). The extensive fluvial-supplied regressive western Cape York barriers (7) are also a comparable size. In the southern province, the largest barriers are all exposed to high waves and strong onshore south through west winds between southern SA (region 17) and the southwest of WA (22) but excluding the sheltered SA gulfs (18). Barrier instability by area (Fig. 34.13b) is reasonably related to the above large southern barrier areas, with the northern more huimd and better vegated barriers generally having more stable systems. By percentage (Fig. 34.13c), the most unstable systems are along the Gippsland region (12), largely due to the Cape Howe active dune field, and western Eyre Peninsula (19) which has extensive area of unstable dunes.

The true size of a barrier system is however its volume, and again east QLD (8–10), with region 10 including the southeast QLD sand islands, and exposed southern regions (17, 19–23) have the highest volumes both in total and per meter volumes (>15,000 $m^3\ m^{-1}$) (Fig. 34.13d and e). The highest per meter volumes occur along the high wave and wind energy southern WA (21, ~48,000 $m^3\ m^{-1}$) and the entire southern coast between the Cape Catastrophe and Cape Leeuwin (19–23, 25,000–45,000 $m^3\ m^{-1}$). Much of northern Australia (2–7) and the moderate energy and generally leeward southeast coast (11–16) has low per meter volumes. However, as noted in Sect.1.6.4, the barrier volumes are conservative and should only be used as a guide to the relative variation in barrier volumes and as a general guide to absolute volumes.

In summary, the barrier size, volume and rate of supply show a strong correlation with beach type/state and through that level of wave energy as concluded by Short and Hesp (1982). In addition, orientation into strong onshore winds is required to transfer large volumes of the sand to substantial transgressive dune systems which form the largest barriers. Likewise, the barrier type is strongly correlated with beach type and wave energy, with low energy chenier beach ridges fronted by low energy tidal mud and sand flats, through to the massive transgressive and clifftop dunes exposed to high waves, high energy WD beaches and strong winds, as illustrated in Fig. 34.4.

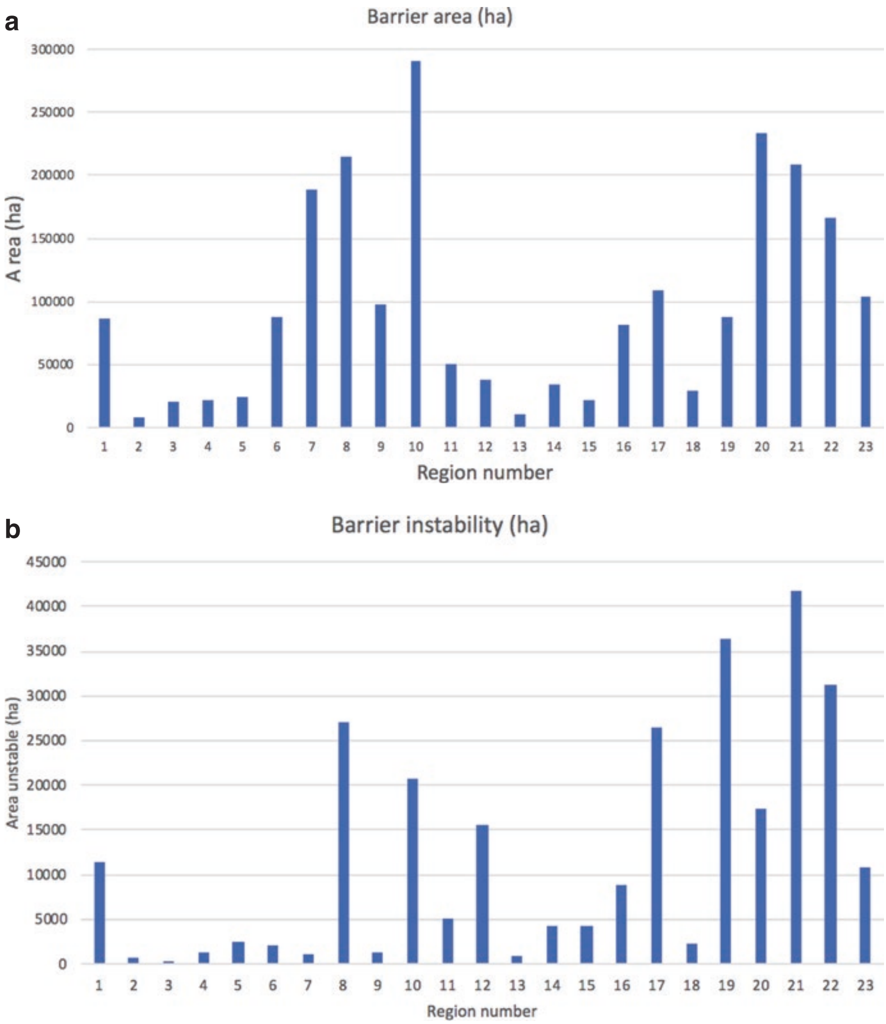

Fig. 34.13 Regional barrier dimensions: (**a**) total area, (**b**) unstable area, (**c**) % unstable, (**d**) total volume and (**e**) volume per meter. See Table 34.5 for data and regional names

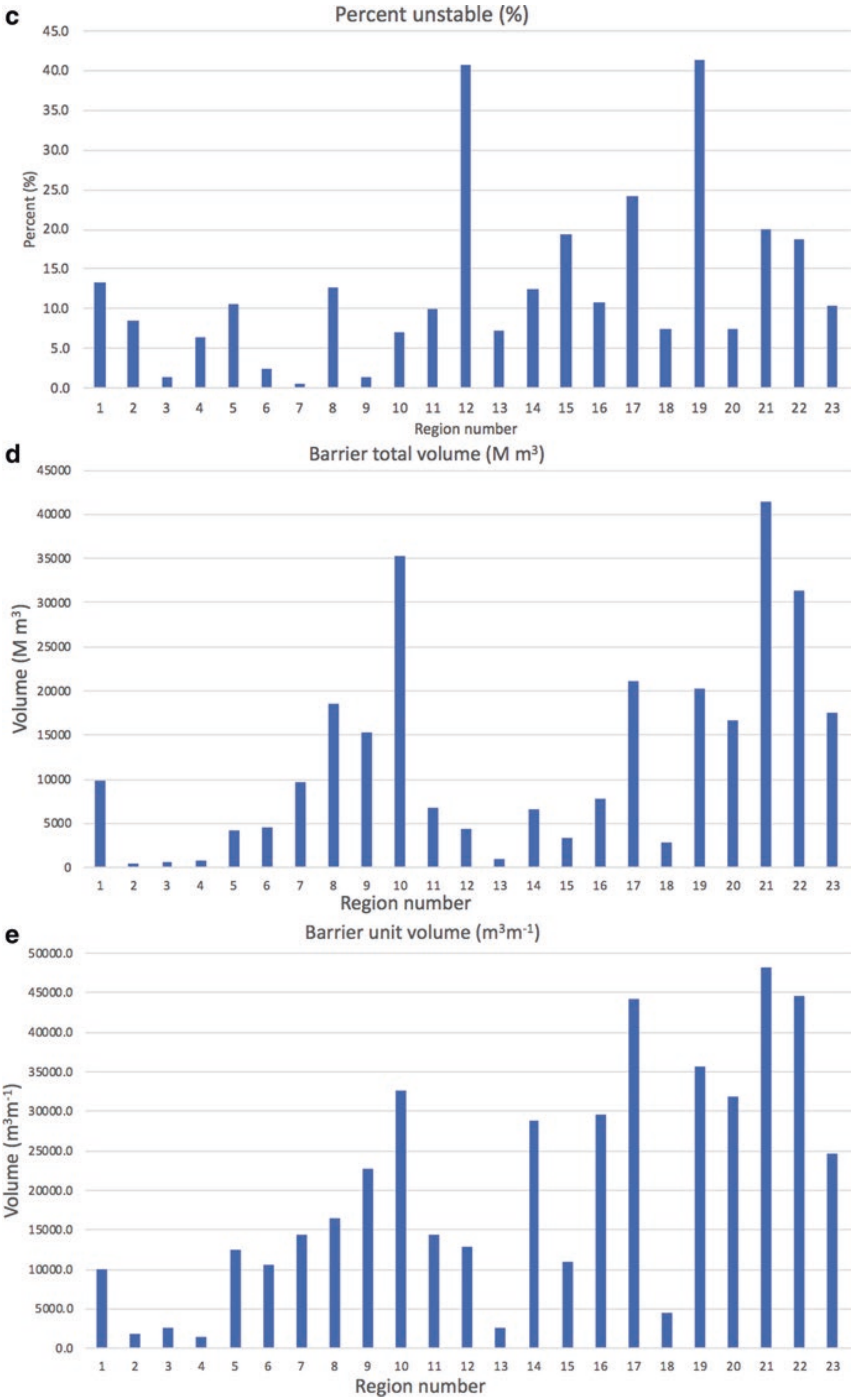

Fig. 34.13 (continued)

34.6 Regional Sediment Characteristics

Sediments around the Australian coast are predominately reasonably well-sorted fine to medium sand composed of quartz and carbonate. There are however significant regional and local variations in its size, texture and composition. At a continental level, Fig. 1.10 shows the dominance of quartz sand in the northeast, east and southwest, with carbonate sand dominating the south, west and much of the north. The sources and nature of the sand have been described in Sect. 1.6.2. Each regional chapter provides a plot of longshore trends in sand size and percent carbonate, and some of these have been selected below to examine large-scale regional trends in sediment texture and transport.

The longshore variation in beach sand characteristics for the Kimberley, north Arnhem Land and eastern Cape York regions is plotted in Fig. 34.14. The 3500 km long very low energy, deeply embayed Kimberley beaches show no trends (Fig. 34.14a), but rather a considerable spatial variation in both size (fine to very coarse) and carbonate 0–100%. This is indicative of numerous individual sediment sources that are trapped and contained in hundreds of separate TCs, each with its own sediment budget and with very limited exchange between any of the TCs and SCs. The 2000 km long northern Arnhem Land is similar with considerable variation in carbonate, though size tends to lie between fine to coarse (Fig. 34.14b). Finally, 2400 km long eastern Cape York Peninsula has a dominance of low carbonate quartz-rich beaches with pockets of high carbonate (Fig. 34.14c). Size however ranges from fine to coarse and carbonate from 0 to 100%. The cape coast does have sections of northerly longshore transport as indicated by the trend in quartz-rich sand; however local supply of coarse material masked any trends in uniform size. These three plots each show heterogeneous sediment characteristics indicative to variable sources, closed compartments and limited sediment transport and exchange.

The variation in beach sand along the 2750 km long central east, southern NSW and Gippsland regions, between Sandy Cape on Fraser Island and the southern tip of the continent at South Point, is shown in Fig. 34.15. This coast is part of the >2000 km long transport system that probably begins in Gippsland and extends to Fraser Island and beyond (Fig. 18.2, Veevers 2015) and has supplied the near pure fine quartz sand to the southeast QLD sand islands. Along the northern central east region, the sand is very uniform fine-medium with low carbonate, apart from two local areas of coarse carbonate enrichment (around 5800 and 6300 km) which are associated with rocky sections of coast. This near continuous uniform population is indicative of a common source and longshore sand transport. This trend continues into southern NSW with a dominance of fine to medium quartz-rich sand, where it is also interrupted by longer coarser carbonate-enriched rockier sections of coast (~7000 and 7400 km). The greater scatter in this region is also indicative of the limited longshore transport along this more deeply embayed coast that contains many closed SC and TC boundaries. Finally, the trend continues into Gippsland with almost exclusively quartz-rich sand, with size initially fine to medium but becoming more variable southwards along Ninety Mile Beach and in eastern

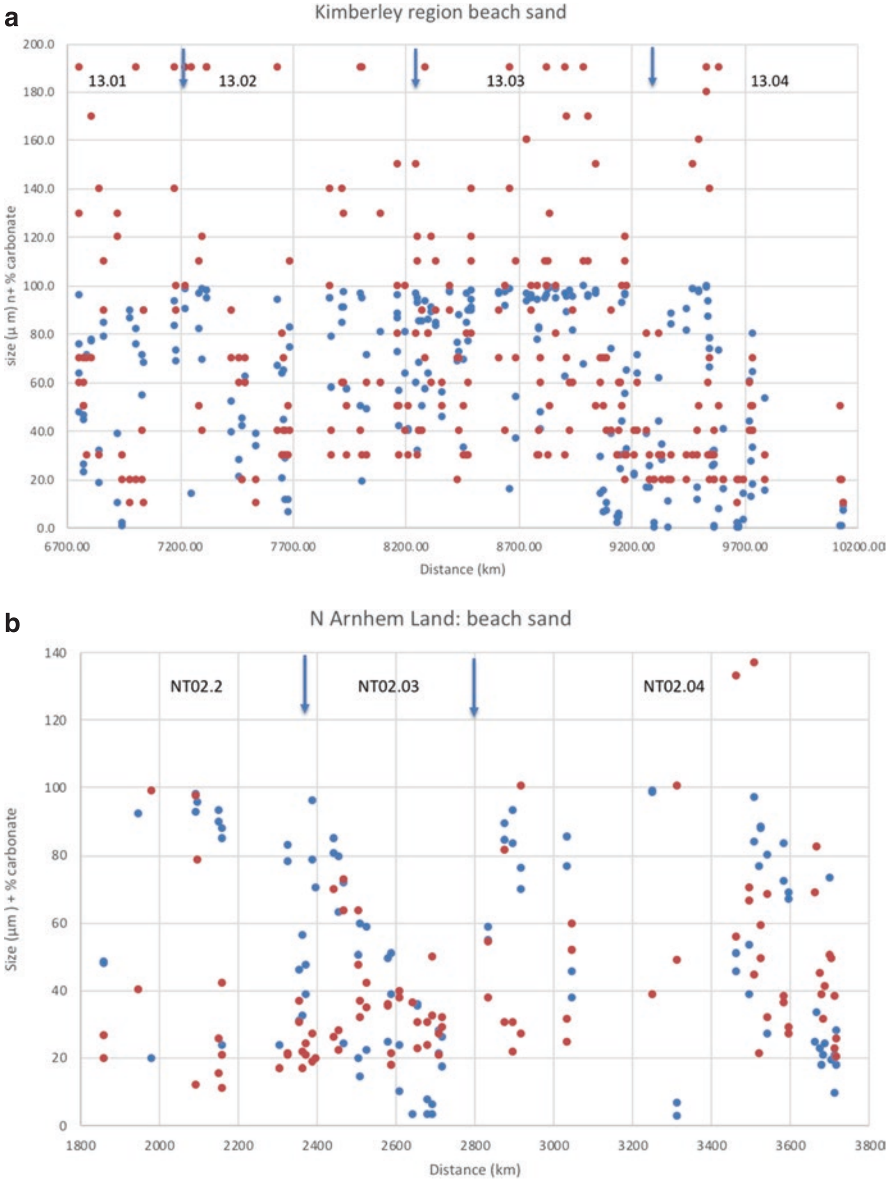

Fig. 34.14 A composite of Figs. 6.2, 8.2a and 14.2 showing the longshore variation in sand size (red, µm) and percent carbonate (blue) for (**a**) the Kimberley, (**b**) northern Arnhem Land and (**c**) eastern Cape York regions. Note distance scale varies between plots. Arrows indicate PC boundaries

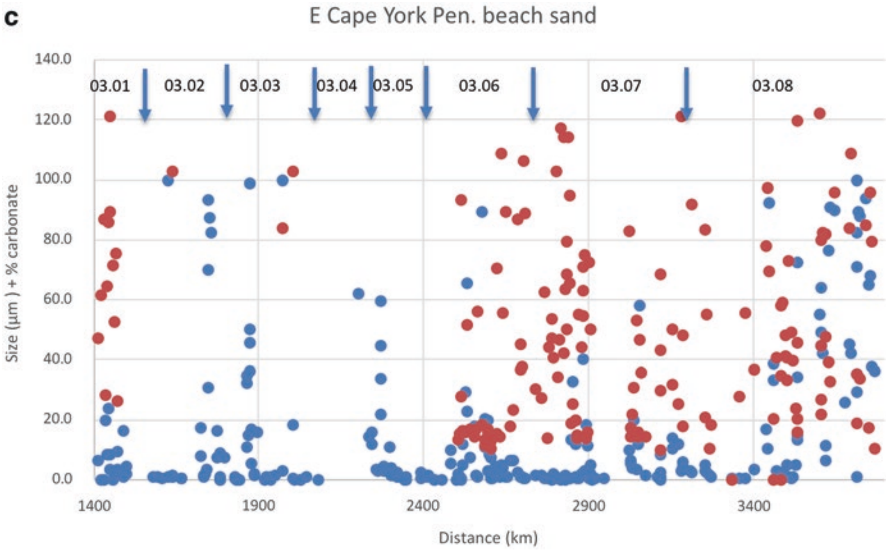

Fig. 34.14 (continued)

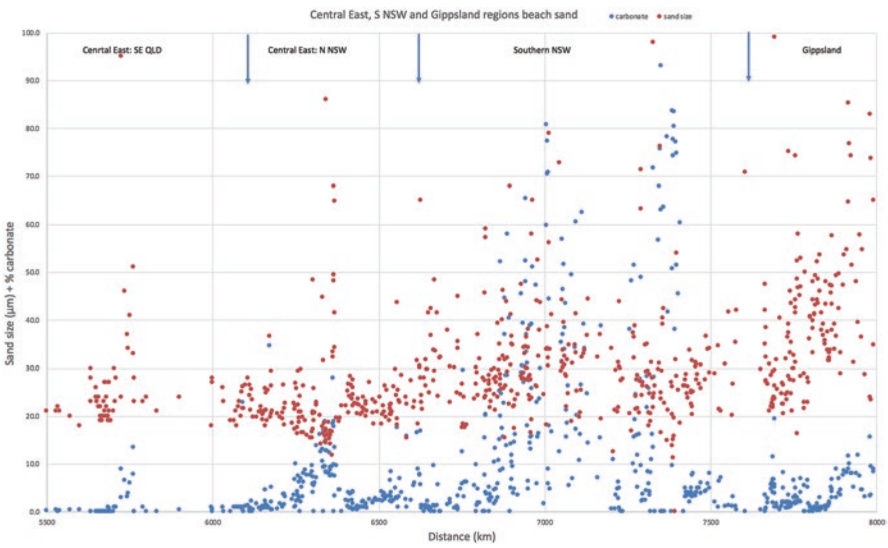

Fig. 34.15 A composite of Figs. 18.3, 19.2 and 20.2 showing the longshore variation in sand size (red, µm) and percent carbonate (blue) for the central east, southern NSW and Gippsland region. Distance is from NT/QLD border

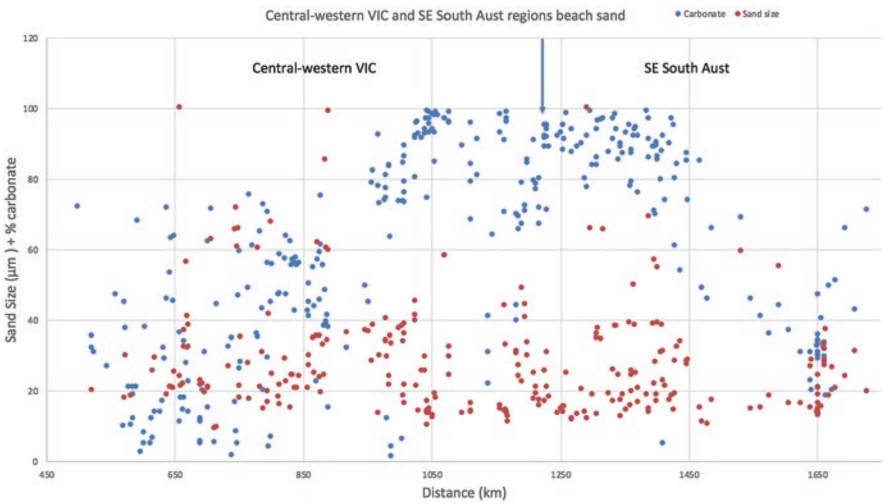

Fig. 34.16 A composite of Figs. 25.3 and 26.2 showing the longshore variation in sand size (red, µm) and percent carbonate (blue) for the central Victoria and southern SA region excluding southern Kangaroo Island. Distance is from NSW/VIC border

Wilsons Promontory. The Ninety Mile coarsening is likely to be associated with the exposure and inclusion of coarser former tidal inlet sand (Thom et al. 1986) coupled with downdrift fining associated with the northerly sand transport. The overall trend is one however of a homogeneous sediment population consisting of fine to medium quartz sand derived from the Eastern Highlands and transport northwards by the southerly waves, with greater physical interruption to the transport and injection of carbonate material occurring during highstands, as at present. As seen in the relevant chapters, longshore transport rates range up to 100,000 m^3 year^{-1} along the Ninety Mile Beach, severely interrupted the length of the southern NSW coast by its rocky, embayed nature and then increase from ~100,000 to a maximum 500,000 m^3 year^{-1} along the central east coast, terminating at Hummock Hill Island on the mainland and offshore at Fraser Island.

The beach sand characteristics of the central-western VIC and the adjoining southern SA, a continuous 1582 km section of mainland coast, are shown in Fig. 34.16. What is interesting is that while the size remains reasonably uniform between fine and medium, the percent carbonate increases westwards across Victoria (Table 25.1) from 28% in PC:VIC03.01 to 49% in PC:VIC03.02 to 78% in the western PC:VIC03.03, with the western coast supplied from the carbonate-rich Otway shelf. The high carbonate continues into SA, until Cape Jaffa (1450 km), after which the percent carbonate begins to decrease along the Coorong beach towards the Murray Mouth at 1560 km owing to the input of Murray River-supplied terrigenous quartz sand. West of Murray Mouth, the carbonate again increases

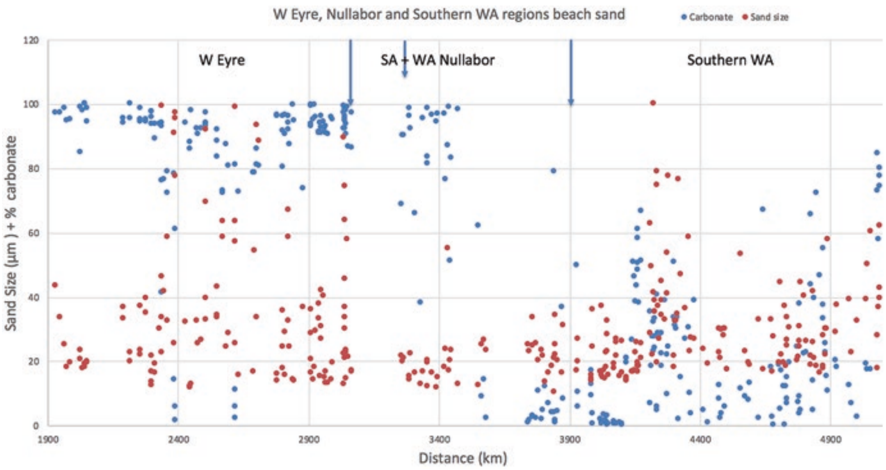

Fig. 34.17 A composite of Figs. 22.2, 29.3 and 30.2 showing the longshore variation in sand size (red, μm) and percent carbonate (blue) for the western Eyre Peninsula, Nullarbor and southern WA regions. Small arropw indicates SA/WA border. Distance is from VIC/SA border

(1560–1740 km). Overall it shows a dominance of shelf carbonate in PCs VIC03.02 and SA01.01, with quartz increasing to the east in VIC and towards Murray Mouth in SA.

The Great Australian Bight contains a continuous 1987 km long section of coast between Cape Catastrophe and Cape Pasley all contained in the western Eyre Peninsula and Nullarbor regions. The nature of the beach sand along this coast, together with the adjoining 1180 km long southern WA region, is shown in Fig. 34.17, in all 3167 km of coast. This is a region dominated by shelf, and in place seagrass supplied carbonate detritus. Carbonate sediment comprised 87% of the western Eyre beaches and ~90% of the eastern Nullarbor coast (1900 km–3480 km). To the west the coast becomes increasingly supplied with terrigenous derived quartz shelf sand (3700–5300 km) with carbonate down to 20%. Starting in the east, the beach sand is predominately carbonate-rich (>80%) and ranges in size from fine to medium, with most of the coarser Eyre Peninsula sections associated with it sheltered western bays. The trend continues along the Nullarbor coast until Twilight Cove (3580 km) where quartz sand derived from the Precambrian granite hinterland to the west has been transported more than 300 km to dominate the beaches west from Twilight Cove. Not noticeable at this scale is an interesting decrease in sand size down Bilbunya beach (3730–3850 km) from medium (0.33 mm) in the north to very fine (0.1 mm) in the south (Table 29.11). The quartz-rich southern WA region can be attributed to its granite hinterland and more humid climate with 36 streams and small rivers (Table 30.1) delivering sand to the shelf at low sea level, together with hundreds of granite islands of the Recherche Archipelago supplying regolith to the shelf sediment. Again the trend reflects a dominance of shelf and seagrass-supplied carbonate, diluted to the west by terrigenous shelf quartz supplied from the granite.

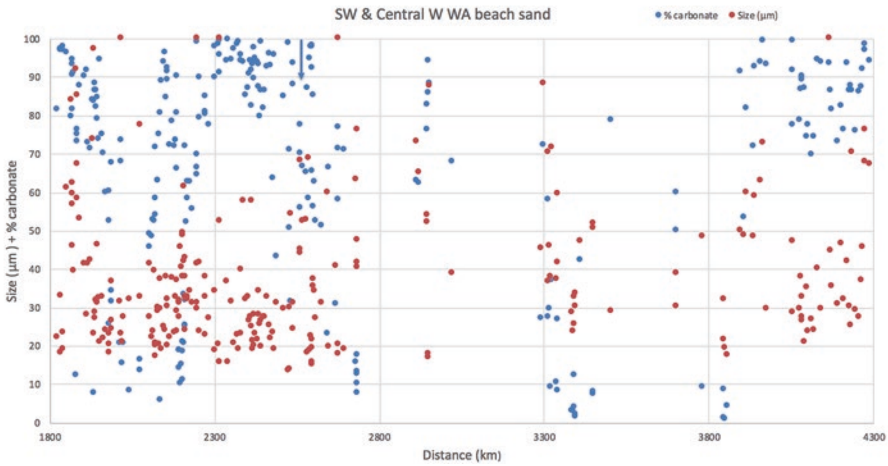

Fig. 34.18 A composite of Figs. 30.2 and 32.1 showing the longshore variation in sand size (red, µm) and percent carbonate (blue) for the southern WA and southwest WA regions. Distance is from SA/WA border

The southwest division contains the north-trending southwest and central west WA regions, with a combined length of 2770 km extending from Cape Leeuwin to Exmouth Gulf. The nature of their beach sand is plotted in Fig. 34.18. These two adjoining regions face west into the prevailing moderate to high southwest swell which is attenuated along much of the coast by the inshore calcarenite reefs. In the southwest the sand is carbonate-rich but highly variable in size along the Leeuwin-Naturaliste coast and then becomes predominately fine to medium north from Cape Naturaliste (1930 km) with generally high (>80%) through variable carbonate. The carbonate is supplied from the carbonate-rich shelf sediment (Collins 1988) and in sheltered areas consists of seagrass-supplied carbonate detritus. Quartz only predominates in patches, in Geographe Bay (PC:WA06.01), the Perth coast (~2200 km) perhaps derived from the Swan River, around the Murchison River mouth (2730 km), in parts of Shark Bay (3300–3500 km) where it may be sourced from eroded quartz desert dunes and the mouth of the Gascoyne River (3850 km). There are areas of significant northerly longshore transport particularly in Geographe Bay (PC:WA06.01–02) and north from the Gascoyne mouth, with rates on the order of 100,000 m^3 $year^{-1}$.

This very broad-scale approach to some of Australia's trends in beach sand characteristics indicates there are both regional trends in sediment source and texture. The humid east and southwest coast is dominated by fine to medium river-supplied quartz, deposited on the shelf at lower sea levels and reworked onshore during and subsequent to the PMT. Most of the great southern coast and WA's southwest and central west has been supplied by shelf carbonate and inshore seagrass detritus. All these southern areas are exposed to moderate to high waves that can winnow, sort and transport the material onshore and where suitable longshore at rates reaching 500,000 m^3 $year^{-1}$ in northern NSW and southeast QLD. In contrast across northern Australia, the sediment texture is far more variable. This is a product of a number of factors including numerous closed TCs (e.g. Kimberley), variable local terrigenous and carbonate sources (e.g. eastern Cape York Peninsula) and the overall low level of wave energy to sort and transport the sand both onshore and longshore.

Finally, while on the subject of beach sand and as indicated in Fig. 16.10, beach sand while usually yellow to whitish in colour can range from black to white and pink to green. A question often asked is which is the whitest beach in Australia, with three candidates usually making the claim: Whitehaven Beach on Whitsunday Islands (QLD), Hyams Beach in NSW and Lucky Bay in WA (Fig. 34.19). All three are composed of white quartz which has had most impurities and iron staining leached from the grains. Table 34.5 answers this question by providing the results of optical quantification of the whiteness and amount of other colours undertaken by Prof Enzo Pranzini at the University of Florence. Lucky Bay is both the lightest and whitest, with the minimum amount of green/red and blue/yellow, followed by Whitehaven and then Hyams.

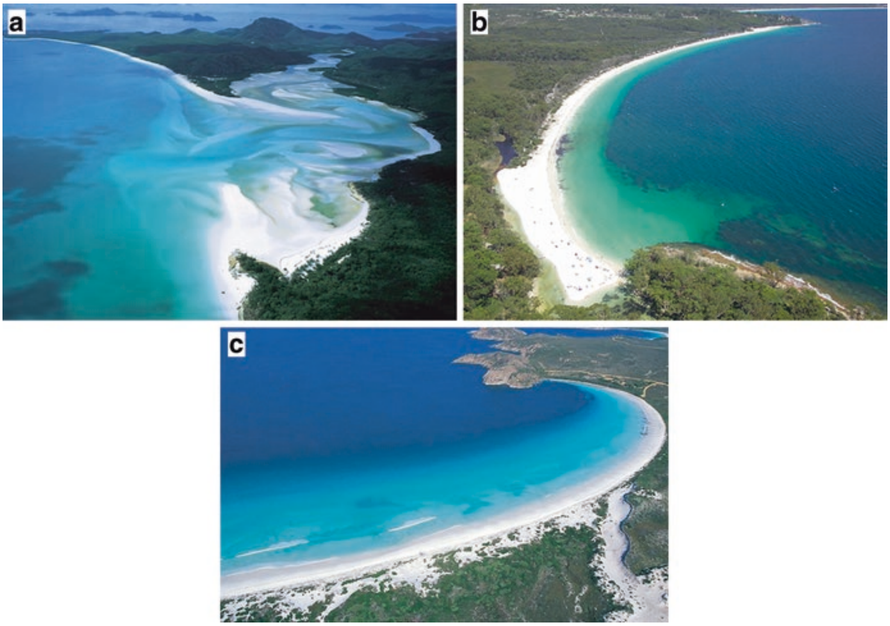

Fig. 34.19 Three claimants to Australia's whitest beach sand: (**a**) Whitehaven Beach QLD (WHIT 1), (**b**) Hyams Beach (NSW 433) and Lucky Bay (WA 132), with Lucky the whitest. (Photo sources: Tourism Queensland, Jervis Bay Tourism, Tourism Western Australia)

Table 34.5 Optical qualities of Lucky Bay, Whitehaven and Hyams Beach sand

	Lightness	Green/red	Blue/yellow
Lucky Bay	81.84	0.64	6.92
Whitehaven	80.83	1.54	10.62
Hyams	80.14	1.34	7.14

34.7 Coastal Impacts of Climate Change

This book is largely about the evolution, nature and present status of the Australian coast, with reference in each chapter to the potential impacts of climate change. This section reviews what is known about the likely impacts of climate change around the Australian coast.

34.7.1 Sea Level

Sea level is rising (SLR) globally (Blunden et al. 2018) and around the Australian coast (Watson 2011). McInnes et al. (2016) reviewed the most recent sea-level projections from the Intergovernmental Panel on Climate Change (IPCC) incorporating contributions from oceans, glaciers, ice sheets, land water and large-scale vertical land motion. Mean global SLR projections for 2090 are 0.47 mm year^{-1} under a mid-range emissions scenario (RCP 4.5) and 0.62 mm year^{-1} under a business-as-usual emissions scenario (RCP 8.5), which equates to a rise of between 6.3 and 8.2 mm year^{-1}, both significantly higher than the rise over the past century which averaged 1.7 mm year^{-1}. However, owing to local factors including neotectonism and land subsidence, the rate varies around the globe and the Australian coast. Between 1970 and 2000, sea level rose 2.5 mm year^{-1} at Fremantle, 2.2 mm year^{-1} at Fort Denison (Sydney) and 4.4 mm year^{-1} at Newcastle (Watson 2011), indicating both the regional variation and more recent increase in the rate of rise. Around Australia the rise has been greatest along the central west, northern and southeast coasts and least in the northeast and across the Bight (SOC 2016). What this means is that sea level on average has risen about 20 cm in the past century and that it is critical that regional tide gauges be used to determine the local/regional changes in sea level, rather than relying on global or national figures. To this end Australia maintains 8 super monitoring sites and 180 tide gauges around the coast with 22 stations part of the Global Sea Level Observing System (GLOSS) (Holmes 1989).

At the coast the rise will have a number of potential physical and ecological impacts. Physical impacts include shoreline retreat (Roy and Thom 1987; Gordon 1988), inundation of low gradient shorelines (e.g. tidal flats and wetlands) (Hanslow et al. 2018), increase in estuarine tidal prism, increased salinisation of coastal wetlands, and increase in the elevation of extreme water levels (DCC 2009). Zheng et al. (2013) however found complex spatial and temporal interactions between tide, surge, wave setup and riverine flooding make assessment of extreme water levels and inundation within estuaries highly complex and in need of further research.

Ecological impacts include landward/upward migration of tide-dependent ecosystems (seagrass, mangroves, salt marsh), upward growth of coral reefs and aggradation of carbonate banks. These responses will however occur at vastly different time scales, with the physical impacts occurring rapidly, while ecological impacts like carbonate banks lagging by centuries to a millennium. While physical impacts on the open coast such as extreme storm and erosion events (Harley et al. 2017) attract most media attention, as Short (1988b) concluded, the areas of greatest risk to inundation are the low gradient coastal plains of northern Australia and in estuarine wetlands right around the coast, with lesser impact on steeper gradient open coast beaches and rocky shores. Likewise, McInnes et al. (2016) also found that within estuaries the number and value of assets that may be impacted by oceanic extremes are at least an order of magnitude higher than those on the open coast. Hanslow et al. (2018) used estuarine morphology and tide gauge data to examine how the different types of estuaries in southeast Australia will respond to sea-level rise. Based on mapping of 184 estuaries and rivers along the NSW coast and applying 0.5, 1.0 and 1.5 m sea-level rise scenarios, they found that there was considerable exposure of property around tidal lagoon systems where the reduced tide range had allowed development to close to present sea level and along larger rivers which have low-lying floodplains exposed to inundation. In WA Semeniuk (2013) used the wide range of wetlands along WA's tropical to temperate coast to examine their potential response to climate change. He concluded that 'Given that climate changes will involve changes in inter-related phenomena, such as air temperatures, evaporation, rainfall patterns, freshwater influx, wind regimes, storm activity, and derivative responses as well as derivative changes in sediment supply, maintenance of coastal forms, coastal groundwater, and biota, the Western Australian model suggests that the response of coastal wetlands to climate change in their landforms, habitats, and biota will not be simple, but will be dominantly related to latitude, the setting of style of coastal habitats, oceanography, and rainfall'. This all implies estuaries/wetlands are very complex systems which will require site-specific investigations in order to assess their response to climate change.

Shand et al. (2013) reviewed shoreline response models to sea-level rise and found they ranged from the application of basic geometric principles to more complex process-based assessment, with none being proven to be categorically correct or adopted universally. They also stressed that while most attention has focussed on open coast beaches, other shoreline types including gravel beaches and low energy coastlines such as lagoons and estuaries are also affected and must be considered. Table 34.6 provides their suggested methodology for assessment of shoreline response. More recently Kinsela et al. (2017) proposed an approach to predicting shoreline and asset exposure within the sediment compartment framework by parameterising the geomorphology and connectivity of sediment-sharing coastal systems in order to determine their sensitivity to erosion impacts. Applying the approach to the NSW sediment compartments, they found that on a regional scale it could be used to estimate potential present and future asset exposure to coastal erosion. The results also indicated that shoreline recession due to sea-level rise could result in a substantial increase in the number and distribution of asset exposure in the present century. At a local scale that found that erosion potential is related to the distinctive coastal geomorphology of individual compartments and that the ability to predict changes increases with the coverage and geomorphic detail that is available to parameterise sediment-sharing systems and sediment budget principles.

Table 34.6 Suggested methods for assessing shoreline response to sea-level change

Shoreline type	Preliminary assessment: large area, minimal or low-quality data	Detailed assessment: site-specific and quality data (all shoreline types)[a]
Sandy beach	Generalised Bruun rule1 using inner and outer Hallermeier limit envelope	1.Define seaward limit of *significant* profile change using range of methods including site-specific cross-shore profile data
Perched beach	Generalised Bruun rule1 using beach face slope	2.Probabilistic assessment using either an equilibrium model
Gravel beach	Generalised Bruun rule1 using combined shoreface and backface slopes	3.With long-term, high-quality data, process-based modelling could be considered

[a]Sediment flux must be assessed and incorporated in any prediction
Source: Shand et al. (2013)

34.7.2 Wave Climates

While sea level determines the position of the shoreline, it is waves that provide much of the energy to do work at the coast; therefore any changes in wave height, period and direction will directly and immediately impact the coast and over time can cause major changes in shoreline position and stability. At a global scale, Camus et al. (2017) predict increases in the Indian Ocean and Southern Ocean wave height and period with direction remaining stable, a trend that has been ongoing since at least 1980 and which will impact all of southern Australia. In the equatorial Pacific including the Coral Sea, they predict increases in height for winter trade wind waves which will impact the GBR and northeast coast. On the east Australian coast, Hemer et al. (2012) found that wave direction is sensitive to the position of the sub-tropical ridge (STR). Mortlock and Goodwin (2015) predicted with a southerly shift in the STR that there would be a reduction in oblique southerly waves and a consequent disruption in the northerly longshore sand transport for the entire NSW coast. This would have impacts on all PCs, SCs and TCs along the coast and major disruptions in northern NSW-southeast QLD where beaches are dependent on the ongoing longshore transport of sand. They do however predict that this could also lead to an increase in onshore transport, which would particularly benefit those beaches with closed boundaries. Likewise McInnes (2018) predicts a 1–2° southerly shift in east coast cyclones by 2100. At the same time, Dowdy et al. (2014) predict a decrease in storminess along the NSW coast leading to fewer large waves. Elsewhere around Australia, Hemer et al. (2013a, b) and McInnes (2018) predict an increase in Southern Ocean wave height, with decreases in wave height elsewhere around Australia, except in the northeast where predicted increase in trade wind-generated waves will impact the QLD and east Arnhem Land coast, while across the north, the summer monsoon waves are predicted to decrease.

These findings suggest an increase in wave height and rates of transport along the tropical east Queensland coast; a decrease in extreme waves, more easterly waves and decreased northerly transport along the southeast QLD-NSW coast; increased southerly wave height across the southern coast; an increase in deepwater wave height on the south-central WA coast; and decrease in summer monsoon wave height across the northern coast. All these changes will impact beach type and state, sediment transport and shoreline behaviour. However, wave monitoring together with more detailed regional and local studies will be required to determine the exact nature of the changes in wave climate and the shoreline response.

Tropical cyclones are the major source of storm waves and storm surges across northern Australia. On a global scale, Knutson et al. (2010) predict that while tropical cyclone frequency will decrease by 6–34%, their intensity will increase by 2–11%, and they will extend more polewards (McInnes et al. 2016). In the Australian region, SOC (2016) reports the same responses. In the southern Indian Ocean, Fitchett (2018) noted a poleward shift in the 26.5 °C SST isotherms and concurrent emergence of more intense category 5 tropical cyclones in the southern Indian Ocean since 1994 and their more poleward trajectory. The increase in intensity will lead to stronger winds, higher waves, greater storm surges and greater coastal flooding and inundation, particularly when coupled with rising sea level, changing tides and interannual variability leading to what McInnes et al. (2016) termed ‘compound hazards’. Their more poleward trajectory will also expose sections of the west and east coast previously distant from tropical cyclones and their impacts. Across southern Australia Camus et al. (2017) modelled future extreme water levels due to increasing wave height, sea level and storm surges and found that they presently range from 0.6 to 1.7 m and will increase with sea-level rise. Haigh et al. (2012) modelled extreme water levels around the coast and found at a 1:100 year return interval they range from 5 to 6 m in the northwest and Gulf of Carpentaria to less than 2 m around southern Australia (Fig. 1.14). However, Hopley and Harvey (1978) concluded that on a global scale the Australian storm surge risk is low to moderate with the higher tides providing a buffer around much of northern Australia.

In addition to changing wave climates, the rise in sea level will increase inshore water depth which is predicted to decrease wave attenuation and result in waves with larger periods, greater amplitudes and higher run-up, impacts which will also affect tides, surge and wave characteristics (Arns et al. 2017).

34.7.3 Tide Regime

Tide regimes will vary at two scales. As sea level rises, it will deepen water over the continental shelf and slowly change the coastal configuration, which will over time impact the way the tidal system behaves (Arns et al. 2017). The change could lead to an increase or decrease in tide range at a regional level, with the former enhancing and latter negating the impact of sea-level rise. At local level the rising sea will increase the tidal prism and tide range in all open estuaries which will have both physical and ecological impacts. Physical impacts will be associated with stronger tidal flow into the estuary, increased accommodation space and reactivation of the flood tide delta, leading to movement of more marine sand into the estuary which could also impact adjacent open coast and estuarine beach systems. Any increase in tide range will also cause tide-dependent ecosystems (salt marshes, mangroves, seagrasses) to shift, while any increase in salinity will also have ecological ramifications. An indication of this impact can be seen at Sydney's Narrabeen Lagoon and other lagoons which are artificially opened to reduce flooding potential and improve water quality. At Narrabeen the more open lagoon has had minimal impact in lagoon tide range, but it has increased salinity near the lagoon entrance leading to the colonisation of mangroves in a previous fresh to brackish water environment (Wiecek and Floyd 2007). Similar impacts on a larger scale have been observed at Tuncurry-Wallis Lake (Nielsen and Gordon 1980) and Lake Entrance-Gippsland Lakes (Bird 1993). In the NT's Mary River Kingston et al. (1991) have documented the significant physical and ecological changes caused by saltwater inundation of the lower reaches of the river system during the past century.

34.7.4 Wind Regimes

Young et al. (2011) provide an overview of global trends in wind speed and wave height which show wind speed increasing globally with maximum increase in the equatorial regions. Wave height is more variable with the only consistent increases around the southern oceans. Colberg and McInnes (2012) predict that across southern Australia there will be an increase in easterly winds between 30 and 35°S and a weakening of westerlies south of 40°S during summer and autumn but a strengthening of the westerlies during winter and spring. Based on these predictions they conclude that across southern Australia extreme sea-level changes will be dominated by changes in mean sea level due to thermal expansion and ice sheet and glacier melt rather than changes in weather patterns.

In northern Australia Hemer et al. (2013a, b) predict that the southeast trade winds will increase in strength during winter, while the summer northwest monsoons will decrease in strength. These changes will impact both the associated wave climates and aeolian sand transport potential, leading to more exposed higher energy east-facing shore and lower energy north- to west-facing shores.

34.7.5 Sea Surface Temperature

Sea surface temperature has risen about 0.4 °C globally between 1981 and 2010 (Blunden et al. 2018), while around the Australian coast over the past century, it has increased 1 °C with the increase greatest in the west and south (SPC 2016). In the southern Indian Ocean, Pearce and Feng (2007) report a rise of ~0.02 °C year^{-1} in the southeast which is confirmed by a 0.013 °C year^{-1} rise since 1951 off the southern WA coast and poleward shift in SST isotherms (Fitchett 2018). The increasing temperature will impact all coastal and marine ecosystems in general causing a poleward shift in marine species. The combination of rising sea temperature and acidity will stress some communities as Kilminister et al. (2018) found when a 2011 heat wave has caused defoliation of seagrass in Shark Bay, while extreme low tide coupled with warmer water caused seagrass dieback in Spencer Gulf, both an indication of what may become more widespread with rising air and water temperatures. On a broader scale, Green and Short (2003) found that the major threats to seagrasses are coastal development, eutrophication, extreme climate events and global warming, with 18% of the world's documented seagrass being lost between 1980 and 2000.

34.7.6 Ocean Acidification

The increase in CO_2 taken up by the oceans is increasing its acidity. This increase can affect marine species that produce shells or skeletons of calcium carbonate. Around Australia the increase in acidity, measured by the decrease in seawater pH, has been greatest across the northern coast. As approximately half of Australia's coastal sediments are composed of carbonate detritus, any impact on their production, supply and resilience will have impacts on all coasts where carbonate detritus is a component of their sediment budget. As Woodroffe et al. (2007) found 'There has been relatively little study of rates of carbonate production, and further research is needed on the supply of biogenic sand and gravel to coastal ecosystems'.

In summary there are a wide range of primary, secondary and tertiary impacts of climate change on the coast. They relate to physical changes (sea level, waves, tides, wind, temperature, rainfall), chemistry (salinity, acidity) and ecology and become increasingly complex at a local scale. For this reason investigations of future change need to be based upon regional predictions of change but undertaken at a scale that takes into account these complex relationships.

34.8 Investigating Coastal Sediment Compartments

This book is structured around the provinces, divisions, regions and primary and secondary sediment compartments that are the Australian coast. Each compartment represents a section of the coast whose shoreline behaviour is linked to the compartment's sediment budget and the processes that impact the compartment. Increasingly compartments are being seen and used as a basis for understanding past, present and future shoreline behaviour so as to inform the development of compartment-based coastal management programs. Our present knowledge of these compartments ranges from very little to a moderate. No compartments have been investigated and modelled to the extent that we can confidently predict future behaviour. In order to get to this point, the following lists what is required to undertake a comprehensive investigation of a sediment compartment. The aim of such an investigation is to understand past and present shoreline behaviour, to map the nature and extent of the sediment system both onshore and offshore, to assess the linkages with adjoining compartments and to model present behaviour and future shoreline behaviour under a changing climate.

Quaternary/Holocene Evolution and Chronology The past is often the key to the present, and this involves mapping of the system using lidar, dating of accretionary sequences using radiocarbon and/or OSL and using ground-penetrating radar (GPR) to detail shallow stratigraphy and potential evolutionary events, such as storm scarps. This can provide information on the chronology of the system's evolution and the nature, volume and rate of sand supply to the system, rates of shoreline change and possibly its variation through time including evidence of extreme events. See, for example, Oliver et al. (2015, 2018).

Seabed Mapping The largest proportion of compartments are subaqueous, and understanding of this area is essential to understanding what is happening at the shoreline. In order to do this, the nearshore/shoreface should be mapped using swath/multibeam surveys which map the seabed elevation and character (sand/rock/reef/etc.) and texture (fine through coarse sand and gravel). This should be followed by surface sampling to calibrate sediment textures, sub-bottom profiling to determine thickness of sediment and vibro-coring to examine nature and age structure of sediments. The results will provide a quantification of the type and volume of sediment in the nearshore, identify potential subaqueous transport routes and assess whether the nearshore is in an equilibrium state or not. In NSW a SeaBed mapping program was initiated by the NSW Office of Environment and Heritage in 2017 with the aim of mapping high-priority NSW secondary sediment compartments with multibeam and marine lidar to (1) determine the distribution and variability in nearshore sediment types to better understand alongshore-across shore sediment transport; and (2) further develop a state-wide coastal digital elevation model (Linklater et al. 2018). This will provide for NSW the information required to better understand the compartments and the nature of their seabed, including sediment location, type, volume and transport pathways, all essential to the understanding of each compartment's sediment and shoreline dynamics.

Processes Coastal processes drive sediment transport and shoreline change and include wave climate, tides, coastal currents, wind regime, storm surge, shelf waves, extreme water levels and response to extreme events and climate indices such as ENSO, IPO and SAM. These processes operate at time scales from seconds to decades and drive responses at the same time scales. It is therefore imperative that the full range of spatial and temporal processes and their impacts and interrelationships be incorporated in any study. It is by understanding and quantifying the impact of extreme events and response to climate indices that an insight will be gained as to how compartments may behave in the future as extreme events herald net change in shoreline behaviour driven by climate-induced changes in the direction and scale of climate indices. See, for example, Mariani et al. (2013).

Shoreline Behaviour The Holocene evolution of a compartment's sedimentary system will indicate whether it is accreting, stable or receding, while monitoring of contemporary behaviour will provide information of storm demand, shoreline oscillation and rotation and trends, i.e. direction of net changes (accreting, stable, receding), and through correlation with processes the drivers of these changes. Contemporary data can be obtained from a time series of shoreline change based on traditional land surveys, historic aerial photographs, satellite imagery (since 1986) and repetitive lidar. See, for example, Coghlan et al. (2017).

Modelling Modelling of compartment behaviour should always start with a conceptual model which shows all the components and how they are linked and behave. The model should include the compartment's coastal processes, sediment transport routes (onshore, offshore, longshore), the nature of the compartment boundaries (open, leaky or closed), estimates of the direction and scale of compartment's sediment linkages including rates of transport, the compartment sediment budget (positive, stable or negative) and shoreline response. See, for example, Table 34.6 and Davies and Hudson (1987). A range of models can then be used to model the existing behaviour and to predict future behaviour based on changes to sea level, tides, wave climate, wind climate, terrigenous sediment supply and extreme events. Woodroffe et al. (2012) review a range of models presently available, while Mariani et al. (2013) present two compartment case studies for the NSW coast. With such an approach, the entire sediment compartment can be mapped; its sediment types, sources and transport routes identified; and the past, present and future shoreline behaviour quantified. Finally, Eliot (2016) provides a manual for coastal managers on how best to manage soft (sedimentary) shores.

34.8.1 The US Approach to Coastal Sediment Management

The US Army Corps of Engineers (USACE 2018) oversees most major beach nourishment and dredging projects in the United States. In 1999 it initiated the Regional Sediment Management (RSM) program to take a regional or systems approach to coastal sediment-related issues. It recognises sediment as a valuable resource and has developed a number of tools available online to assist in regional sediment management (see http://rsm.usace.army.mil/#).

The RSM process involves four phases which are summarised below:

1. Understand the region including sediment sources and processes, morphological evolution and sediment-related challenges.
2. RSM strategies project scale: Strategies to improve the management and use of sediments are identified and evaluated.
3. RSM strategies regional scale: Integrates project-level strategies into a regional strategy.

4. Take action – Construction and adaptive management: Monitor the evolution of the project; adaptively manage the project; quantify the value and benefits.

In understanding the regional sediment budget, they recommend four steps (and time frames):

1. Conceptual sediment budget (days).
2. Interim sediment budget or working budget with quantification of rates (months).
3. Operation sediment budget or final budget (months to years).
4. Macro-budget compiles all sediment budgets in a sediment compartment (years).

At a regional level, the tools required to assess the sediment budget include comprehensive regional surveys and environmental mapping, regional hydrodynamic and hydrologic data and regional hydrodynamic, hydrologic and sediment transport modelling. One of their online tools is the Sediment Budget Analysis System (SBAS) which provides the framework for formulating, documenting and calculating sediment budgets, including estimation of uncertainty and reliability of the budget.

34.9 Summary and Conclusions

Half the Australian coast consists of sandy beaches most backed by sandy vegetated barrier systems. These systems are all located adjacent to the ocean or sea and are generally low-lying, unconsolidated and exposed to coastal processes that vary considerably both spatially and temporally. They have all gone through a dynamic evolution since the early to mid-Holocene, with the present systems ranging from receding to stable to accretionary, with the direction of change largely dependent on their sediment budget, a budget controlled by a number of parameters all of which will be impacted by changing climate. The nature and evolution of these systems are becoming better understood as their nature, stratigraphy and chronology are investigated at an increasing number of locations around the coast, with most of these studies mentioned in this book. This book has also documented the location and nature of all Australian beach and barrier systems at a SC, PC, regional, divisional and provincial level, noting at the same time the type and sources of sediment to supply the beach barrier systems and the strong relationship between coastal processes and barrier type, form, extent and volume. Combined this information provides an insight into the evolution, nature and stability of the beach and barrier systems that comprise half the coast.

While these systems have been evolving since their first sediments were deposited during the PMT and remain responsive to changes in coastal processes and sediment supply, the more recent changes in climate and predictions of future changes and their coastal impacts has added an additional set of variables that must be considered when assessing their present and future behaviour and response. As reviewed above rising sea level and changes in climate, wave climate, tide regimes, wind regimes, sea surface temperature and acidification will all have direct and indirect impacts on all these systems. The nature and extent of the impacts will however vary considerably around the coast (Hennessy et al. 2007; Semeniuk 2013). This is in part because of the considerable existing variation in coastal processes, especially waves, wind and tide, and the variable nature and impact of future changes including variable rates of sea-level rise and increases or decreases in regional wave climate and tide and wind regimes. Therefore, while the above had provided some general insight into potential impacts of these changes, far more regionalised and localised studies will be required to more accurately identify and quantify impacts at the regional and local level, as recommended for shorelines by Shand et al. (2013) and Kinsela et al. (2016) and for estuaries-wetlands by Zheng et al. (2013), Hanslow et el. (2018) and Semeniuk (2013).

The sediment compartment approach used in this book provides a framework for such studies from a provincial down to TC level. While this book covers the provincial to SC level, most of ~1000 TCs around the coast received little or no attention. It is at this level however that the most detailed information on geomorphic systems and sediment budgets is required to model and predict future behaviour and response to climate impacts. This book therefore provides a first approximation of the nature and behaviour of the beach-barrier systems, with far more work to be done before we can start understand this behaviour at the TC level.

As McInnes et al. (2016) concluded 'how the Australian coastline will respond to SLR and extreme events, such as storm surges and waves through erosion or deposition, remains a major gap in our knowledge'. In order to fill this gap, improved regional climate models together with coordinated investigations of the coast at the SC and TC level are required, with an aim to understand the drivers and behaviour of sediment within each compartment and its response to future changes in coastal processes. As Kinsela et al. (2017) concluded, 'Coastal sediment compartments provide a hierarchical framework to conceptualise and quantify potential sediment redistribution between the various depositional environments (sources and sinks) of sediment-sharing coastal systems. Sub-compartment classifications allow for sediment transport processes, which accumulate into meaningful sediment exchanges between sources and sinks across varying time scales, to be connected with the spatial scales of their impact on beach fluctuation and cumulative shoreline change'. Such sediment redistribution and transport has been occurring in most compartments since the PMT to produce the present wide variety of beach and barrier systems as detailed in this book. We now need to look to future behaviour if we are to effectively manage the coast and mitigate the impacts of climate change and reduce the risk to assets and society.

In their thought provoking book *Tomorrow's Coasts: Complex and Impermanent*, Wright and Nichols (2018) consider the coast a *process* that is continuously changing, with the change predicted to accelerate with climate change. In the same book, Thom (2018) called for adaptive management to accommodate the ever-changing coast but at the same time lists six impediments to such an approach including being unable to reach a unified approach, following historical procedures, leaving the coast to care for itself, the high cost of some management options, multi-jurisdictions in the coastal zone and the reduced capacity of managers to manage. Thom supports Thornton and Goodman's (2017) five phase life cycle of the law for managing future (coastal) risks. It begins with scientific input, input that must be credible and relevant and conveyed in a language understandable by the decision makers. It is part of the aim of this book to provide such input.

Cosby et al. (2018) make the telling point that disasters are not natural. Rather they are man-made as a result of poor planning which has created conditions for natural events to become disasters, in other words placing people and assets in harm's way. They argue that the natural event is not a disaster; rather it is its effects on humans which are disastrous. If we replace the term 'disaster' with 'hazard', the same can be applied to coastal hazards. They are natural phenomena in a dynamic coastal system, which only become a hazard when humans intervene in the system dynamics by placing themselves and their assets in situations where they will be impacted by the dynamics, whether it be storm surge inundation, shoreline recession or getting caught in a rip current. We have already placed considerable assets and people in harm's way through their location in the coastal hazard zone. Now that we can map the nature and extent of existing coastal hazards and predict future hazards, it is time to ensure we no longer place society at unnecessary risk in the coastal zone.

A. Appendices

Appendix 34.1 Australian Secondary Sediment Compartment (SC) Boundaries and Dimensions

1–23 Are Regional Boundaries and Names. See Relevant Chapters for Full PC and SC Details
Beach ID is state beach number; state km is distance clockwise from state border

Region/SC	Boundaries	Beach ID	No. beaches	State km	Total km
1.	**Pilbara**				
WA11.01.01	Giralia-Locker Pt	WA 1634-1658	25	4393–4532	139
WA11.02.01	Locker Pt-Coolgra Pt	WA 1659-1676	18	4532–4598	66
WA11.02.01	Coolgra Pt-Peter Ck	WA 1677-1689	13	4598–4693	95
WA11.02.03	Peter Ck-James Pt	WA 1690-1703	14	4693–4750	56
WA11.03.01	James Pt-C. Preston	WA 1704-1708	5	4750–4770	20
WA11.03.02	C. Preston-W Intercourse. Is	WA 1709-1725	17	4770–4820	50
WA11.03.03	W. Intercourse Is-Dolphin Is	WA 1726-1777	52	4820–4905	85
WA11.03.04	Dolphin Is-C. Lambert	WA 1778-1831	54	4905–5015	110
WA11.04.01	C Lambert-C. Cossigny	WA 1832-1867	36	5015–5145	130
WA11.04.02	C. Cossigny-Beebingara Ck	WA 1867-1908	41	5145–5258	112

(continued)

Region/SC	Boundaries	Beach ID	No. beaches	State km	Total km
WA12.01.01	Beebingara Ck-Yan Well	WA 1909-1922	14	5258–5310	52
WA12.01.02	Yan Well-Condini Landing	WA 1923-1930	8	5310–5352	42
WA12.01.03	Condini Land.-Shoonta Well	WA 1931-1957	27	5352–5466	114
WA12.02.01	Shoonta Well-Wallal	WA 1958-1965	8	5466–5549	83
WA12.02.02	Wallal-C. Jaubert	WA 1966-1974	9	5549–5668	119
WA12.03.01	C. Jaubert-C. Villaret	WA 1975-2048	74	5668–5803	135
WA12.03.02	C. Villaret-Entrance Pt	WA 2048-K12	15	5803–5877	74
WA12.03.04	Entrance Pt-Coulomb Pt	K 12-34	22	5877–5954	77
WA12.03.04	Coulomb Pt-Swan Is	K 35-93	50	5954–6221	267
WA12.04.01	Swan Is-Coenambie Pt	K 94-148	54	6221–6357	136
WA12.04.02	Coenambie Pt-Jangerie	K 149-152	4	6357–6415	58
WA12.04.03	Jangerie-Pt Torment	–	0	6415–6535	120
WA12.04.04	Pt Torment-Pt Usborne	K 153-155	3	6535–6746	211
2.	**Kimberley**				
WA13.01.01	Pt Usborne-Nares Pt	K 156-244	90	6746–7014	268
WA13.01.02	Nares Pt-Shoal Bay	K 245-271	27	7014–7203	189
WA13.02.01	Shoal Bay-Battery Pt	K 272-359	88	7203–7547	344
WA13.02.02	Battery Pt-C. Wellington	K 360-390	31	7547–7860	313
WA13.02.03	C. Wellington-Augereau Is	K 391-515	125	7860–8245	385
WA13.03.01	Augereau Is-Davidson Pt	K 516-647	132	8245–8472	227
WA13.03.02	Davidson Pt-C. Bougainville	K 648-868	221	8472–8920	448
WA13.03.03	C. Bougainville-Anjo	K 869-986	118	8920–9162	242
WA13.03.04	Anjo-C. Londonderry	K 986-1102	116	9162–9434	272
WA13.04.01	C. Londonderry-C.Bernier	K 1103-1244	142	9434–9600	166
WA13.04.02	C. Bernier-Thurburn Bluff	K 1245-1319	75	9600–9760	160
WA13.04.03	Thurburn Bluff C. Domett	K 1320-1345	26	9760–10,126	366
WA13.05.01	C. Domett-Turtle Pt	K 1346-1360	15	10,126–10,205	79
		NT 1-2	2	1–120	120
NT13.05.02	Turtle Pt-Pearce Pt	NT 3-14	12	120–505	385
3.	**West Northern Territory**				
NT01.01.01	Pearce Pt-C Ford	NT 15-64	50	505–702	197
NT01.01.02	C Ford-Dundee Beach (N)	NT 65-103	39	702–885	183
NT01.01.03	Dundee Beach (N)-Charles Pt	NT 104-110	7	885–1051	166
NT01.01.04	Charles Pt-Gunn Pt	NT 111-149	39	1051–1256	205
NT01.01.05	S Bathurst & Melville Is	–	–	–	–
NT01.02.01	Gunn Pt-C Hotham	NT 150-155	6	1256–1323	67
NT01.02.02	C Hotham-Pt Stuart	NT 156-161	6	1323–1411	88
NT01.02.03	Pt-Stuart-Pt Farewell	NT 162-166	5	1411–1593	182
NT01.02.04	Pt Farewell-Waragil Pt	NT 167-178	12	1593–1771	178
NT01.02.05	Waragil Pt-C Don	NT 179-183	5	1771–1859	88

(continued)

Region/SC	Boundaries	Beach ID	No. beaches	State km	Total km
4.	**North Arnhem Land**				
NT02.01.01	W Bathurst-Melville Is	–	–	–	–
NT02.01.02	N Bathurst-Melville Is	–	–	–	–
NT02.01.03	E Bathurst-Melville Is	–	–	–	–
NT02.02.01	C Don-C Crocker	NT 184-410	227	1859–2243	384
	Crocker Is (W)	CIs 45-139	95	61–136	75
NT02.02.02	Crocker Is (E)	CIs 1-44	44	0–61	61
	C Crocker-Angulari Ck (north)	NT 411-506	96	2243–2373	130
NT02.03.01	Angulari Ck-Hall Pt	NT 507-578	72	2373–2528	155
NT02.03.02	Hall Pt-C Stewart	NT 579-656	78	2528–2734	206
NT02.03.03	C Stewart-Woolen R	NT 657-676	20	2734–2809	75
NT02.04.01	Woolen R-Rimbija Is	NT 677-776	100	2809–3114	305
NT02.04.02	Rimbija Is-C Arnhem	NT 777-1053	277	3114–3731	617
5.	**East Arnhem Land**				
NT03.01.01	C Arnhem-Wanyanmear Pt	NT 1054-1110	57	3731–3832	101
NT03.01.02	Wanyanmear Pt-C Shield	NT 1111-1300	190	3832–4063	231
NT03.01.03	C Shield-C Barrow	NT 1301-1395	95	4063–4403	340
NT03.01.04	N Bickerton & N Groote Eylandt	–	–	–	–
NT03.02.01	E Groote Eylandt	–	–	–	–
NT03.02.02	S Groote Eylandt	–	–	–	–
NT03.02.03	C Barrow-Warrakunta Pt	NT 1397-1437	41	4403–4559	156
6.	**Southern Gulf of Carpentaria**				
NT04.01.01	Warrakunta Pt-Rosie Ck	NT 1438-1452	15	4559–4721	162
NT04.01.02	Rosie Ck-Calvert R	NT 1452-1482	30	4721–4988	267
QLD01.01.01	Calvert R (NT)-Bayley Pt (Qld)	NT 1483-1488	6	4988–5029	41
		QLD 1-16	16	0–126	126
QLD01.01.02	Bayley Pt-Karumba	QLD 17-29	13	126–384	258
7.	**Western Cape York Peninsula**				
QLD02.01.01	Karumba-S Mitchell R	QLD 30-56	27	384–667	283
QLD02.02.01	S Mitchell R – Worbody Pt	QLD 57-78	22	677–906	239
QLD02.02.02	Worbody Pt-Van Spoult Pt	QLD 79-177	99	906–1399	493
8.	**Eastern Cape York Peninsula**				
QLD03.01.01	Van Spoult Pt-C York	QLD 178-213	36	1399–1469	70
QLD03.01.02	Cap[e York-Sharp Pt	QLD 214-231	18	1469–1573	104
QLD03.02.01	Sharpe Pt-False Orford Ness	QLD 231-288	57	1573–1633	60
QLD03.02.02	False Orford Ness-Red Cliffs	QLD-289-309	21	1633–1688	55
QLD03.02.03	Red-Cliffs-C Granville	QLD 310-338	29	1688–1747	59
QLD03.03.01	C Granville-Bolt Hd	QLD 339-362	24	1747–1802	55

(continued)

Region/SC	Boundaries	Beach ID	No. beaches	State km	Total km
QLD03.03.02	Bolt Hd-C Weymouth	QLD 363-405	43	1802–1867	65
QLD03.03.03	C Weymouth-Chisolm Pt	QLD 406-425	20	1867–1928	61
QLD03.03.04	Chisolm Pt-C Sidmouth	QLD 426-464	39	1928–2004	76
QLD03.03.05	C Sidmouth-Stewart R	QLD 465-486	22	2004–2082	78
QLD03.04.01	Stewart R-Bathurst Hd	QLD 487-498	12	2082–2187	105
QLD03.04.02	Bathurst Hd-C Melville	QLD 499-516	18	2187–2234	47
QLD03.05.01	C. Melville-Murdoch Pt	QLD 517-582	66	2234–2333	99
QLD03.05.02	Murdoch Pt- C Flattery	QLD 583-614	32	2333–2412	79
QLD03.06.01	C Flattery- Endeavour R	QLD 615-640	26	2412–2501	89
QLD03.06.02	Endeavour R-C Kimberley	QLD 641-690	50	2501–2624	123
QLD03.06.03	C Kimberely-Port Douglas	QLD 691-696	6	2624–2658	34
QLD03.06.04	Port Douglas-C Grafton	QLD 697-734	38	2658–2759	101
QLD03.07.01	C Grafton-Saltwater Ck	QLD 735-741	7	2759–2781	22
QLD03.07.02	Saltwater Ck-Cooper Pt	QLD 742-759	18	2781–2830	49
QLD03.07.03	Cooper Pt-Double Pt	QLD 760-772	13	2830–2864	34
QLD03.07.04	Double Pt-Tam O'Shanter Pt	QLD 773-787	15	2864–2908	44
QLD03.07.05	Tam O'Shanter Pt-C Richards	QLD 788-799	12	2908–3022	114
QLD03.07.06	C Richards-Lucinda	QLD 800-827	28	3022–3082	60
QLD03.07.07	Hinchinbrook Channel	–		–	
QLD03.07.08	Lucinda-Eleanor Ck	QLD 828-835	8	3082–3124	42
QLD03.07.09	Eleanor Ck-C Pallarenda	QLD 836-858	23	3124–3197	73
QLD03.07.10	C Pallarenda-C Cleveland	QLD 859-874	16	3197–3244	47
QLD03.08.01	C Cleveland-C Bowling Green	QLD 875-889	15	3244–3336	92
SC03.08.02	C Bowling Green-C Upstart	QLD 890-921	32	3336–3445	109
QLD03.08.03	C Upstart-Abbott Pt	QLD 922-942	21	3445–3502	57
QLD03.08.04	Abbott Pt-C Edgecumbe	QLD 943-954	12	3503–3531	29
QLD03.08.05	C Edgecumbe-C Gloucester	QLD 955-979	25	3532–3595	64
QLD03.08.06	C Gloucester-Pioneer Pt	QLD 980-1019	40	3596–3711	116
QLD03.08.07	Pioneer Pt-C Conway	QLD 1020-1037	18	3712–3777	66
9.	**Central Queensland**				
QLD04.01.01	C Conway-Proserpine R	QLD1038-1047	10	3777–3816	39
QLD04.01.02	Proserpine R-C Hillsborough	QLD1048-1097	50	3816–3931	115
QLD04.01.03	C Hillsborough-Pioneer R	QLD1098-1118	21	3931–3997	66
QLD04.01.04	Pioneer R-Dudgeon Pt	QLD1119-1128	10	3997–4024	27
QLD04.01.05	Dudgeon Pt-C Palmerston	QLD1129-1170	42	4024–4113	89
QLD04.02.01	C Palmerston-N Red Bluff	QLD1171-1214	44	4114–4224	111
QLD04.02.02	N Red Bluff-	QLD1215-1222	8	4224–4451	227
QLD04.02.03	North Pt-Townshend Is	QLD1223-1299	77	4451–4647	196
QLD04.03.01	Townshend Is-C Manifold	QLD1300-1347	48	4647–4800	153
QLD04.03.02	C Manifold-Yeppoon	QLD1348-1365	18	4800–4881	81

(continued)

Region/SC	Boundaries	Beach ID	No. beaches	State km	Total km
QLD04.03.03	Yeppoon-Zilzie Pt	QLD1366-1380	15	4881–4906	25
QLD04.03.04	Zilzie Pt-Station Pt	QLD1381-1394	14	4906–5000	94
QLD04.03.05	Station Pt-C Capricorn	QLD1395-1406	12	5000–5039	39
QLD04.03.06	The Narrows	–	–	–	66
QLD04.03.07	C Capricorn-Gatcombe Pt	QLD1407-1427	21	5039–5073	34
		Facing Is 1-7	7	0–18	18
QLD04.03.08	Gatcombe Pt-Richard s pt	QLD1428-1446	19	5139–5227	88
QLD04.03.09	Richards Pt-Round Hill	QLD1447-1467	21	5227–5288	61
QLD04.04.01	Round Hill-Burnett R	QLD 1468-1496	29	5288–5387	99
QLD04.04.02	Burnett R-Elliott R	QLD 1497-1511	15	5387–5412	25
QLD04.04.03	Elliott R-Sandy C	QLD 1511-1527	17	5412–5492	80
	W Fraser Island	FIs 12-17	6		112
10.	**Central east**				
QLD05.01.01	Sandy C-Indian Hd	Fraser Is 1-7	7	0–38	38
QLD05.01.02	Indian Hd-Double Island Pt Inskip Pt-Double is Pt	Fraser Is 8-10	3	38–139	101
		QLD 1528-1530	3	5618–5647	29
QLD05.01.03	Noosa River	–		–	–
QLD05.01.04	Double Is Pt-Noosa Hd	QLD 1531-1536	6	5647–5706	59
QLD05.01.05	Noosa Hd-Caloundra	QLD 1537-1555	19	5706–5761	55
QLD05.01.06	Caloundra-Skirmish Pt	QLD 1556	1	5761–5792	31
QLD05.02.01	Skirmish Pt-Brisbane R-C. Moreton	QLD-1557-1575	19	5792–5860	68
		More Is 7-15, 1-4	13	40–87 + 1–2	49
QLD05.02.02	Brisbane R-Amity	QLD 1576-1579	4	5860–5985	125
QLD05.03.01	C. Moreton-Pt Lookout	More Is 5-6	2	2–40	38
		QLD 1580-1584	5	5985–5999	14
QLD05.03.02	Pt Lookout-Pt Danger	QLD 1585-1601	17	5999–6091	92
NSW01.01.01	Pt Danger-C. Byron	NSW 1-15	15	0–61	61
NSW01.01.02	C. Byron-Richmond R	NSW 16-28	13	61–92	31
NSW01.01.03	Richmond R-Evans Hd	NSW 29-30	2	92–123	31
NSW01.01.04	Evans Hd-Yamba	NSW 31-43	13	123–167	44
NSW01.02.01	Yamba-Barcoongere	NSW 44-74	31	167–228	61
NSW01.02.02	Barcoongere-Bare Bluff	NSW 75-93	19	228–263	35
NSW01.02.03	Bare Bluff-Coffs Harbor	NSW 94-112	19	263–290	27
NSW01.02.04	Coffs Hbr-Nambucca Hd	NSW 113-127	15	290–333	43
NSW01.02.05	Nambucca Hd-SW Rocks	NSW 128-137	10	333–368	35
NSW01.03.01	SW Rocks-Tacking Pt	NSW 138-170	33	368–450	82
NSW01.03.02	Tacking Pt-Crowdy Hd	NSW 171-184	14	450–508	58
NSW01.03.03	Crowdy Hd-Black Hd	NSW 185-192	8	508–540	32
NSW01.03.04	Black Hd-C Hawke	NSW 193-200	8	540–560	20

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Region/SC	Boundaries	Beach ID	No. beaches	State km	Total km
11.	**Southern NSW**				
NSW02.01.01	C Hawke-Seal Rocks	NSW 201-217	17	560–594	34
NSW02.01.02	Seal Rocks-Yaccabba	NSW 218-223	6	594–648	54
NSW02.01.03	Yaccabba-Zenith Pt	PS 1-15	15	0–25	25
NSW02.01.04	Zenith Pt-Birubu Pt	NSW 224-237	14	648–671	23
NSW02.01.05	Birubi Pt-Nobbys Hd	NSW 238-240	3	671–704	33
NSW02.02.01	Nobbys Hd-Norah Hd	NSW 241-272	32	704–762	58
NSW02.02.02	Norah Hd-C Three Pts	NSW 273-289	27	762–800	38
NSW02.03.01	C Three Pts-Barrenjoey	NSW 290-299	10	800–838	38
		Broken Bay 1-21	21	39	39
NSW02.03.02	Barrenjoey-North Hd	NSW 300-319	20	838–876	38
NSW02.03.03	North Hd-South Sd	Sydney Hbr 1-52	52	64	64
NSW02.03.04	South Hd-C Banks	NSW 320-330	11	876–905	29
NSW02.03.05	C Banks-Hacking Pt	NSW 331-340	10	905–926	21
		Botany Bay 1-23	23	49	49
		Port Hacking 1-8	8	10	10
NSW02.04.01	Hacking Pt-Bellambi Pt	NSW 341-367	27	926–974	48
NSW02.04.02	Bellambi Pt-Red Pt	NSW 368-378	11	974–992	18
NSW02.04.03	Red Pt-Bass Pt	NSW 379-385	7	992–1010	18
NSW02.04.04	Bass Pt-Black Hd	NSW 386-399S	14	1010–1044	34
NSW02.04.05	Black Hd-Beecroft Pt	NSW 400-408	9	1044–1084	40
NSW02.05.01	Beecroft Hd-Pt Perpendicular	0	0	1084–1093	9
NSW02.05.02	Pt Perpendicular-Bowen Is	NSW 409-438	30	1093–1146	53
NSW02.05.03	Bowen Is-St Georges Hd	NSW 439	1	1146–1159	13
NSW02.05.04	St George Hd-Red Hd	NSW 440-460	21	1159–1185	27
NSW02.05.05	Red Hd-Warden Hd	NSW 461-471	11	1185–1203	17
NSW02.05.06	Warden Hd_Wasp Hd	NSW 472-514	43	1203–1264	61
NSW02.06.01	Wasp Hd-Three Islet Pt	NSW 515-522	8	1264–1276	12
NSW02.06.02	Three Islet Pt-Mosquito Bay Pt	NSW 523-540	18	1276–1302	26
NSW02.06.03	Mosquito Bay Pt-Bingie Bingie Pt	NSW 541-577	37	1302–1346	44
NSW02.06.04	Bingie Bingie Pt-Mystery Bay	NSW 578-611	34	1346–1383	37
NSW02.06.05	Mystery Bay-Goalen Hd	NSW 612-637	26	1383–1418	35
NSW02.06.06	Goalen Hd-Tathra Hd	NSW 638-659	22	1418–1444	26
NSW02.06.07	Tathra Hd-Worang Pt	NSW 660-678	19	1444–1497	53
NSW02.06.08	Worang Pt-Red Rock	NSW 679-703	25	1497–1521	24
NSW02.06.09	Red Rock-Green C	NSW 704-709	6	1521–1548	27
NSW02.06.10	Green C-Jane Spiers	NSW 710-713	4	1548–1570	22
NSW02.06.11	Jane Spiers-C Howe	NSW 714-721	8	1570–1592	22

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Region/SC	Boundaries	Beach ID	No. beaches	State km	Total km
12	**Gippsland**				
VIC01.01.01	C Howe-Rame Hd	VIC 1-42	42	0–60	60
VIC01.02.02	Rame Hd-C Conran	VIC 43-71	29	60–133	73
VIC01.02.01	C Conran-Red Bluff	VIC 72-76	5	133–193	60
VIC01.02.02	Red Bluff-Shoal Inlet	VIC 77-78	2	193–331	138
VIC01.02.03	Shoal Inlet-Entrance Pt	VIC 79-87	9	331–381	50
VIC01.03.01	Entrance Pt-South Pt	VIC 88-106	19	381–449	68
13.	**Eastern Tasmania**				
TAS01.01.01	Stanley Pt-Sellars Pt	Flinders 1-7	7	0–45	45
TAS01.01.02	Sellars Pt-C Barren	Flinders 8-28	21	45–109	64
TAS01.02.01	C Portland-Eddystone Pt	TAS 1-49	49	0–59	59
TAS01.02.02	Eddystone Pt-St Helens Pt	TAS 50-100	51	59–107	48
TAS01.02.03	St Helens Pt-Wardlaws Pt	TAS 101-125	25	107–151	44
TAS01.02.04	Wardlaws Pt-Friendly Pt	TAS 126-158	33	151–208	57
TAS01.02.05	Friendly Pt-C Sonnerat	TAS 159-160	2	208–254	46
TAS01.03.01	C Sonnerat-C Bougainville	TAS 161-254	94	254–366	112
TAS01.03.02	C Bougainviulle-C Bernier	TAS 255-284	30	366–414	48
		Maria Is 1-19	19	0–65	65
TAS01.03.03	C Bernier-C Frederick Hendrick	TAS 285-299	15	414–445	31
TAS01.03.04	C Frederick Hendrick-C Pillar	TAS 300-309	10	445–514	69
TAS01.04.01	C Pillar-Outer North Hd	TAS 310-335	26	514–612	98
TAS01.04.02	Outer N Hd-C Contrariety	TAS 336-409	74	612–779	167
TAS01.04.03	C Contrariety-C Direction Deenes Pty-Tasman Hd	TAS 410-414	5	779–789	10
		Bruny Is 1-25	25	0–75	75
TAS01.04.04	Tasman Hd-Hopwood Pt	Bruny Is 26-38	13	75–111	36
TAS01.04.05	C Direction-Rossel Pt Hopwood Pt-Deenes Pt	TAS 415-527	113	789–1042	253
		Bruny Is 39-94	56	111–233	122
TAS01.04.06	Roissel Pt-South East C	TAS 528-565	38	1042–1097	55
14.	**Western Tasmania**				
TAS02.01.01	SE C-SW C	TAS 566-614	49	1097–1227	130
TAS02.02.01	SW C-Hillard Hd	TAS 615-630	16	1227–1264	37
TAS02.02.02	Hillard Hd-Davey Hd	TAS 631-666	36	1264–1320	56
TAS02.02.03	Davey Hd-Low Rocky Pt	TAS 667-705	39	1320–1405	85
TAS02.02.04	Low Rocky Pt-C Sorrell	TAS 706-789	84	1405–1540	135
TAS02.03.01	C Sorrell-Braddon Pt	TAS 790-791	2	1540–1545	(170)[4]
TAS02.03.02	Ocean Beach	TAS 792-795	4	1545–1578	33
TAS02.03.03	Ocean Beach-Ahrberg Bay	TAS 796-816	21	1578–1609	31
TAS02.03.04	Ahrberg Bay- Sandy C	TAS 817-846	30	1609–1657	48
TAS02.03.05	Sandy C-Bluff Hill Pt	TAS 847-910	64	1657–1724	67
TAS02.03.06	Bluff Hill Pt-Woolnorth Pt	TAS 911-964	54	1724–1798	74
TAS02.03.07	Hunter Island (west coast)		–	–	(32)
TAS02.03.08	Stokes Pt-C Wickham (King Is)	King Is 46-80	35	96–196	100

(continued)

Region/SC	Boundaries	Beach ID	No. beaches	State km	Total km
15.	**North Tasmania**				
TAS03.01.01	Hunter Island-North Pt	TAS 965-984	20	1798–1868	70
TAS03.01.02	North Pt-Regatta Pt	TAS 985-1138	154	1868–2012	144
TAS03.02.01	Regatta Pt- Low Hd	TAS 1139-1186	48	2012–2081	69
TAS03.02.02	Low Hd-East Sandy Pt	TAS 1187-1224	38	2081–2144	63
TAS03.02.03	East Sandy Pt-C Portland	TAS 1225-1269	45	2144–2237	93
TAS03.03.01	C Portland-C Sir John	C Barren Is	–	–	–
TAS03.03.02	C Sir John-Stanley Pt	Flinders I 29-133	105	FI 109–235	126
TAS03.04.01	C Wickham-Fraser Bluff	King Is 1-13	13	KI 0–48	48
TAS03.04.01	Fraser Bluff-Stokes Pt	King Is 14-45	32	KI 48–96	48
16.	**Central & western Victoria**				
VIC03.01.01	South Pt-Tongue Pt	VIC 107-115	9	449–480	31
VIC03.01.02	Tongue Pt-C Liptrap	VIC 116-135	20	480–532	52
VIC03.01.03	C Liptrap-C Patterson	VIC 136-156	21	532–585	53
VIC03.01.04	C Patterson-C Woolamai	VIC 157-186	30	585–624	39
VIC03.01.05	C Woolamai-Pt Grant	VIC 187-209	23	624–654	30
VIC03.01.06	Pt Grant-Flinders	VIC 210-244	35	654–712	58
VIC03.01.07	Flinders-C Schankl	VIC 245-250	6	712–729	17
VIC03.01.08	C Schank-Pt Nepean	VIC 251-280	30	729–760	31
VIC03.01.09	Pt Nepean-Gellibrand Pt	Port Phillip 1-67	67	0–114	114
VIC03.01.10	Gellibrand Pt-Pt Lonsdale	PP 68-132	65	114–260	146
VIC03.01.11	Pt Nepean-Pt Lonsdale	–	–	761–763	3
VIC03.02.01	Pt Lonsdale-Table Rock	VIC 281-327	47	763–823	60
VIC03.02.02	Table Rock-C Otway	VIC 328-410	83	823–902	79
VIC03.03.01	C Otway-Falls Halladale	VIC 411-466	66	902–982	80
VIC03.03.02	Falls Halladale-C Nelson	VIC 467-547	81	982–1150	168
VIC03.03.03	C Nelson-Danger Pt	VIC 548-560	13	1150–1232	82
		SA 1-2	2	0–14	14
17.	**Southern South Australia**				
SA01.01.01	Danger Pt-C Banks	SA 3-43	41	14–65	51
SA01.01.02	C Banks-C Jaffa	SA 44-147	104	65–216	151
SA01.02.01	C Jaffa-Middleton Rocks	SA 148-149	2	216–428	212
SA01.03.01	Middleton Rocks-Newland Hd	SA150-169	20	428–458	30
SA01.03.02	Newland Hd-C Jervis	SA 170-186	17	458–502	44
	Kangaroo Hd-C Willoughby	KI 45-57	13	KI 76–113	37
SA01.04.01	C Willoughby-C Gantheaume	KI 58-83	26	KI 113–200	87
SA01.04.02	C Gantheaume-C Du Couedic	KI 84-135	52	KI 200–293	93
SA01.04.03	C Du Couedic-C Borda	KI-136-145	10	KI 293–345	52

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Region/SC	Boundaries	Beach ID	No. beaches	State km	Total km
18.	**South Australian gulfs**				
SA02.01.01	C Borda-Marsden Pt	KI 146-218	73	KI 345–459	114
SA02.01.02	Marsden Pt-Kangaroo Hd	KI 1-44	44	KI 0–76	76
SA02.01.03	C Jervis-Sellicks Beach	SA 187-213	27	502–548	46
SA02.01.04	Sewllicks-North Haven	SA 214-233	20	548–616	68
SA02.01.05	North Haven-Clinton	SA 234-245	12	617–715	99
SA02.01.06	Clinton-Sultana Pt	SA 246-335	90	715–840	125
SA02.01.07	Sultana Pt-C Spencer	SA 336-391	56	840–945	105
SA02.02.01	C Spencer-Corny Pt	SA 392-448	57	945–1012	67
SA02.02.02	Corny Pt-Pt Pearce	SA 449-482	34	1012–1120	108
SA02.02.03	Pt Pearce-Fishernman Bay	SA 483-546	64	1120–1268	148
SA02.02.04	Fisherman Bay-Port Augusta	SA 547-564	18	1268–1430	162
SA02.02.05	Port Augusta-Shoalwater Pt	SA 565-613	49	1430–1587	157
SA02.02.06	Shoalwater Pt-C Catastrophe	SA 614-803	190	1587–1924	337
19.	**Western Eyre Peninsula**				
SA03.01.01	C Catastrophe-Pt Whidbey	SA 804-872	69	1924–2065	141
SA03.01.02	Pt Whidbey-Pt Sir Issac	SA873-893	21	2065–2090	25
SA03.01.03	Pt Sir Issac-Frenchmans Bluff	SA 894-955	62	2090–2183	93
SA03.01.04	Frenchmans Bluff-C Finniss	SA 956-1046	91	2183–2303	120
SA03.01.05	C Finniss-C Radstock	SA 1047-1092	46	2303–2401	98
SA03.02.01	C Radstock-C Bauer	SA 1093-1155	63	2401–2497	96
SA03.02.02	C Bauer-Pt Brown	SA 1156-1221	66	2497–2617	120
SA03.02.03	Pt Brown-Pt Peter	SA 1222-1305	84	2617–2770	153
SA03.03.01	Pt Peter- C Adieu	SA 1306-1377	72	2770–2949	179
SA03.03.02	C Adieu-Hd of Bight	SA 1378-1441	64	2949–3067	118
20.	**Nullabor**				
SA03.04.01	Hd of Bight-Wilson Bluff	SA 1442-1454	13	3067–3273	206
WA01.01.01	Wilson Bluff-Red Rock Pt	WA 1-8	8	0–160	160
WA01.01.02	Red Rock Pt-Scorpion Bight	WA 9-11	3	160–235	75
WA01.01.03	Scorpion Bight-Twilight Cove	WA 12-16	5	235–308	73
WA01.02.01	Twilight Cove-Pt Dover	WA 17	1	308–365	57
WA01.02.02	Pt Dover-Pt Culver	WA 18	1	365–450	85
WA01.03.01	Pt Culver-Wattle Camp	WA 19-23	5	450–528	78
WA01.03.02	Wattle Camp-Pt Lorenzen	WA 23-25	2	528–571	43
WA01.03.03	Pt Lorenzen-Pt Malcolm	WA 26-30	5	571–605	34
WA01.03.04	Pt Malcolm-C Palsey	WA 31-52	22	605–638	33
21.	**Southern Western Australia**				
WA02.01.01	C Pasley-C Arid	WA 53-73	21	638–683	45
WA02.01.02	C Arid-Tagon Pt	WA 74-88	15	683–720	37
WA02.01.03	Tagon Pt-Hammer Hd	WA 89-109	21	720–770	50
WA02.01.04	Hammer Hd-Mississippi Pt	WA 110-127	18	770–811	41

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Region/SC	Boundaries	Beach ID	No. beaches	State km	Total km
WA02.01.05	Mississippi Pt-C La Grande	WA 128-139	12	811–843	32
WA02.01.06	C LaGrande-Observation Pt	WA 140-157	18	843–896	53
WA02.01.07	Observation Pt-Shoal C	WA 158-186	29	896–966	70
WA02.02.01	Shoal C-Mason Bay	WA 187-236	50	966–1046	80
WA02.02.02	Mason Bay-Hopetoun	WA 237-254	18	1046–1074	28
WA02.02.03	Hopetoun-Red Is	WA 255-277	23	1074–1116	42
WA03.01.01	Red Is-Pt Hood	WA 278-301	24	1116–1176	60
WA03.01.02	Pt Hood-C Knob	WA 302-321	20	1176–1248	72
WA03.01.03	C Knob-Groper Bluff	WA 322-331	10	1248–1292	44
WA03.01.04	Groper Bluff-Bald Is	WA 332-363	32	1292–1376	84
WA03.01.05	Bald Is-C Vancouver	WA 364-378	15	1376–1417	41
WA03.01.06	C Vancouver-Herald Pt	WA 379-387	9	1417–1436	19
WA03.02.01	Herald Pt-Bald Hd	WA 388-411	24	1436–1467	31
WA04.01.01	Bald Hd-Torbay Hd	WA 412-431	20	1467–1517	50
WA04.01.02	Torbay Hd-Wilson Hd	WA 432-444	13	1517–1556	39
WA04.01.03	Wilson Hd-Pt Hillier	WA 445-471	27	1556–1577	21
WA04.01.04	Pt Hillier-Pt Irwin	WA472-496	25	1577–1605	28
WA04.01.05	Pt Irwin-Pt Nuyts	WA 497-522	26	1605–1636	31
WA04.02.01	Pt Nuyts-West Cliff Pt	WA 523-563	41	1636–1676	40
WA04.02.02	W Cliff Pt-Pt D'Entrécasteaux	WA 564-569	6	1676–1704	28
WA04.03.01	Pt D'Entrécasteaux-Black Pt	WA 570-598	29	1704–1770	66
WA04.03.02	Black Pt-C Leeuwin	WA 599-617	19	1770–1818	48
22.	**Southwest Western Australia**				
WA05.01.01	C Leeuwin-C Naturaliste	WA 618-730	113	1818–1930	112
WA06.01.01	C Naturaliste-Casuarina Pt	WA 731-761	31	1930–2018	88
WA06.01.02	Casuarina Pt-Robert Pt	WA 762-789	28	2018–2119	101
WA06.02.x1	Rottnest Island	RI 1-63	(63)	1–36	(36)
WA06.02.01	Robert Pt-Challenger Beach	WA 790-818	29	2119–2174	55
WA06.02.02	Challenger Beach-Pinnaroo Pt	WA 818-862	44	2174–2217	43
WA06.02.03	Pinnaroo Pt-Pt Moore R	WA 863-906	44	2217–2272	55
WA07.01.01	Moore R-Ledge Pt	WA 907-921	15	2272–2301	29
WA07.01.02	Ledge Pt-Wedge Is Pt	WA 922-935	14	2301–2342	41
WA07.01.03	Wedge Is Pt-Thirsty Pt	WA 936-963	28	2342–2380	38
WA07.01.04	Thirsty Pt-North Hd	WA 964-987	24	2380–2416	36
WA07.02.01	North Hd-Green Hd	WA 988-1012	25	2416–2436	20
WA07.02.02	Green Hd-Illawong	WA 1013-1052	40	2436–2477	41
WA07.02.03	Illawong-Cliff Hd	WA 1053-1057	5	2477–2499	22
WA07.02.04	Cliff Hd-Leander Pt	WA 1058-1061	4	2499–2528	29
WA07.02.05	Leander Pt-Nine Mile Beach	WA 1062-1071	10	2528–2546	18
WA07.02.06	Nine Mile Beach-C Burney	WA 1072-1077	6	2546–2583	37

(continued)

Region/SC	Boundaries	Beach ID	No. beaches	State km	Total km
WA07.02.07	C Burney-Glenfield Beach	WA 1078-1090	13	2583–2608	25
WA08.01.01	Glenfield Beach-Bowes R	WA 1091-1104	13	2608–2644	36
WA08.01.02	Bowes R-Broken Anchor Bay	WA 1105-1116	12	2644–2665	21
WA08.02.01	Broken Anchor -Murchinson R	WA 1117-1133	17	2665–2734	69
23.	**Central west Western Australia**				
WA09.01.01	Murchinson R-Nuginjay Spring	WA 1134-1137	4	2734–2751	17
WA09.01.02	Nuginjay Spring-Steep Pt	WA 1138-1187	50	2751–2945	194
WA09.01.03	Steep Pt-C Inscription	–	(7)	–	(82)
WA09.02.01	Dirk Hartog Is (E)	–	(99)	–	113
	C Inscription-C Bellefin	WA 1188-1205	18	2912–2991	79
WA09.02.02	C Bellefin-Giraud Pt	WA 1206-1283	78	2991–3164	173
WA09.02.03	Giraud Pt-Goulet Bluff	WA 1284-1311	28	3164–3302	138
WA09.02.04	Goulet Bluff-C Peron North	WA1312-1367	55	3302–3397	95
WA09.03.01	C Peron North-Monkey Mia	WA 1368-1383	16	3397–3448	51
WA09.03.02	Monkey Mia-Pell Pt	WA 1384-1397	14	3448–3539	91
WA09.03.03	Pell Pt-Hamelin Pool (S)	WA 1398-1403	6	3539–3613	74
WA09.03.04	Hamelin Pool (S)-Wooramel R	WA 1404-1423	20	3613–3702	89
WA09.03.05	Wooramel R-Grey Pt	WA 1424-1426	3	3702–3802	100
WA09.04.01	Grey Pt-Miaboolya	WA 1427-1431	5	3802–3874	72
WA09.04.02	Miaboolya-Pt Quobba	WA 1431-1436	5	3874–3897	23
WA10.01.01	Pt Quobba-C Culver	WA1437-1447	11	3897–3930	33
WA10.01.02	C Culver-Gnaraloo	WA 1448-1468	21	3930–3986	56
WA10.01.03	Gnaraloo-Alison Pt	WA 1469-1488	20	3986–4029	43
WA10.02.01	Alison Pt-Pt Maud	WA 1489-1515	27	4029–4078	49
WA10.02.02	Pt Maud-Pt Cloates	WA 1516-1532	17	4078–4135	57
WA10.02.03	Pt Cloates-Winderabandi Pt	WA 1533-1539	7	4135–4167	32
WA10.02.04	Winderabandi Pt-North West C	WA 1540-1602	63	4167–4267	100
WA10.03.01	North West C-Learmouth	WA 1603-1618	16	4267–4313	46
WA10.03.02	Learmouth-Giralia	WA 1619-1633	15	4313–4393	80

Appendix 34.2 Regional (1–23) and PC Barrier Dimensions

See Relevant Chapters for Full Barrier Details

Region name	PC	PC	Barrier	Barrier	Barriers	Barriers	Unstable	Barriers	Barriers	Holocene rate
			Number	Length	Area	Unstable	%	Volume	Per meter	
				(km)	(ha)	(ha)		Mm^3	m^3/m	$m^3\ m^{-1}\ year^{-1}$
Northwest division										
N Carnarvon	WA11.01	1	8	28	3820	1400	36.6	205	5394	0.9
	WA11.02	2	23	126	1360	740	54.4	922	7318	1.2
Pilbara	WA11.03	3	22	56	3605	25	0.7	290	5478	0.9
	WA11.04	4	26	125	10,520	875	8.3	872	6363	1.1
Canning	WA12.01	5	13	132	17,360	820	4.7	1590	12,046	2.0
	WA12.02	6	4	190	34,730	1070	3.1	3625	18,290	3.0
	WA12.03	7	56	293	14,107	6400	45.4	2345	8357	1.4
	WA12.04	8	19	33	840	130	15.5	52	1590	0.3
	Region 1		171	983	86,342	11,460	13.3	9901	10,072	1.7
Kimberley-territory division										
W Kimberley	WA13.01	9	22	2	14	0	0.0	0.5	264	0.0
	WA13.02	10	71	12	95	0	0.0	3	268	0.0
	WA13.03	11	113	107	2164	94	4.3	78	733	0.1
E Kimberley	WA13.04	12	46	93	4400	70	1.6	225	2438	0.4
	WA13.05	13	3	64	1774	554	31.2	205	3201	0.5
	Region 2		255	278	8447	718	8.5	511.5	1840	0.3
W NT	NT01.01	14	43	206	16,348	310	1.9	532	2582	0.4
	NT01.02	15	15	51	4842	0	0.0	145	2859	0.5
	Region 3		58	256	21,190	310	1.9	677	2636	0.4
N Arnhem	NT02.02	16	79	190	4955	211	4.3	232	1218	0.2
	NT02.03	17	50	199	12,480	799	6.4	430	2159	0.4
	NT02.04	18	82	183	4183	374	8.9	169	942	0.2
	Region 4		211	572	21,618	1384	6.6	831	1452	0.3
Gulf of Carpentaria division										
E Arnhem	NT03.01	19	84	244	16,766	2022	12.1	3449	10,055	1.7
	NT03.02	20	17	99	7740	560	7.2	804	8116	1.4
	Region 5		101	343	24,506	2582	10.5	4253	12,399	2.1
S gulf	NT04.01	21	16	133	10,155	540	5.3	435	3263	0.5
	QLD01.01	22	14	294	78,110	1560	2.0	4065	13,808	2.3
	Region 6		30	427	88,265	2100	2.4	4500	10,539	1.8
W Cape York	QLD02.01	23	10	188	88,000	0	0.0	4200	22,340	3.7
	QLD02.02	24	36	481	100,705	1188	1.2	5475	11,395	1.9
	Region 7		46	669	188,705	1188	0.6	9675	14,462	2.4
Northeast division										
E Cape York	QLD03.01	25	21	46	2803	58	2.1	594	12,945	2.2
	QLD03.02	26	9	140	26,420	1261	4.8	2642	27,870	4.6
	QLD03.03	27	30	200	60,368	106	0.2	5379	26,922	4.5

(continued)

Region name	PC	PC	Barrier	Barrier	Barriers	Barriers	Unstable	Barriers	Barriers	Holocene rate
			Number	Length	Area	Unstable	%	Volume	Per meter	
				(km)	(ha)	(ha)		Mm^3	m^3/m	$m^3\ m^{-1}\ year^{-1}$
	QLD03.04	28	14	107	13,567	10	0.1	681	6364	1.1
	QLD03.05	29	27	85	6540	394	6.0	540	6330	1.1
	QLD03.06	30	35	128	67,135	22,546	33.6	6390	49,800	8.3
	QLD03.07	31	57	254	23,368	40	0.2	1501	5934	1.0
	QLD03.08	32	38	164	15,173	2712	17.9	746	4550	0.8
	Region 8		231	1124	215,374	27,127	12.6	18,473	16,435	2.7
Central QLD	QLD04.01	33	51	185	3766	0	0.0	228	1237	0.2
	QLD04.02	34	62	122	2769	47	1.7	141	1155	0.2
	QLD04.03	35	48	218	70,047	1232	1.8	13,831	63,520	10.6
	QLD04.04	36	22	149	20,974	40	0.2	1142	7686	1.3
	Region 9		183	674	97,556	1319	1.4	15,342	22,763	3.8
Southeast division										
Fraser Is	QLD05.01	37	15	423	2E+05	15,000	6.8	23,363	79,710	13.3
Moreton Bay	QLD05.02	38	5	32	14,530	600	4.1	330	640	0.1
Mort Is-Gold Coast	QLD05.03	39	7	176	23,390	2450	10.5	8436	65,564	10.9
N NSW	NSW01.01	40	21	143	16,060	646	4.0	1048	7316	1.2
	NSW01.02	41	38	163	7560	464	6.1	1411	8664	1.4
	NSW01.03	42	22	147	7465	1587	21.3	690	4701	0.8
	Region 10		108	1084	290,965	20,747	7.1	35,278	32,544	5.4
S NSW	NSW02.01	43	15	104	17,753	3477	19.6	4471	42,867	7.1
	NSW02.02	44	15	46	1902	577	30.3	359	7818	1.3
	NSW02.03	45	24	29	1596	442	27.7	203	7082	1.2
	NSW02.04	46	30	70	23,278	172	0.7	1204	17,115	2.9
	NSW02.05	47	46	91	2690	192	7.1	405	5437	0.9
	NSW02.06	48	69	133	3539	214	6.0	183	1380	0.2
	Region 11		199	473	50,758	5074	10	6825	14,429	2.4
Gippsland	VIC01.01	49	25	101	24,852	15,227	61.3	2766	27,657	4.6
	VIC01.02	50	9	209	8070	130	1.6	1070	5131	0.9
	VIC01.03	51	6	34	5420	270	5.0	600	2735	0.5
	Region 12		40	344	38,342	15,627	40.8	4436	12,895	2.1
E Tasmania	TAS01.01	52	13	78	4742	20	0.4	407	5200	0.9
	TAS01.02	53	44	131	2495	524	21.0	247	1893	0.3
	TAS01.03	54	28	62	1803	154	8.5	95	1538	0.3
	TAS01.04	55	45	76	2392	133	5.6	162	2142	0.4
	Region 13		130	347	11,432	831	7.3	911	2625	0.4
Great Southern Division										
W Tasmania	TAS02.01	56	14	24	586	54	9.2	264	11,016	1.8
	TAS02.02	57	35	34	4500	330	7.3	1219	35,585	5.9
	TAS02.03	58	39	170	29,470	3910	13.3	8534	50,320	8.4
	Region 14		88	228	34,556	4294	12.4	10,017	43,934	7.3

(continued)

Region name	PC	PC	Barrier Number	Barrier Length (km)	Barriers Area (ha)	Barriers Unstable (ha)	Unstable %	Barriers Volume Mm^3	Barriers Per meter m^3/m	Holocene rate m^3 m^{-1} year^{-1}
N Tasmania	TAS03.01	59	32	79	3090	2	0.1	156	1979	0.3
	TAS03.02	60	37	139	14,792	3990	27.0	2742	19,689	3.3
	TAS03.03	61	25	38	2535	125	4.9	359	9415	1.6
	TAS03.04	62	14	54	1083	70	6.5	169	3085	0.5
	Region 15		108	310	21,500	4187	19.5	3426	11,052	1.8
C Victoria	VIC03.01	63	24	57	56,530	2950	5.2	2870	50,783	8.5
	VIC03.02	64	17	46	1870	27	1.4	317	6942	1.2
W Victoria	VIC03.03	65	32	160	23,663	5880	24.8	4593	28,796	4.8
	Region 16		73	263	82,063	8857	10.8	7780	29,582	4.9
Southern South Aust	SA01.01	66	15	181	21,106	12,714	60.2	4426	24,442	4.1
Coorong	SA01.02	67	2	211	39,000	11,800	30.3	6850	32,464	5.4
	SA01.03	68	2	4	350	110	31.4	105	24,418	4.1
Kangaroo Is	SA01.04	69	7	83	48,800	1900	3.9	9760	117,590	19.6
	Region 17		26	479	109,256	26,524	24.3	21,141	44,136	7.4
SA Gulfs	SA02.01	70	26	153	6410	37	0.6	459	2998	0.5
	SA02.02	71	73	472	23,276	2203	9.5	2326	4933	0.8
	Region 18		99	625	29,686	2240	7.5	2785	4456	0.7
W Eyre Peninsula	SA03.01	72	32	221	43,300	12,565	29.0	11,216	50,800	8.5
	SA03.02	73	26	126	9780	3235	33.1	1253	9961	1.7
	SA03.03	74	27	221	35,065	20,645	58.9	7776	35,202	5.9
	Region 19		85	568	88,145	36,445	41.3	20,245	35,643	5.9
Nullarbor	SA03.04	75	1	9	1900	1300	68.4	380	44,705	7.5
	WA01.01	76	6	305	2E+05	10,500	7	11,700	38,423	6.4
	WA01.02	77	3	59	49,000	0	0	4300	72,880	12.1
	WA01.03	78	7	150	32,560	5550	17.0	325	2170	0.4
	Region 20		17	523	233,460	17,350	7.4	16,705	31,941	5.3
Southern WA	WA02.01	79	43	212	85,268	24,354	28.6	16,991	80,243	13.4
	WA02.02	80	17	105	9802	1706	17.4	1914	18,308	3.1
	WA03.01	81	31	248	23,795	5195	21.8	4517	30,600	5.1
	WA03.02	82	5	12	604	0	0.0	63	5172	0.9
	WA04.01	83	15	121	21,820	490	2.2	4332	35,950	6.0
	WA04.02	84	6	58	18,115	300	1.7	3580	61,960	10.3
	WA04.03	85	5	103	49,790	9800	19.7	9955	96,380	16.1
	Region 21		122	859	209,194	41,845	20.0	41,352	48,140	8.0
Southwest Division										
Southwest WA	WA05.01	86	19	65	13,264	450	3.4	2582	40,034	6.7
	WA06.01	87	9	164	13,355	3222	24.1	2430	14,791	2.5
	WA06.02	87	7	101	27,850	1100	3.9	4032	40,124	6.7
	WA07.01	87	5	124	63,000	7250	11.5	12,600	102,024	17.0
	WA07.02	88	10	177	40,735	16,300	40.0	8616	48,820	8.1

(continued)

Region name	PC	PC	Barrier	Barrier	Barriers	Barriers	Unstable	Barriers	Barriers	Holocene rate
			Number	Length	Area	Unstable	%	Volume	Per meter	
				(km)	(ha)	(ha)		Mm^3	m^3/m	$m^3\ m^{-1}\ year^{-1}$
	WA08.01	89	4	22	1650	500	30.3	283	12,840	2.1
	WA08.02	90	3	49	6650	2480	37.3	830	16,928	2.8
	Region 22		57	702	166,504	31,302	18.8	31,373	44,691	7.4
Central West WA	WA09.01	91	8	135	53,450	6340	11.9	10,708	79,426	13.2
	WA09.02	92	15	22	320	40	12.5	17	790	0.1
	WA09.03	93	28	198	4600	70	1.5	197	995	0.2
	WA09.04	94	4	47	21,850	300	1.4	2468	52,510	8.8
	WA10.01	95	14	104	11,500	1860	16.2	2190	20,974	3.5
	WA10.02	96	25	149	11,135	2140	19.2	1845	12,368	2.1
	WA10.03	97	7	54	1300	10	0.8	88	1612	0.3
	Region 23		101	709	104,155	10,760	10.3	17,513	24,701	4.1

References

Arns A, Dangendorf S, Jensen J, Talke S, Bener J, Pattiaratchi C (2017) Sea-level rise induced amplification of coastal protection design heights. Sci Rep 7:40171. https://doi.org/10.1038/srep40171

Belperio AP, Hails JR, Gostin VA, Polach HA (1984) The stratigraphy of coastal carbonate banks and Holocene sea levels of northern Spencer Gulf, South Australia. Mar Geol 61:297–313

Belperio AP, Gostin VA, Cann JH, Murray-Wallace CV (1988) Sediment-organism zonation and the evolution of Holocene tidal sequences in southern Australia. In: de Boer PL et al (eds) Tide-influenced sedimentary environments and facies. D Reidel Publ Co, Dordrecht, pp 475–497

Bird ECF (1993) The coast of Victoria. Melbourne University Press, Melbourne, 324 p

Blunden J, Arndt DS, Hartfield G (eds) (2018) State of the climate in 2017. Bull Amer Meteor Soc 99(8):Si–S332. https://doi.org/10.1175/2018BAMSStateoftheClimate.1

Brooke BP, Pietsch TJ, Olle JM, Sloss CR, Cox ME (2015) A preliminary OSL chronology for coastal dunes on Moreton Island, Queensland, Australia–marginal deposits of a large-scale Quaternary shelf sediment system. Continental Shelf Res 105:79–94

Burne RV (1982) Relative fall of Holocene sea level and coastal progradation, northeastern Spencer Gulf. South Australia: BMR J Australian Geol Geophysics 7:35–45

Camus P, Losada IJ, Izaguirre C, Espejo A, Menéndez M, Pérez J (2017) Statistical wave climate projections for coastal impact assessments. Earth's Future 5. https://doi.org/10.1002/2017EF000609

Coghlan IR, Carley JT, Harrison AJ, Howe D, Short AD, Ruprecht JE, Flocard F, Rahman P (2017) Eurobodalla coastal hazard assessment. WRL Tech. Rpt 2017/09, Water Research Laboratory, UNSW, Sydney, 180 p plus appendices

Colberg F, McInnes KL (2012) The impact of future changes in weather patterns on extreme sea levels over southern Australia. J Geophys Res Oceans 117:C08001. https://doi.org/10.1029/2012jc007919

Collins LB (1988) Sediments and history of the Rottnest Shelf, southwest Australia: a swell-dominated, non-tropical carbonate margin. Sed Geol 60:15–50

Cosby AFG, Mendez GR, Khandekar H (2018) Data-intensive alternatives for human adaption to coastal change. In: Wright LD, Nichols CR (eds) Tomorrow's coast: complex and impermanent, Coastal Research Library 27. Springer, Cham, pp 319–340

Davies JL (1973) Geographical variation in coastal development. Hafner, New York, 204 p

Davies JL, Hudson JP (1987) Differential supply and longshore transport as determinants of sediment distribution on the north coast of Tasmania. Mar Geol 77:233–245

DCC (2009) Climate change risks to Australia's coast: a first pass national assessment. Department of Climate Change, Australian Government, Canberra, 168 p

Dowdy AJ, Mills GA, Timbal B, Wang Y (2014) Fewer large waves projected for eastern Australia due to decreasing storminess. Nat Clim Chang 4:283–286. https://doi.org/10.1038/nclimate2142

Eliot M (2016) Coastal sediments, beaches and other soft shores. Info Manual 8, National Climate Change Adaptation Research Facility, Gold Coast, 68 p

Eliot M, Travers AS (2011) Dynamics of Scarborough Beach, City of Stirling, Western Australia. In: 20th Australasian coastal and ocean engineering conference, Institution of Engineers Australia, Perth, 6 p

Fitchett J (2018) Recent emergence of CAT5 tropical cyclones in the South Indian Ocean. S Afr J Sci 114(11/12):1–6. https://doi.org/10.17159/sajs.2018/4426

Gontz AM, Moss PT, Wangenknecht EK (2014) Stratigraphic architecture of a regressive strand plain, Flinders Beach, North Stradbroke Island, Queensland, Australia. J Coastal Res 30:575–585

Gordon AD (1988) A tentative but tantalizing link between sea-level rise and coastal recession in New South Wales. In: Pearman GI (ed) Greenhouse: planning for climate change. CSIRO, EJ Brill, Leiden, Australia, pp 121–134

Green EP, Short FT (2003) World atlas of seagrasses. University of California Press, Berkeley

Haigh ID, Wijeratne EMS, MacPherson LR, Mason MS, Pattiaratchi CB, Crompton RP, George S (2012) Technical report: estimating present day extreme total water level exceedance probabilities around the Australian coastline. UWA Ocean Institue, University of Western Australia, Perth, 89 p

Hanslow DJ, Morris BD, Foulsham E, Kinsela MA (2018) A regional scale approach to assessing current and potential future exposure to tidal inundation in different types of estuaries. Scientific Reports 8:7065. https://doi.org/10.1038/s41598-018-25410-y

Harley MD, Turner IL, Kinsela MA, Middleton JH, Mumford PJ, Splinter KD, Phillips MS, Simmons JA, Hanslow DJ, Short AD (2017) Extreme coastal erosion enhanced by anomalous extratropical storm wave direction. Scientific Reports, nature.com

Harvey N, Bowman GM (1987) Coastal management implications of a Holocene sediment budget: Le Fevre Peninsula, South Australia. J Shoreline Manag 3:77–93

Hemer MA, McInnes KL, Ranasinghe R (2012) Climate and variability bias adjustment of climate model-derived winds for a southeast Australian dynamical wave model. Ocean Dyn 62(1):87–104

Hemer MA, McInnes KL, Ranasinghe R (2013a) Projections of climate change-driven variations in the offshore wave climate off south eastern Australia. Int J Climatol 33:1615–1632. https://doi.org/10.1002/joc.3537

Hemer MA, Fan Y, Mori N, Semedo A, Wang XL (2013b) Projected changes in wave climate from a multi- model ensemble. Nat Clim. Change advance online publication. http://www.nature.com/nclimate/journal/ vaop/ncurrent/abs/nclimate1791.html#supplementary-information

Hennessy K, Fitzharris B, Bates BC, Harvey N, Howden SM, Hughes L, Salinger J, Warrick R (2007) Australia and New Zealand. Climate change 2007: impacts, adaptation and vulnerability. In: Parry ML, Canziani OF, Palutikof JP, van der Linden PJ, Hanson CE (eds) Contribution of working group II to the fourth assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge, pp 507–540

Hesp PA (1993) Late Quaternary coastal geomorphology of the South Sydney-Illawarra coast. In: Thoms MC (ed) Catchments Coasts Eastern Australia, Res Mono 5. Department of Geography, University of Sydney, Sydney, pp 72–87

Hesp PA, Short AD (1999) Barrier morphodynamics. In: Short AD (ed) Beach and Shoreface morphodynamics. Wiley, Chichester, pp 307–333
Holmes GM (1989) Global climate change and the role of the permanent committee on Tides and Mean Sea Level. In: 9th Australasian conference on coastal and ocean engineering, Adelaide, Institution of Engineers Australia, pp 280–286
Hopley DA (1983) Evidence of 15 000 years of sea level change in tropical Queensland. In: Hopley DA (ed) Australian sea levels in the last 15,000 years: a review, Mono Series 3. Department of Geography, James Cook University, Townsville, pp 93–104
Hopley D, Harvey N (1978) Regional variation in storm surge characteristics around the Australian coast: a preliminary investigation. In: Heathcote RL, Thom BG (eds) Natural hazards in Australia. Institute Australian Geographers, Canberra, pp 164–185
Hopley D, Smithers SG, Parnell KE (2007) The geomorphology of the Great Barrier Reef: development, diversity and, change. Cambridge University Press, Cambridge, 532 p
Kilminister K, Hovey R, Waycott M, Kendrock GA (2018) Seagrasses of southern and southwestern Australia. In: Larkum AWD, Kendrick GA, Ralph PHJ (eds) Seagrasses of Australia: structure, ecology and conservation. Springer, Cham, pp 61–92
Kinsela MA, Morris BD, Daley MJA, Hanslow DJ (2016) A flexible approach to forecasting coastline change on wave-dominated beaches. J Coast Res SI 75:952–956
Kinsela MA, Morris BAS, Linklater M, Hanslow DJ (2017) Second-pass assessment of potential exposure to shoreline change in New South Wales, Australia, using a sediment compartments framework. J Mar Sci Engr 5:61. https://doi.org/10.3390/jmse5040061
Knighton AD, Mills K, Woodroffe CD (1991) Tidal-creek extension and saltwater intrusion in northern Australia. Geol 19:831–834
Knutson TR, McBride JL, Chan J, Emanuel K, Holland G, Landsea C, Held I, Kossin JP, Srivastava AK, Sugi M (2010) Tropical cyclones and climate change. Nat Geosci 3:157–163
Lees BG (1992) The development of a chenier sequence on the Victoria Delta, Joseph Bonaparte Gulf, northern Australia. Mar Geol 103:215–224
Lees B (2006) Timing and formation of coastal dunes in northern and eastern Australia. J Coastal Res 22:78–89
Lees BG, Yanchou L, Price DM (1992) Thermoluminescence dating of dunes at Cape St Lambert, East Kimberley, northwestern Australia. Mar Geol 106:131–139
Lewis M (1976) Beach ridge development in Cullendulla Creek embayment, Batemans Bay, New South Wales. B.Sc. Hons thesis, Department of Geography, University of Sydney, Sydney
Linklater M, Ingleton T, Kinsela M, Morris B, Allen K, Sutherland M, Hanslow D (2018) Seabed classification approach for SeaBed NSW coastal seafloor mapping program. HYDRO18 Conference, Australian Hydrographic Society, Sydney, 14 p
Loehr H, Watterson E, Harry M (2018) Monitoring coastal change from space. 27th New South Wales Coastal Conference, Merimbula, 71 (abstract)
Logan BW (1970) Carbonate sedimentation and environments, Shark Bay, Western Australia. Amer Assoc Petroleum Geol, Mem 13:1–38
Logan BW, Read JF, Davies GR (1970) History of carbonate sedimentation, Quaternary Epoch, Shark Bay, Western Australia. In: Logan BW et al (eds) Carbonate Sedimentation and Environments, Shark Bay, Western Australia, Mem13. Amer Assoc Petroleum Geol, Tulsa, pp 38–85
Luijendijk A, Hagenaars G, Ranasinghe R, Baart F, Donchyts G, Aarninkhof S (2018) The state of the world's beaches. Scientific Reports, 9 p. https://doi.org/10.1038/s41598-018-24630-6
Mariani A, Flocard F, Carley JT, Drummond C, Guerry N, Gordon AD, Cox RJ, Turner IL (2013) East coast study project – national geomorphic framework for the management and prediction of coastal erosion, water research laboratory, WRL research report. School Civil Environmental Engr, UNSW, Manly Vale
McInnes K (2018) Towards a better understanding of the role of the ocean and cryosphere in coastal risk and resilience. In: 27th New South Wales Coastal Conference, Merimbula, 22 (abstract)
McInnes K et al. (2016) Natural hazard in Australia: sea level and coastal extremes. Climate Change, published on line, 15 p. https://doi.org/10.1007/s10584-016-1647-8

McLean R, Thom BG (2018) 'Big bite, little bite: fast recovery, slow recovery': storm impacts at Bengello Beach, Moruya, 1998–2018. In: 27th NSW Coastal Conference, Merimbula, p 73 (abstract)

Mortlock TR, Goodwin ID (2015) Directional wave climate and power variability along the Southeast Australian shelf. Continental Shelf Res 98:36–53. https://doi.org/10.1016/j.csr.2015.02.007

Murray-Wallace CV (2018) Quaternary history of the coorong coastal plain, Southern Australia. Springer, Cham, 229p. https://doi.org/10.1007/978-3-319-89342-6_3

Murray-Wallace CV, Belperio AP (1991) The last interglacial shoreline in Australia – a review. Quat Sci Rev 10:441–461

Murray-Wallace CV, Woodroffe CD (2014) Quaternary sea-level changes: a global perspective. Cambridge University Press, Cambridge, p 484

Murray-Wallace CV, Banerjee D, Bourman RP, Olley JM, Brooke BP (2002) Optically stimulated luminescence dating of Holocene relict foredunes, Guichen Bay, South Australia. Quat Sci Rev 21:1077–1086

Nielsen AF, Gordon AD (1980) The impact of breakwater construction on estuary stability – a case study. 17th I international conference on coastal engineering, Sydney, pp 445–448 (abstract)

Nott J, Smithers S, Walsh K, Rhodes E (2009) Sand beach ridges record 6000 year history of extreme tropical cyclone activity in northeastern Australia. Quat Sci Rev 28(15–16):1511–1520

Nott J, Forsyth A, Rhodes E, O'Grady E (2015) The origin of centennial- to millennial-scale chronological gaps in storm emplaced beach ridge plains. Mar Geol 367:83–93

Nyberg B, Howell JA (2016) Global distribution of modern shallow marine shorelines. Implications for exploration and reservoir analogue studies. Mar Petroleum Geol 71:83–104. https://doi.org/10.1016/j.marpetgeo.2015.11.025

Ohmori H, Endo K, Vesigi Y, Horikoshi M (1987) Stratigraphy and geomorphic history of Holocene dune field near Millicent along the southeastern coast of South Australia. Geo-Sci J (Japan) 96:1–22

Oliver TSN, Woodroffe CD (2016) Chronology, morphology and GPR-imaged internal structure of the Callala Beach prograded barrier in southeastern Australia. J Coast Res SI 75:318–322

Oliver TSN, Dougherty AJ, Gliganic LA, Woodroffe CD (2015) Towards more robust chronologies of coastal progradation: optically stimulated luminescence ages for the coastal plain at Moruya, south-eastern Australia. The Holocene 25:536–546

Oliver TSN, Thom BG, Woodroffe CD (2017a) Formation of beach-ridge plains: an appreciation of the contribution by Jack L Davies. Geogr Res 55:305–320

Oliver TSN, Tamura T, Short AD, Woodroffe CD (2017b) Changing rates of sand deposition at Pedro Beach, southeastern Australia: implications for compartment-based management. 26th NSW Coastal Conference, Port Stephens. http://www.coastalconference.com/papers.php

Oliver TSN, Tamura T, Short AD, Woodroffe CD (2018) Rapid shoreline progradation followed by vertical foredune building at Pedro Beach, southeastern Australia. Earth Surf Process Landf. https://doi.org/10.1002/esp.4510

Oliver TAN, Murray-Wallace CV, Woodroffe CD (in press) The drivers of Holocene shoreline progradation at Guichen and Rivoli Bays, South Australia. Holocene

Pearce A, Feng M (2007) Observations of warming on the western Australian continental shelf. Marine Freshwater Res 58:914–920

Pye K (1982) Morphological development of coastal dunes in a humid tropical environment, Cape Bedford and Cape Flattery, North Queensland. Geografiska Annaler 64A:213–227

Pye K, Bowman GM (1984) The Holocene marine transgression as a forcing function in episodic dune activity in eastern Australia. In: Thom BG (ed) Coastal geomorphology in Australia. Academic Press, Sydney, pp 179–196

Pye K, Switsur S (1981) Radiocarbon dates from the Cape Bedford and Cape Flattery dunefields. Search 12:225–226

Roy PS, Crawford EA (1979) Holocene geological evolution of the southern Botany Bay-Kurnell region, central New South Wales. Records of Geological Survey NSW, Sydney, 20, Part2:159–250

Roy PS, Thom BG (1987) Sea-level rise – an eminent threat? In: 8th Australasian Conference, Coastal Ocean Engineering, Launceston, pp 186–190

Searle DJ, Semeniuk V, Woods PJ (1988) The sedimentology and stratigraphy of a cuspate foreland, south-western Australia. J Coastal Res 4:551–564

Semeniuk V (2013) Predicted response of coastal wetlands to climate changes: a Western Australian model. Hydrobiologia 708:23–43. https://doi.org/10.1007/s10750-012-1159-0

Shand T, Shand R, Reinen-Hamill R, Carley J, Cox R (2013) A review of shoreline response models to changes in sea level. In: 21st Australasian conference on coastal and ocean engineering, Institution of Engineers Australia, pp 676–684

Short AD (1988a) The South Australian coast and Holocene sea-level transgression. Geog Rev 78:119–136

Short AD (1988b) Areas of Australia's coast prone to sea-level inundation. In: Pearman GI (ed) Greenhouse, planning for climatic change. CSIRO, Melbourne, pp 93–104

Short AD (2006) Australian beach systems – nature and distribution. J Coastal Res 22:11–27

Short AD (2010a) Role of geological inheritance in Australian beach morphodynamics. Coastal Engr 57:92–97. https://doi.org/10.1016/j.coastaleng.2009.09.005

Short AD (2010b) Sediment transport around Australia—sources, mechanisms, rates, and barrier forms. J Coastal Res 26:395–402

Short AD, Hesp PA (1982) Wave, beach and dune interactions in south eastern Australia. Mar Geol 48:259–284

Short AD, Hesp PA (1984) Beach and Dune morphodynamics of the South East Coast of South Australia. Coastal Studies Unit Tech Report 84/1. University of Sydney, Sydney, 142 p

Short AD, Buckley RC, Fotheringham DG (1989) Preliminary investigation of beach ridge progradation on the Eyre Peninsula and Kangaroo Island. Trans R Soc S Aust 113:145–161

Short AD, Woodroffe CD (2009) The coast of Australia. Cambridge University Press, Melbourne, 288 p

Short AD, Bracs MA, Turner IL (2014) Beach oscillation and rotation: local and regional response at three beaches in southeast Australia. J Coast Res 70:712–717

SOC (2016) State of the climate 2016. CSIRO Bureau Meteorology, Commonwealth Australia, 23 pp (http://www.bom.gov.au/state-of-the-climate/)

Thom BG (2018) Future adaptive coastal management. In Wright LD, Nichols CR (eds) Tomorrow's coast: complex and impermanent. Coastal Research Library 27, Springer, Cham, 305–318

Thom BG, Polach HA, Bowman GM (1978) Holocene structure of coastal; sand barriers in New South wales, Australia. Department of Geography, University of New South Wales Mono, Canberra

Thom BG, Bowman GM, Gillespie R, Temple R, Barbetti M (1981) Radiocarbon dating of Holocene beach-ridge sequences in south-east Australia. Department of Geography, University of New South Wales Mono. 11, Canberra, 36 p

Thom BG, Roy PS, Short A D, Hudson J, Davis RA Jr (1986) Modern coastal and estuarine environments of deposition in southeastern Australia. Guide Excursion 4A, 12th International Sedimentological Congress, Canberra, 279 p

Thom BG, Shepherd M, Ly CK, Roy PS, Bowman GM, Hesp PA (1992) Coastal geomorphology and Quaternary geology of the Port Stephens-Myall Lakes area. Department of Biogeography Geom, Mono, 6, The Australian National University, Canberra, 407 p

Thornton J, Goodman N (2017) Client Earth. Scribe, London, 314 p

USACE (2018) Regional sediment management tools and technologies. Engineer Research and Development Center, US Army Corps of Engineers, V1, 14 p plus appendices (http://rsm.usace.army.mil/pubs/brochures/2018_RSM_Coastal_Tools_Technologies_Brochure.pdf)

Veevers JJ (2015) Beach sand of SE Australia traced by zircon ages through Ordovician turbidites and S-type granites of the Lachlan Orogen to Africa/Antarctica: a review. Australian J Earth Sci 62:385–408

Vos K, Splinter K, Simmons J, Harley M, Turner IL (2018) Satellite remote sensing to extract long-term time series of shoreline change. In: 27th NSW Coastal Conference, Merimbula, 95 (abstract)

Watson PJ (2011) Is there evidence yet of acceleration in mean sea level rise around mainland Australia. J Coastal Res 27:368–377

Website. An online map-based tool which provides access to spatial data from Australian government agencies, including a range of coastal data sets. https://nationalmap.gov.au

Wiecek D, Floyd J (2007) Does dredging in Icoll entrances improve tidal flushing? NSW Coastal Conference, Yamba, 20 p

Woodroffe CD, Hall FR, Farrell JW, Harris PT (2007) Chapter 7: Calcium carbonate production and contribution to coastal sediments. United Nations, 15 p

Woodroffe CD, Cowell PJ, Callaghan DP, Ranasinghe R, Jongejan R, Wainwright DJ, Barry SJ, Rogers K, Dougherty AJ (2012) Approaches to risk assessment on Australian coasts: a model framework for assessing risk and adaptation to climate change on Australian coasts, National Climate Change Adaptation Research Facility, Gold Coast, 205 p

Wright LD (1976) Nearshore wave-power dissipation and the coastal energy regime of the Sydney-Jervis Bay region, New South Wales, a comparison. Australian J Mar Freshw Res 27:633–640

Wright LD, Nichols CR (eds) (2018) Tomorrow's coast: complex and impermanent, Coastal Research Library 27. Springer, Cham, 350 p

Young IR, Zieger S, Babanin AV (2011) Global trends in wind speed and wave height. Science 332:451–455. https://doi.org/10.1126/science.1197219

Zheng F, Westra S, Sisson SA (2013) Quantifying the dependence between extreme rainfall and storm surge in the coastal zone. J Hydrol 505:172–187

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https://doi.org/10.1007/978-3-030-14294-0