Chapter 6

Geological framework of the Andaman–Nicobar Islands

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Abstract: The Andaman–Nicobar archipelago that forms the western margin of the Andaman Sea is a sediment-dominated accretionary wedge (outer-arc island) associated with a convergent margin tectonic setting. The Andaman accretionary ridge consists of two stratigraphically and structurally distinct terranes, juxtaposed and telescoped into a north–south-trending high-relief fold-thrust belt formed along the obliquely subducting eastern margin of the Indo-Australian oceanic lithospheric plate. The geology and structure of the ridge reflect the complexity of the evolving tectonics and stratigraphy of an accretionary wedge. Pre-Cretaceous meta-sedimentary rocks, Upper Cretaceous ophiolites and Palaeogene–Neogene sedimentary formations indicate rapid, spatial and temporal changes in lithology, sedimentology, sedimentary and tectonic environments, and palaeogeographic setting. This chapter outlines the current geodynamic setting, evidence for the history of accretion and regional geology and introduces the regional stratigraphic framework.

The Andaman–Nicobar Islands are part of a 5600 km long curvilinear belt of accretionary ridges and outer-arc islands that stretches from Sumba in Eastern Indonesia to Western Burma in the north associated with the subduction of Indo-Australian oceanic lithosphere below an overriding Eurasian (Sunda) Plate (Fig. 6.1). The Andaman–Sumatra section is broadly aligned north–south sub-parallel to the present-day travel direction (N11°) of the Indo-Australian oceanic lithosphere, resulting in oblique convergence at a rate of 43 mm a^{-1} (Moeremans *et al.* 2014). By contrast, along the broadly east–west-trending section of the Java Trench to the south convergence is nearly orthogonal. A small embayment in the Andaman forearc in the region of 9° N to the west of the Nicobar Islands records the proximity of the Ninety-East Ridge (Fig. 6.1), which is the largest bathymetric feature in the Indian Ocean, related to the Kerguelen hotspot (Krishna *et al.* 2012). This paper outlines the origins of the Andaman–Nicobar accretionary ridge and explains the structural and regional stratigraphic framework. The gravity map in Figure 6.2 shows the principal features of the Andaman region. An outline of the tectonic evolution of the Andaman–Sumatra margin can also be found in Chakraborty & Khan (2009).

Early development of the Andaman–Nicobar accretionary ridge

Chapter 5 in this volume (Morley & Searle 2017) explained the Cenozoic tectonic regime that drove the opening of the Andaman Sea and the separation of the Andaman and Nicobar Ridge from SE Asia. By contrast, the formation history of the Andaman Ridge is poorly preserved due to the destruction of older oceanic lithosphere that carried information about plate drift paths and timing for onset of subduction. While it is known that continental SE Asia is formed from a number of relatively small continental blocks that separated from the northern margin of Gondwana, drifted northwards and accreted to Asia throughout the Palaeozoic and Mesozoic (e.g. Metcalfe 1999; Seton *et al.* 2012), the timing of some of these collisions is debatable. Even the drift path of the Indian continental block soon after break-up of eastern Gondwana into Australia–Antarctica and Greater India is not well defined prior to chron C34 (*c.* 83.5 Ma) because subduction has removed this information (Seton *et al.* 2012).

By the Middle Jurassic it is likely that a recognizable SE Asian margin existed with a subduction zone extending from West Burma to Sumatra and beyond (Hall 2012). Although there is little evidence preserved on Andaman for an early active margin, the geology of Sumatra and Myanmar provides some insights. Upper Jurassic–Lower Cretaceous development of the proposed Woyla intra-oceanic arc (Barber 2000; Barber & Crow 2005), that separated Mesotethys from Cenotethys, ended in the Upper Cretaceous with the acceleration in drift of India and thrusting and accretion of the arc onto the Sumatran–Sundaland margin. Although the timing of the Woyla collision is not well-defined, Upper Cretaceous intrusions dated by the K–Ar method yielded ages of 87–98 Ma (Bennett *et al.* 1981). As these bodies were emplaced into imbricated and deformed Woyla Group rocks, the associated ophiolitic rocks (represented by a dismembered oceanic assemblage including peridotites and ocean-floor sediments) must have been emplaced before 98 Ma (Barber 2000). Further north in Myanmar, Mitchell (1993) recognized similarities in the geology between West Burma and the Woyla Nappe of West Sumatra. He noted that the geology of West Burma includes Upper Cretaceous andesites, basalts, ophiolites, serpentinites and cherts, belonging to an intra-oceanic arc that was thrust to the NE over the Eurasian margin as the Mawgyi Nappe. Although the Upper Cretaceous geology of Andaman is confined to a dismembered oceanic crustal sequence, of which trondhjemitic rocks on South Andaman have been dated to 95 $\pm$ 2 Ma by zircon U–Pb geochronology (Pedersen *et al.* 2010), it is interesting to note the broad similarity in timing with the arc accretion events elsewhere along the Burmese and Sumatran sectors of the subduction zone. Given the lack of older basement rocks on Andaman it is probable that formation of the Andaman Ridge, by subduction and off-scraping of oceanic lithosphere, accretion, uplift and thrusting of a thick pile of trench and ocean-floor sediments and lithosphere, overlapped with the Woyla–Mawgyi arc collision and may even have involved the collision of a precursor oceanic arc.

Since the observation made by Tipper (1911) and Gee (1927) on the occurrences of ‘Older sedimentaries’ (schist, gneiss, quartzite, marble) of inferred pre-Tertiary age, many workers have identified metasedimentary rocks in the

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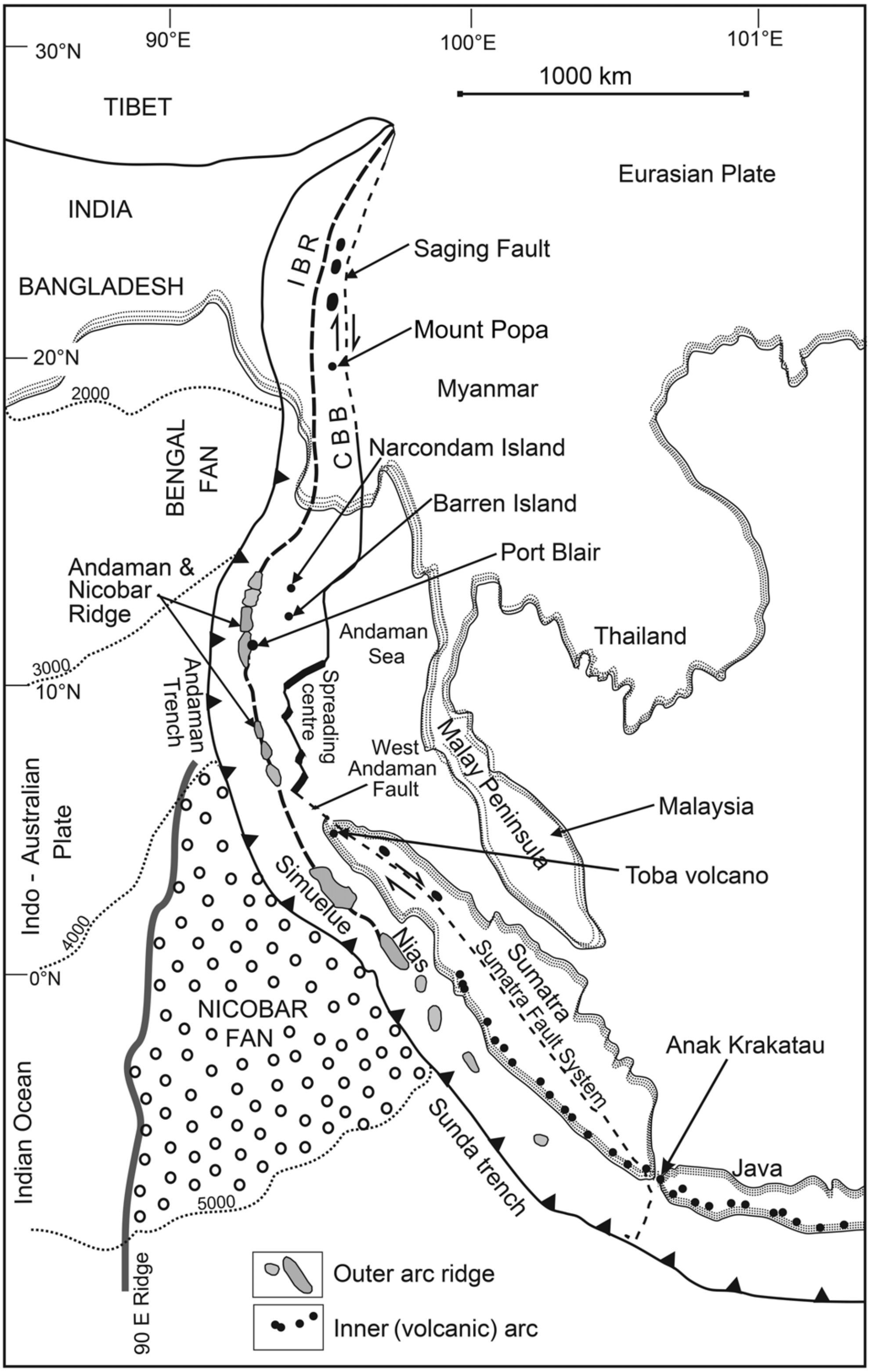

Fig. 6.1. Tectonic map of the Western Sunda Arc showing major present-day morphotectonic elements including Andaman–Nicobar accretionary ridge and Barren and Narcondam volcanic islands. IBR, Indo-Burma Ranges; CBB, Central Burma Basin. Chain of solid black circles indicates volcanic are (modified after Curray 2005).

Andaman Islands (see Chapter 4 for details) and interpreted the existence of nearby continental crust as implying that the Andaman Islands were located close to a continental margin during the early Cenozoic. While there is clear evidence for a continental origin for much of the Palaeogene sediment on Andaman (Allen *et al.* 2008), the bulk of this material was transported by large submarine flows (Andaman Flysch; see Chapter 7 for details) and do not require source regions proximal to the Andaman Ridge (Bandopadhyay & Ghosh 2015). However, this does not appear to be the case for the older sedimentary rocks within the Mithakhari Mélange (Chapter 6 for details) that include arc and continental material from more local source regions. A new interpretation outlined by Morley (2017) makes a strong case for the Alcock and Sewell rises (Fig. 6.2), located east of the Andaman Ridge, to be formed of hyper-extended continental or island-arc crust, not Miocene oceanic crust.

Cenozoic deformation events on Andaman are not well dated. The Andaman Flysch was deposited during 30–20 Ma, and based on apatite fission track data uplifted at 20 Ma (Allen *et al.* 2008). During the Miocene and Pliocene the top of the ridge was dominantly shallow-marine and the

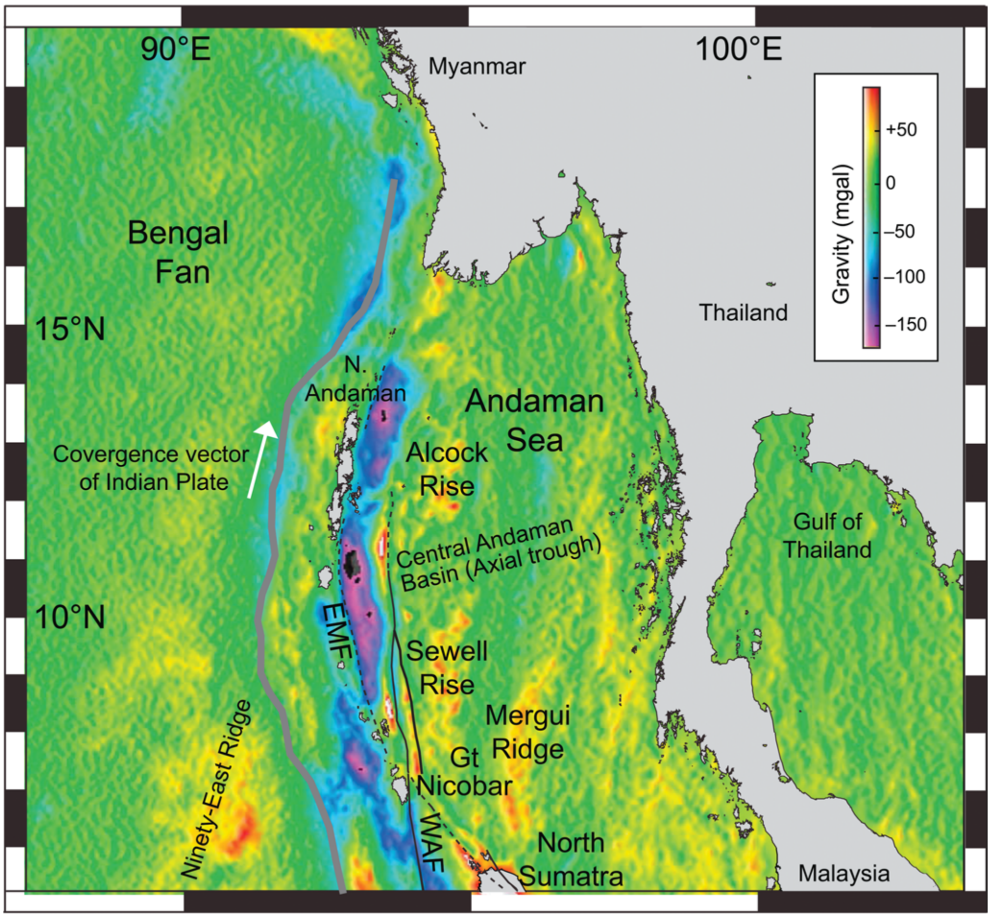

Fig. 6.2. Gravity map (Sandwell & Smith 1997) of the principal features of the Indian oceanic plate, the Andaman subduction zone and the Andaman Sea. EMF, Eastern Margin Fault; WAF, West Andaman Fault.

flanks remained in a relatively deep-marine environment, resulting in the deposition of subtidal to intertidal sediments mixed with subordinate deep-water sediments and reworked arc-related tuffs. The evolution of the Andaman–Nicobar arc during the Neogene involved several episodes of uplift and subsidence (Sharma & Srinivasan 2007) (see Chapter 11 for details) associated with the changing stress regime with slab rollback, final indentation of India and the opening of the Andaman Sea. Seismic data indicate a switch from Oligocene east–west to WNW–ESE extension to NNW–SSE-orientated extension from the late Oligocene onwards (Morley 2017). As the 2004 earthquake revealed, the Andaman–Nicobar Islands were tilted by uplift by >1 m in the west and a similar amount of subsidence in the east (see Chapters 14 & 15 for further details). It is interesting to note that in 1925 Sewell, while studying the Andaman region, concluded that recent tectonism had tilted the region westwards. The geology of these islands therefore records key information on the Palaeogene–Neogene–Quaternary tectonics of the Western Sunda Arc as well as other geological processes associated with an active margin.

Structure of the accretionary wedge

Banghar (1987) noted that most of the earthquakes across the Andaman arc between January 1967 and December 1982 were shallow, and inferred that the focal mechanism solutions of 13 shallow events were characterized by thrust, normal and strike-slip faulting. The orientation of the slip vectors deduced from the thrusting is consistent with the underthrusting of the Indian Ocean lithosphere below the Andaman–Nicobar Islands in a northeasterly direction. A compilation of depths of earthquakes greater than magnitude 4.5 since 1973–2009 by the USGS National Earthquake Information Center includes deeper earthquakes (focal depths >50 km), and these reveal the location of the Indian Ocean Plate within the mantle. Beneath the exposed Andaman Ridge, the bottom of the seismic zone is around 160 km (Fig. 6.3) shallower than further south along the Sunda margin. Below Java the deepest earthquakes are >500 km (McCaffrey 2009). This difference is consistent with normal subduction behaviour whereby there is a correlation between the maximum depth of earthquakes in the subducting slab and the rate of subduction perpendicular to the margin. Subduction along the Java margin is currently *c.* 59 mm a^{-1} compared to 43 mm a^{-1} along the Andaman sector.

In an accretionary setting new material is progressively accreted to the thin outer end of the accretionary wedge, while the oldest and thickest inner part of the accretionary wedge near the inner trench wall may be thickened further, increased in volume by underplating and consequently uplifted and exposed to form a chain of fold-thrust belt islands (Morley *et al.* 2011). Early knowledge of the underlying structure of the Andaman Ridge was obtained from regional seismic reflection studies performed by the Scripps Institution of Oceanography between 1968 and 1979 and the Indian state Oil and Natural Gas Commission (ONGC) in the mid-1970s and early 1980s. The latter carried out a detailed seismic reflection study across the Andaman Islands, calibrated against offshore boreholes drilled to the east and west of the islands (see Chapter 16). However, the stratigraphic framework applied to these drill cores used some of the original Oldham (1885) names for the formations. These data, presented in Roy (1983, 1992) and later combined with the Scripps datasets in Curray (2005), show that the Andaman Ridge is formed of imbricate thrusts of east-dipping fault slices and folds with a westerly vergence linked to rollback of the subduction zone.

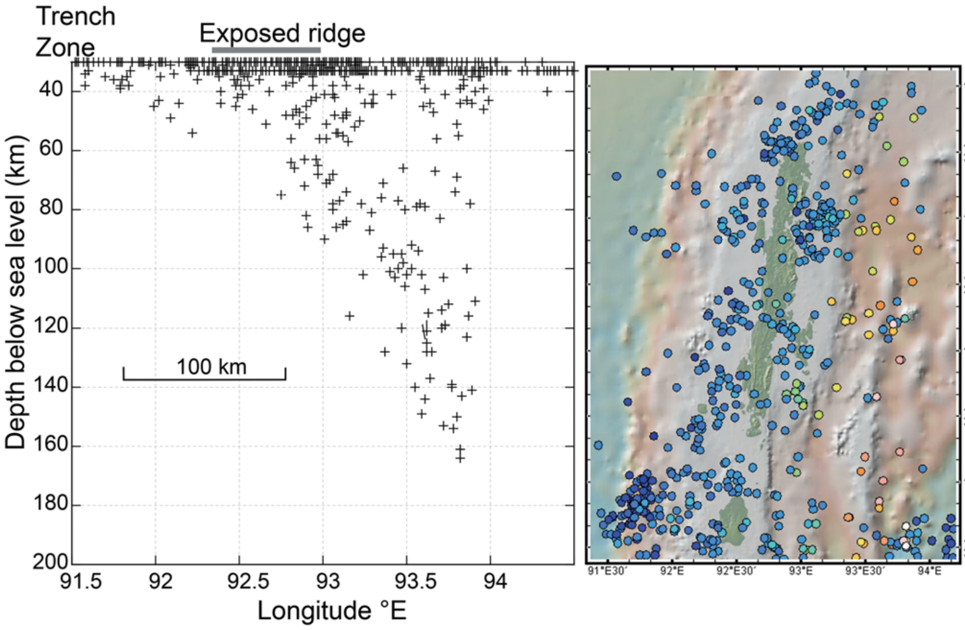

Fig. 6.3. Distribution of deep earthquakes beneath Andaman greater than magnitude 4.5 between 1973 and 2009, compiled by the USGS National Earthquake Information Centre. These earthquakes trace the location of the Indian ocean plate within the mantle. Plotted using Geomapapp (http://www.geomapapp.org/) and the Global Multi-Resolution Topography (GMRT) Synthesis (Ryan *et al.* 2009)

More recent work following the 2004 Sumatra earthquake provides high-resolution deep seismic reflection profiles across the subduction front, accretionary prism, forearc and the volcanic arc off northern Sumatra, to the north of Great Nicobar and to the south of Little Andaman (Moeremans *et al.* 2014). This study observed a northwards increase in the thickness of the sedimentary cover on the subducting plate along the margin, as would be expected from sediment delivered by the Bengal and Nicobar fans that were first delineated and named by Curray & Moore (1974). The exception to this trend was in the area around 9° N where the Ninety-East Ridge converges on the trench and where, because of the shallower bathymetry, the sediment cover is much thinner. This contrast in thickness of sediment cover can be seen on the two interpreted seismic profiles in Figure 6.4. Another noticeable difference is that near Sumatra the frontal slope of the accretionary wedge displays landwards-vergent faulting that reverses on the upper slopes, whereas just to the south of Andaman all of the thrust slices are seawards-verging, the most common style of deformation in accretionary wedges. The most likely explanation for this difference is the change in thickness of sediment cover on the incoming ocean plate from 3.5–6 km west of the Nicobar Island decreasing to 1.2–2 km near the Andaman Islands (Fig. 6.3). A wider discussion of this topic can be found in Moeremans *et al.* (2014).

Structural trends on the exposed ridge

The main structural features of the Andaman Islands are readily seen on digital elevation models (DEMs) and satellite images (Fig. 6.5) and comprise: (1) north–south-trending parallel ridges, running along the western side of the Middle and South Andaman and Rutland Islands; and (2) discrete hills that include the highest peaks on the islands (300–700 m a.s.l.). These differences relate to the two main geological units: the Oligocene marine fan sedimentary rocks of the Andaman Flysch; and the Upper Cretaceous ophiolites and Eocene mélange of Mithakhari shallow-marine sedimentary rocks (Fig. 6.6). The eastern side of the island chain represents a disrupted terrane (Jones *et al.* 1983) or a chaotic terrane (Cowan 1985). By contrast, the western side can be classed as a coherent terrane made up of deep-marine turbidite sandstones; although faulted, folded and sheared, these units can be traced along-strike from the northern tip of North Andaman Island (13° 25′ 759″ N; 92° 53′ 040″ E) to the southern tip of Rutland (11° 25′ 406″ N, 92° 37′ 387″ E) (Fig. 6.6). This striking distribution extends offshore, confirmed by drilling on the western side of North Andaman and offshore the east coast of Middle and South Andaman (Roy 1992; Roy & Das Sharma 1993).

The contact between the two main structural grains on the map is drawn as a major thrust lineament along Hubdeypur (11° 39′ 55″ N, 92° 38′ 20″ E): Farargunge–Buratage in South Andaman and Kadamtala–Bajato (12° 45′ 720″ N, 92° 48′ 272″ E) in Middle Andaman (Fig. 6.6). This feature divides the main islands of Andaman into an eastern sector, where deformation has been more intensely associated with ophiolite thrusts and mélange-like outcrops, from a western section of flysch rocks deformed into anticlines and synclines, truncated locally at the crest of the anticlines by thrusts and small tear faults that break the longitudinal continuity of the flysch (Karunakaran *et al.* 1968; Ray 1982). Pandey *et al.* (1992) named the main thrust as the Jarawa Thrust, although we prefer to describe it as the Jarawa Over-thrust to distinguish it from the widespread imbricate thrusting that produced tectonically interleaved thrust-packages of ophiolite and Mithakhari Mélange.

All of the tectonostratigraphic thrust slices exposed on Andaman dip to the east and conform to the fundamental tenet of the stratigraphy and structure of the accretionary wedge model of a terrane that shows an oceanwards younging (Ogawa 1998). The tectonostratigraphy of the Andaman Islands discussed below shares many features in common with accretionary margins such as Barbados, Cascadia, Aluetians, Makran and Nias islands (Clift & Vannucchi 2004). The fold-thrust belt of the Andaman accretionary wedge compares with deep-water fold-thrust belts (DWFTBs) formed in an accretionary setting, as characterized and classified by Morley *et al.* (2011). Among other characteristics, Type 1 DWFTBs are dominated by continent-derived quartz-rich sandstones. For Type 2 DWFTBs, diagenetically reactive minerals derived from igneous and ophiolitic sources are commonly present, or are poorly preserved in well-developed turbidite sandstone units. In Andaman–Nicobar, both quartz-rich, classical turbidites and quartz-poor, volcanic-lithic-rich, poorly developed turbidites occur (Bandopadhyay 2012). In this respect, the Andaman DWFTB bears signatures of both Type 1 and Type 2 DWFTBs systems and appears atypical.

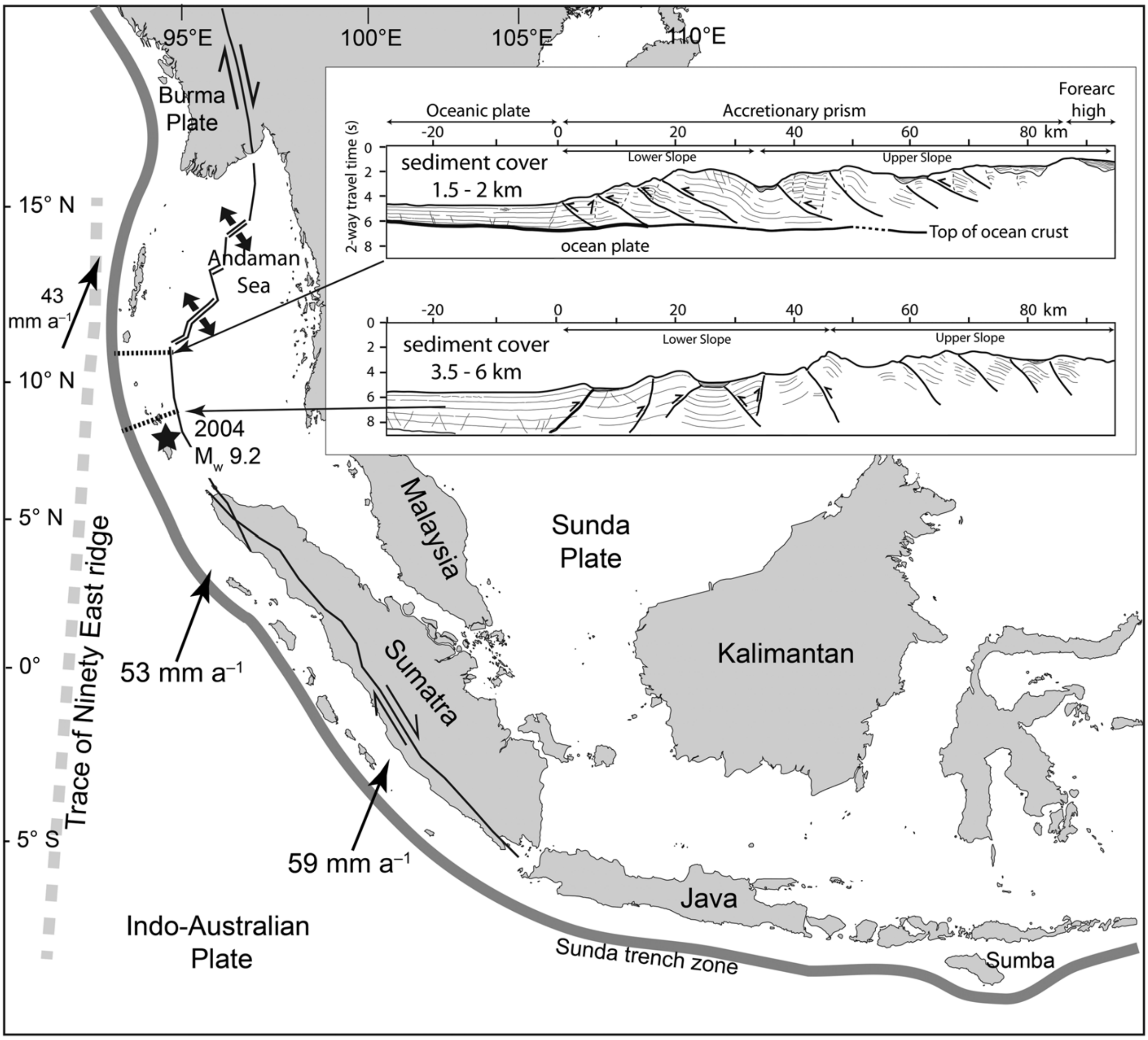

Fig. 6.4. Two seismic reflection profiles across the subduction front and accretionary prism, to the north of Great Nicobar and to the south of Little Andaman, show differences in vergence of thrusts at the frontal part of the wedge associated with changes in thickness of sediment cover on the ocean plate due to the influence of the Ninety-East Ridge (after Moeremans *et al.* 2014). The star shows the location of the 2004 earthquake.

Stratigraphy

The pioneering study of Oldham (1885) classified the rocks of the Andaman Islands into a Port Blair Series and a younger Archipelago Series separated by extrusive and intrusive igneous rocks represented by serpentines and volcanics, later recognized as ophiolites. Tipper (1911) and Gee (1927) broadly accepted the nomenclature of Oldham and also recognized rocks such as calc-gneisses, quartzite and chert. They described these rocks as ‘Older Sedimentaries’ formed before the Tertiary. Boileau (1950) covered parts of Baratang Island, South Andaman and Ritchie’s Archipelago. The argillaceous sedimentary rocks of Baratang Island were classified as the Baratang Formation while the fossiliferous calcareous, arenaceous and lutitic rocks of Ritchie’s Archipelago have been assigned to the Archipelago Series. Systematic geological mapping, drilling and stratigraphic study by GSI and ONGC began in 1959. Since then, M.B. Pawde, K.K. Ray, S.S. Saha, A.K. Chatterjee and K.C. Karunakaran of GSI and P.K. Chatterjee, S.K. Pandey, T.K. Roy and S.K. Roy and many other geologists of GSI and ONGC have mapped large areas of the Andaman Islands, including Great Nicobar.

Arising from these studies has been a long debate on the stratigraphy, leading to modifications in formation names as well as the introduction of new names. For a detailed scrutiny of the stratigraphy, a number of reviews are available (e.g. Karunakaran *et al.* 1967; Bandyopadhyaya *et al.* 1973; Mukherjee 1982; Srinivasan 1988; Acharyya *et al.* 1989; Pandey *et al.* 1992; Sharma & Srinivasan 2007). Table 6.1 outlines the current stratigraphy based on a wide body of data including lithology, tectonic and palaeoenvironmental setting, sedimentary facies, petrography, palaeontology and radiometric dating. A few of the major developments are summarized below.

Early studies considered the different geological units of the Mithakhari/Baratang Group to be stratigraphically related. These units were mapped at 1:50 000 scale and assigned

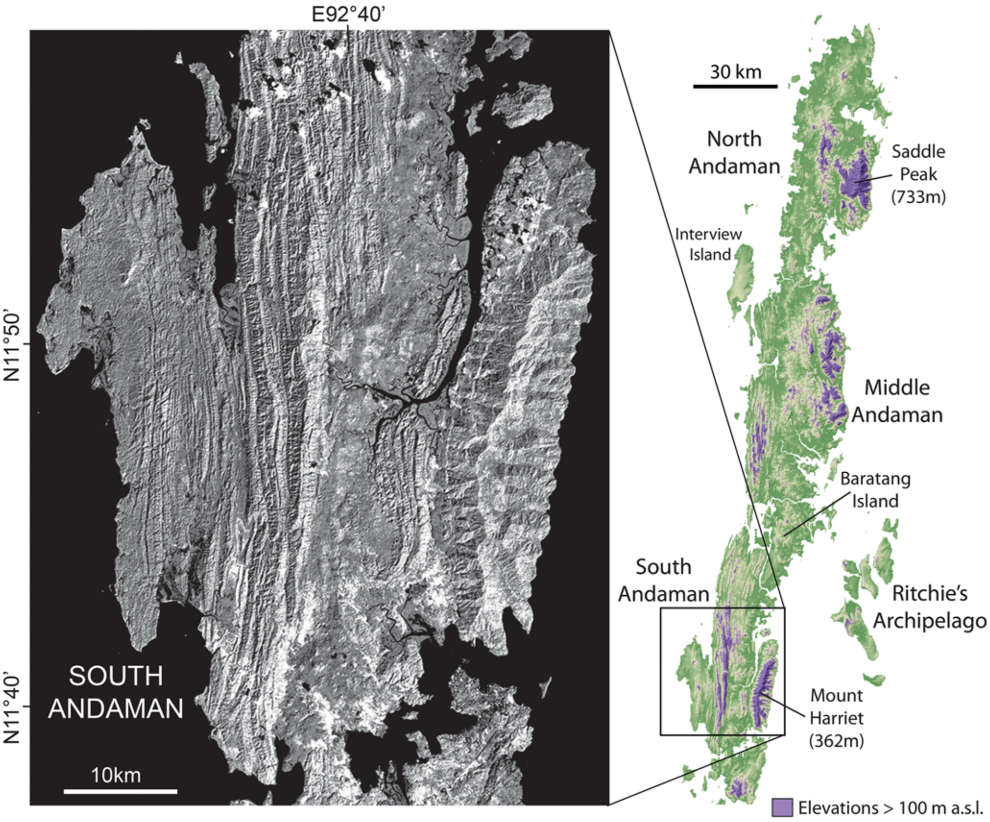

Fig. 6.5. DEM of the Andaman Islands and a more detailed LandSat image of South Andaman show two main structural units: (1) north–south-trending parallel ridges, running along the western side of the Middle and South Andaman and Rutland islands; and (2) a series of hills that include the highest peaks on the islands.

'formation' status (Karunakaran *et al.* 1968; Ray 1982; Pandey *et al.* 1992). Later studies (Acharyya *et al.* 1989; Bandopadhyay 2005, 2012; Acharyya 2007) recognized that these 'formations' are not stratigraphically related and most outcrops occur as chaotic units resembling boulders and blocks. Some of the marginally deformed blocks (coherent units) preserve a relict stratigraphy that facilitates reconstruction of an earlier history. Otherwise, these units show strong shearing and folding including fold-thrust slices in tectonic contact with the younger Flysch Formation. The term 'mélange' instead of 'formation' therefore appears more appropriate for rocks of the Mithakhari unit and the term 'Mithakhari Mélange' should be used in future study.

Reviewing the tectonostratigraphy of the Tertiary succession, Acharyya *et al.* (1989) proposed that the ophiolite occurred at a higher (outer) structural level compared to the accretionary wedge sedimentary rocks that tectonically floored the ophiolite. Structural sections that expose the contact between the ophiolite and sedimentary rocks of the accretionary wedge (Mithakhari Mélange) are seldom available. One such exposure occurs in the Badmash Pahar ultramafic quarry (11° 39′ 003″ N, 92° 39′ 548″ E) in South Andaman where the contact can be seen between NE-trending and east-dipping fractured and sheared serpentinized harzburgite of the upper structural level that directly overlies the Mithakhari conglomerate-sandstone-shale unit of the lower structural level (Fig. 6.7a). The contact is defined by a layer a few centimetres thick consisting of numerous polished mud chips showing a scaly foliated fabric, typical of shales which have been mobilized in mud diapirs, and due to crystallization of clay minerals on shear surfaces (Barber *et al.* 1986). These occur between the altered dark-greenish ultramafics (above) and light-pink-coloured mudstone that, to some extent, still preserve sedimentary laminations (Fig. 6.7b, c). Elsewhere, the Mithakhari rocks are tectonically imbricated with oceanic pelagic sediments or beds of the Lipa Formation (Acharyya *et al.* 1989). In a few cases coherent units of the accretionary sediments (Mithakhari Mélange) overlie ophiolitic rocks of the upper structural belt, such as to the east of Saddle Hill in North Andaman. Karunakaran *et al.* (1968) observed that a prominent unconformity separates the Mio-Pliocene Archipelago Group from the pre-Miocene formations. They compared the intense folding and thrusting of the pre-Archipelago Group and associated erosional unconformity to the Helvetic phase of the European Alps.

Chatterjee (1964) was the first to apply biostratigraphy and place the Palaeogene lithostratigraphy into a temporal framework. He identified *Distichoplax biserialis*, an index alga of late Paleocene age, from limestone clasts occurring in conglomerates of the Hope Town Conglomerate, South Andaman Island. Kundal & Wanjarwadkar (2002) also identified *Distichoplax biserialis* in a massive deposit of the same limestone from the Middle Andaman Island. Both studies confirm a late Paleocene age for these limestones, providing a maximum age constraint for the Hope Town Conglomerate (HTC). Chatterjee (1964) suggested an early Eocene age for the HTC based on identification of *Assilina* daveisi de Cizancourt in the conglomerate matrix. He also assigned a middle Eocene age for the Namunagarh Grit (NG) based on the occurrence of *Nummulites atacicus* Leymerie, *Assilina papillata* Nuttall, *N. subatacicus* Douville and *Discocyclina sp*. Gururaja & Rao (1976) identified *Pellatispira Sp* and *Biplanispira Sp* in addition to *Nummulites* and *Discocyclina* in limestones occurring in the upper part of NG in South Andaman and suggested the existence of an upper Eocene limestone horizon above the NG formation and below the Andaman Flysch. Roy *et al.* (1988) conducted detailed palaeontological investigations of the sedimentary rocks interstratified or immediately overlying the ophiolites, and their work suggested a Upper Cretaceous–Paleocene age for the sediments described in the literature as oceanic pelagic sediments (described and discussed in Chapter 5 of this volume). Pawde & Ray (1964) stated that the unfossiliferous Andaman Flysch overlain by the Mio-Pliocene limestone of Archipelago Group must have been deposited during the Oligocene. Allen *et al.* (2008) reported zircon and apatite fission track (ZFT and AFT),

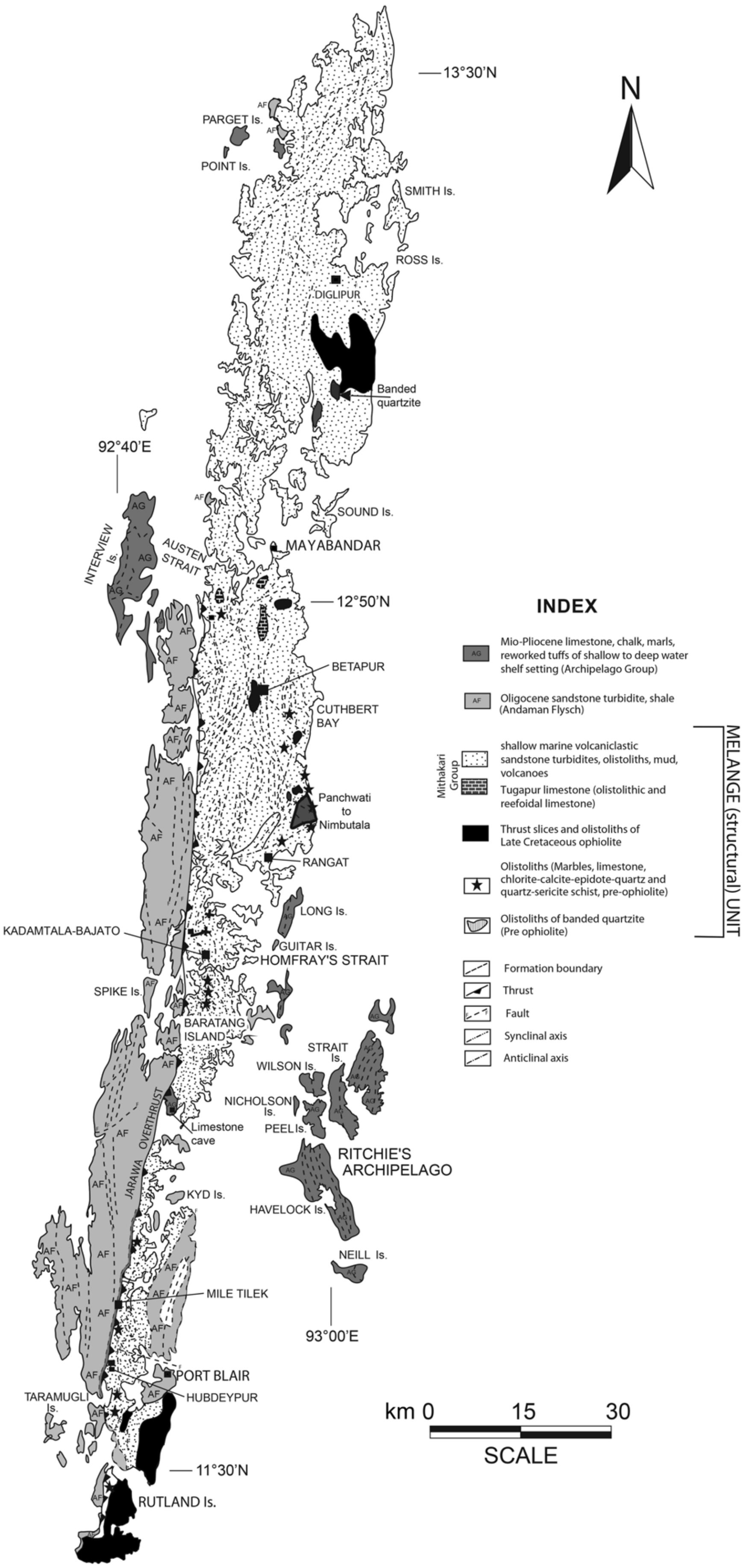

Fig. 6.6. Geological map of the Andaman Islands showing the main geological units and structural features (after Karunakaran *et al.* 1964*a*, *b*, *c*; Chatterjee 1967; Acharyya *et al.* 1989; Pandey *et al.* 1992; Acharyya 2007).

Table 6.1. *Stratigraphy of the rocks of Andaman–Nicobar convergent margin accretionary ridge (islands); compiled and modified after Chatterjee (1964, 1967), Karunakaran et al. (1968), Pandey et al. (1992), Rajshekhar & Reddy (2003a, b) and Bandopadhyay (2012)*

Epoch	Isotopic ages	Group Name	Formation name and members		Structure/lithology	Sedimentary environment/ tectonic setting	Biostratigraphic indicators
Holocene – Pleistocene	^{14}C-dating of beach rock (1350–4410 years BP*)	Archipelago	Neil Formation • Neil Limestone Member • Chidiyatapu Member (Rajshekhar & Reddy 2003*a*, *b*)		Alluvium, mangrove, coral rags (Holocene); beach rock and conglomeratic shell limestone (late Pleistocene)	Sub-aerial to intertidal	
Miocene–Pliocene		Archipelago (*c.* 400 m thick)	Karunakaran *et al.* (1968) 5. Jirkatang Limestone 4. Muralat Chalk 3. Melvile/ Guiter Limestone 2. Round Chalk 1. Strait Conglomerate and shell-sandstone	Srinivasan & Sharma (1973) 5. Malacca Limestone 4. Sawai Bay 3. Long Siltstone 2. Nancowry Mudstone 1. Strait Sandstone	Cross- and parallel laminated bioclastic limestone, marls, calcareous mudstone/siltstone, chalk, and felsic turbiditic tuffs	Shallow marine, shelf	Foraminifers, *Lepidocyclina*, *Miogypsina*, *bryozoan* and algae (Srinivasan & Chatterjee 1981)
Late Eocene–Oligocene	Ar–Ar mica ages limit deposition to between 30 and 20 Ma[†]	1. Andaman Flysch (Karunakaran *et al.* 1968) 2. Port Blair Series (Chatterjee 1964) (thickness estimation varies from 300 to >3000 m)	3. Corbyn's Cove Formation 2. South Point Formation 1. Galathea Formation (Ray 1982)	3. Greywacke Stage (unfossiliferous) 2. Grit Stage (Kirthar) 1. Conglomerate Stage Nummulites of Kirthar age are reworked (Pandey *et al.* 1992; Bandopadhyay 2012)	Parallel-bedded quartz-rich greywackes; shale turbidites, Bouma sequences sole marks are abundant	Deepsea fan	Barren of fossils (Chatterjee 1964; Allen *et al.* 2008)
Late Paleocene–Eocene	U–Pb and FT ages show deposition after 60 Ma and no later than 40 Ma[†]	Mithakhari Group[‡] (Karunakaran *et al.* 1968) Baratang Group (Mukherjee 1982) (thickness estimation varies from <700 to 1400 m)	2. Namunagarh Grit including Wrightmyo Nummulitic Limestone Member. 1. Hope Town-Conglomerate with Tugapur Limestone Member		2. Massive and locally graded and channelized beds of gritty and coarse grained volcanolithic sandstone, graded tuff, lithic-poor arkoses and limestones; trace fossils and shale flake conglomerates common 1. Matrix to clast-supported polymictic conglomerates and sandstone with shale and foraminiferal limestones	2. Shallow water basins perched on slopes of the accretionary wedge and fed by small fans 1. Same as Namunagarh Grit	*Atacicus Leymerie*, *Assilina papillata Nuttall*, *N. subatacicus Douville* and *Discocyclina* (middle Eocene); *Nummulites acutus*, *N. atacicus*, *Assilina papillata*, *Pelatispira*, *Biplanispira* (upper Eocene) (Chatterjee 1964) 1. *Distichoplax biserialis* in limestones (late Paleocene) (Chatterjee 1964); *Assilina daveisi de Cizancourt* in conglomerate matrix (lower Eocene) (Chatterjee 1964)
Late Cretaceous–Paleocene	Zircon U–Pb age of 95 ± 1.3 Ma trondhjemite (Pedersen *et al.* 2010)	Ophiolite			Serpentinized harzburgite, peridotites, dunite, pyroxenite gabbro, diorite plagiogranite, basalt radiolarian chert, muddy carbonate, mudstone, tuffaceous siltstone	Thrust slices of ocean floor turbidites and oceanic lithosphere to form accretionary ridge	*Spumellarion radiolarian*, *Globigerina eugubina*, *G. trilloculinsides*, *Globorotalia compressa* and *Globotruncana* (Roy *et al.* 1988)
Pre-Cretaceous rocks	–	Metasediments Port Meadow Formation Prolog Group			Olistoliths of limestones, Mithakhari sandstones, red mudstone, breccias, pelagic red chert, quartz-chlorite-muscovite schist, garnet-pemontite- actinolite schist, crystalline limestones and banded quartzite	Represent elements of passive continental margin or metamorphic sole	

*Rajshekhar & Reddy (2003*a*, *b*)
[†]Allen *et al.* (2008).
[‡]Mithakhari Group redefined as Mithakhari Mélange (Acharyya 1997; Bandopadhyay 2005, 2012).

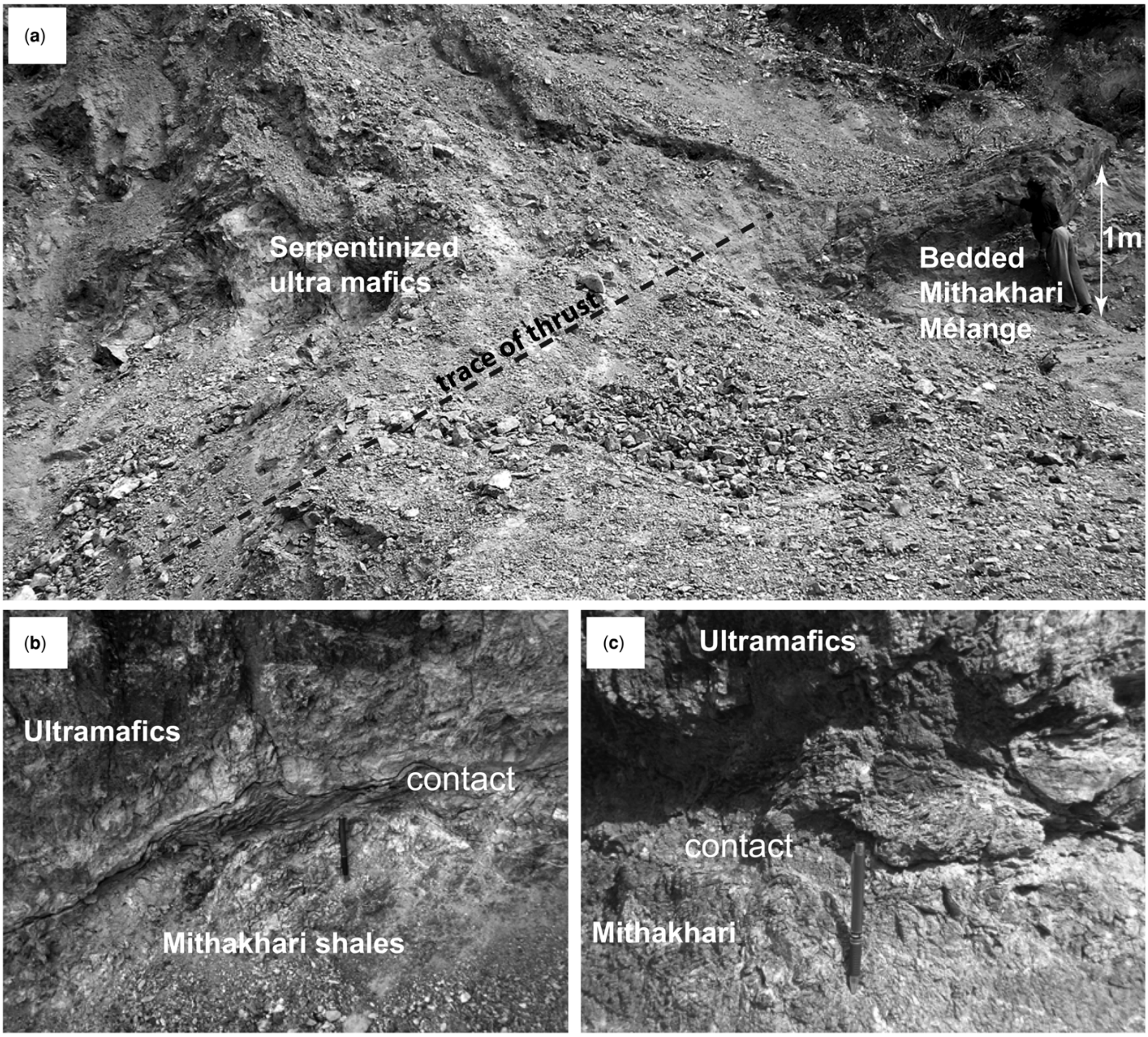

Fig. 6.7. (**a**) Ophiolite quarry, Badmash Pahar, South Andaman. Bedded sequence of pebbly sandstone-shale showing easterly dip of the Mithakhari Mélange in lower structural level, tectonically flooring the serpentinized ophiolite of the upper structural level. The contact zone is covered with scree deposits derived from the upper slope. Close views from adjacent outcrops show (**b**) sharp contrast between the ultramafic rocks (above) and the Mithakhari shale (below); the contact shows the presence of centimetre-thick crenulated layers of scaly and foliated chips of shale; and (**c**) sharp planar contact and laminations in the left middle part of the shale. Pen is 14 cm long.

apatite (U–Th)/He, $^{40}Ar/^{39}Ar$ muscovite and zircon U–Pb ages from the main Palaeogene formations. These data constrained deposition of the sampled Mithakhari sediments to after 60 Ma and no later than 40 Ma, and the Andaman Flysch from the east coast of South Andaman to 30–20 Ma (Table 6.1). Neogene and Holocene biostratigraphy is more established due to better preservation and four decades of detailed work on planktic foraminifera, radiolaria and other nannofossils, conducted mainly by Professor M.S. Srinivasan and co-workers (Sharma & Srinivasan 2007).

With regard to the stratigraphy of Baratang Island, Mukherjee (1982) noted that ophiolites were surprisingly absent given that they occur on the South, Middle and North Andaman islands. Baratang Island is almost entirely covered by the rocks of the Mithakhari Mélange. Other lithologies on Baratang include minor outcrops of older sedimentary rocks and limestone of the Mio-Pliocene Archipelago Group. This island is virtually free of large faults and thrusts. Instead, active mud volcanoes are found on Baratang Island (Poddar 1952) (Fig. 6.8), unlike the other islands apart from North Andaman Island (Fig. 6.6). Gentle effusive eruptions from the mud volcanoes produce grey liquid mud, gas and brown oily substances that ooze out of the crater mouths and form small mud streams (insets of Fig. 6.6). Current studies reveal emission of thermogenic hydrocarbon gases, water with much lower chlorinity than seawater, and young (<40 ka) smectite-illite-kaolinite-chlorite-dominated argillaceous sediments (Ray *et al.* 2013*b*). When more explosive eruptions occur, the flows often contain rock fragments of Mithakhari sandstones and rarely chert, chaotically embedded in a mud matrix. They represent diapiric mélanges, and similar mélanges are widespread in mud volcano sites on the islands of Indonesia, Pakistan and Barbados (Barber *et al.* 1986; Barber 2013). In contrast to Andaman mud volcanoes, mud volcanoes on Nias

Island contain clasts from a wide range of geological formations including fragments of recent corals (Samuel & Harbury 1996). Boileau (1950) considered Baratang Island as a suitable target for gas/oil-bearing stratigraphic traps. Researchers have also established a seismo-geochemical monitoring station at Jarawa Creek (12° 07′ 26″ N; 92° 47′ 21″ E) to monitor gas emissions (Chaudhuri *et al.* 2012).

Stratigraphic studies of Quaternary deposits on the Andaman Islands in relation to understanding neotectonics and Quaternary sea-level history have only recently been taken seriously, mainly in the post-tsunami period (Rajshekhar & Reddy 2003*a*, *b*; Bandopadhyay *et al.* 2008; Rajendran *et al.* 2008; Awasthi *et al.* 2013; see also Chapter 15). Deposits consisting of Pleistocene limestone (soft, granular and white) and recent beach rocks, terraces, coral rags and shell limestones are classified as the Neill Formation, part of the Archipelago Group (Rajshekhar & Reddy 2003*a*). The Neill Formation is subdivided into a lower Neill Limestone Member (Pleistocene; Srinivasan & Azmi 1976*a*) and upper Chidiya Tapu Member (Holocene) consisting of beach rock.

Geological summary

The published literature detailing geological fieldwork and mapping of Andaman is not extensive (Karunakaran *et al.* 1964*a*, *b*, *c*, 1965, 1968, 1975; Chatterjee 1967; Srinivasan & Sharma 1973; Srinivasan & Azmi 1976*a*, *b*; Srinivasan & Chatterjee 1981; Srinivasan & Dave 1981; Parthasarathy 1984; Haldar 1985; Srinivasan 1988; Acharyya *et al.* 1989; Vohra *et al.* 1989; Sengupta *et al.* 1990; Pandey *et al.* 1992; Bandopadhyay & Ghosh 1998; Chakraborty *et al.* 1999; Chakraborty & Pal 2001; Pal *et al.* 2003, 2005; Bandopadhyay 2005, 2012; Pal & Bhattacharya 2010), leaving scope for future detailed work. In this section we outline the main features and issues associated with the regional geology. Subsequent chapters provide more in-depth examination of these units.

The large-scale geological map of South Andaman (Fig. 6.9) shows a tectonically interleaved package of ophiolites, Mithakhari Mélange and Andaman Flysch. The whole package displays open antiformal and synformal structures with NNE–SSW trends (Fig. 6.9). The entire folded sequence has been further thrust over the Andaman Flysch of the western terrane. The Andaman Flysch in the eastern terrane has been mapped as a regionally folded open anticline. The folds are generally upright with a low plunge varying over 5–10° in northerly and southerly directions. The axial planes of the folds generally dip at high angles towards the east making the folds asymmetric, verging westwards in places and developing into overfolded structures with the one overturned limb showing a reverse order of superposition (Karunakaran *et al.* 1968; Ray 1982). The overturned limb of the Andaman Flysch of the eastern terrane forms the Mount Harriet range and its continuation through Port Blair to Corbyn's Cove, South Andaman (Fig. 6.9). On the shore platform at South Point (11°39′ 30″ N; 92° 45′ 20″ E) are well-developed swarms of flute casts, exposed due to overturning of the sandstone bed (fig. 2f of Bandopadhyay & Ghosh 2015).

A widely accepted view, deep-rooted in the Andaman literature, is that the turbidite sandstones of the western and eastern terranes are stratigraphically and age-wise the same; however, our own preliminary studies involving integration of field, petrographic and geochemical data reveal differences that do not fit with this simple interpretation and the two units may not be stratigraphic equivalents. Our efforts to sample for nannofossils in the shale couplets of the turbidites found no preserved material for biostratigraphic dating. Garzanti *et al.* (2013) recorded staurolite in beach sands along the western coast, but did not find any in the beach sands at Corbyn's Cove on the eastern side of South Andaman (for both areas the local source rocks for the sands are the so-called Andaman Flysch). They considered this significant and proposed different sources for the beach sands of western and eastern outcrops. Framework and heavy mineral analyses of Oligocene Andaman Flysch from the western and eastern outcrops (carried out at the Provenance Analysis Laboratory, University of Milano, Boccaccio, Italy; Chapter 10), published petrographic and geochemical data of flysch sandstones from both eastern and western outcrops (Allen *et al.* 2008; Bandopadhyay & Ghosh 2015) and detailed geochemistry of sandstones from these two areas (undertaken at PRL, Ahmadabad by J.S. Ray) have highlighted significant differences that call into question whether the western succession is contemporaneous with the more widely studied and accessible Palaeogene Andaman Flysch mapped along the eastern side of Andaman. Also, the dismembered ophiolites and the associated accretionary sedimentary rocks in this belt are interpreted as allochthonous, occurring as nappes thrust westwards over the upper Palaeogene distal shelf to flysch sedimentary rocks (Andaman Flysch) (Sengupta *et al.* 1990; Acharyya 1997). The comments of Curray (1992) in this regard are worth noting. He questioned whether the westwards-thrust ophiolite nappes are allochthonous. Is the tectonically underlying Oligocene Andaman Flysch autochthonous? Or are they both allochthonous and part of an accretionary prism, which has had a very complex history, possibly including subduction zone flips (Mitchell 1985)?

The geological framework of South Andaman Island as mapped by Karunakaran *et al.* (1968) has been widely adopted in later studies (Acharyya *et al.* 1989; Acharyya 1997, 2007) but there are problems with this work. The geological map (Fig. 6.9) shows that the tectonic pile of mélange sediments and ophiolites were not thrust over the distal flysch sediments as mentioned by Acharyya *et al.*, but instead were thrust over the rocks of the younger Archipelago Group. The geological map of Middle Andaman (Fig. 6.6) shows thrusting of the mélange units over the flysch sediments and not over the Archipelago Group. The geology of Baratang Island does not contain any evidence of thrusting. Do these differences point to diachronous thrusting events in different parts of the island arc? These are the intriguing problems that need to be addressed by future studies.

Across the Andaman–Nicobar Islands sedimentary rocks are by far the most abundant; ophiolite and metamorphic rocks are subordinate components of the exposed lithologies. Due to the tropical climate and large expanses of densely vegetated areas, fresh rock exposures are rare and largely confined to the coast, stone quarries, road sections and building sites. The next section summarizes the key attributes and current interpretations of the main geological units exposed on Andaman:

1. olistoliths of metasedimentary rocks ('Older Sedimentaries');
2. bedded sequences: slivers and olistoliths of thinly laminated multi-coloured, siliceous and calcareous mudstones, radiolarian jasper and chert and minor limestones;
3. thrust sheets (nappes) and blocks (olistoliths) of ophiolites (mélange);
4. Mithakhari Mélange: slumps, slides, debris flows (matrix- to clast-supported) polymict conglomerates, volcaniclastic turbidites (gritty to fine-grained sandstones, graded beds of greenish tuffs), siltstone, carbonaceous shale, coal, mudstones, shallow-water limestones and mud volcanoes;
5. Andaman Flysch: deep-marine turbidite sandstones and interbedded shale and coal (minor);

Fig. 6.8. Mud volcano at Jarawa Creek on Baratang Island (12° 07′ 26″ N, 92° 47′ 21″E). (**a**) Several minutes after the 26 December 2004 Indian Ocean 9.2 *M* earthquake, there was a large eruption triggered by seismic shaking. (**b**) By contrast, recent activity is small scale.

6. Archipelago Group: shallow- to deep-water and highly fossiliferous shelf sediments consisting of chalk, limestones, mudstone, calcareous sandstones and reworked tuffs; and
7. terrace deposits, beach rocks, coral rag and alluvial conglomerates.

The pre-Cretaceous metasedimentary rocks, to be discussed in detail in Chapter 7, comprise small (up to a few metres across) lenses, blocks and irregular-shaped bodies spread over low-lying areas between the ophiolite and Mithakhari Mélange (Fig. 6.6). All along the eastern side of the islands are heterogeneous blocks of these rocks in a sheared argillaceous matrix.

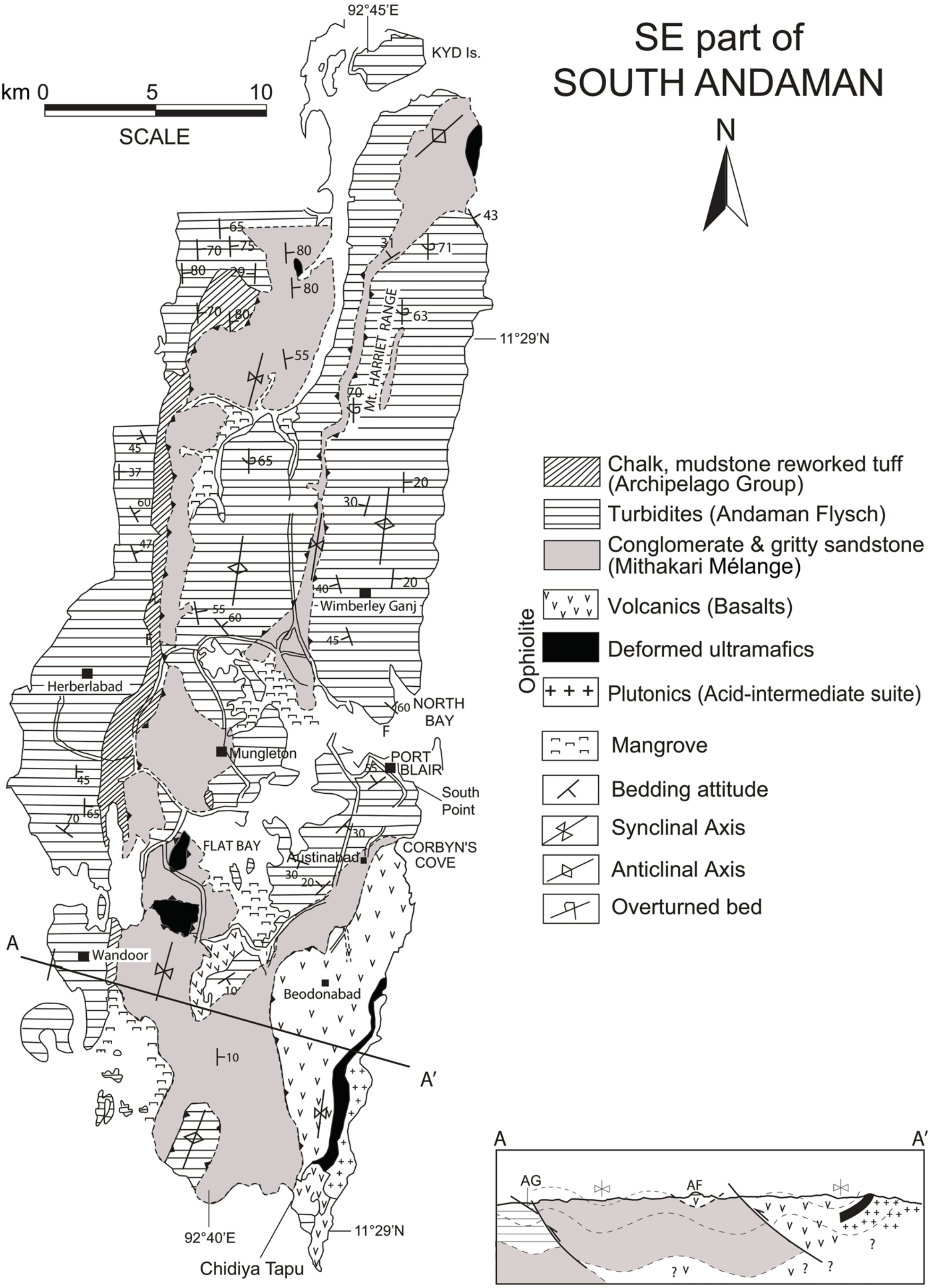

Fig. 6.9. The geological map of South Andaman shows a thrust package of Mithakhari Mélange, Andaman Flysch and ophiolite which have been folded and juxtaposed against the Jarawa overthrust, forming a division between western and eastern terranes.

The blocks are limestones and marbles, cherts, quartzite and garnet-bearing actinolite–chlorite schists and gneisses interpreted either as remnants of an older continental margin or as formed during low-grade, subduction-zone metamorphism, possibly as the ophiolite sole (Sengupta *et al.* 1990; Pal & Bhattacharya 2010). Gee (1927) and Tipper (1911) described these rocks as 'Older Sedimentaries'. Since then, several studies also interpreted them as metasedimentary rocks derived from a continental margin setting (Bandyopadhyaya *et al.* 1973; Ray 1982; Acharyya *et al.* 1989; Bandopadhyay 2012). In the Sumatran outer-arc islands, the mixing of ophiolitic material which has been subducted with material of continental basement origin led to the proposition that the Sumatran continental basement extended beneath the forearc basin as far as the outer-arc islands, against which subducted material and oceanic material has been accreted (Barber & Crow 2005). This model seems to fit the Andaman situation exactly.

The Cretaceous ophiolites described and discussed in detail in Chapter 7 comprise incomplete (dismembered) units of a thick mantle sequence (tectonically deformed) and serpentinized peridotites (mainly harzburgites with subordinate pyroxenite) hosting dunite pods (Vohra *et al.* 1989; Pal 2011). The complete (mantle-crustal) sequence (cumulates, gabbros, rare plagiogranites, sheeted dykes, basaltic pillow lavas, an andesite–dacite volcanic suite and the lenses of bedded radiolarian chert/jasper overlain or interstratified with basalt can be recognized in a *c.* 17 km long stretch along the east coast of South Andaman from south of Corbyn's Cove to Chidiya Tapu (Fig. 6.9) (Ray *et al.* 1988; Vohra *et al.* 1989; Pal *et al.* 2003; Saha *et al.* 2010). Recent work by Ghosh *et al.* (2014) recorded a petrologic signature of a Moho transition zone within a 6 m wide petrological section exposed in the Kodiaghat area, 10–12 km south of Corbyn's Cove. Acharyya *et al.* (1989), Acharyya (1992, 1997, 2007) and Sengupta *et al.* (1990) described the Andaman ophiolites as flat-lying nappe sheets that are openly folded, and not as steeply east-dipping slices as described by Pal *et al.* (2003). Further detailed mapping is required to resolve this. Although discussed in detail in Chapter 7, it is worth mentioning that the zircon U–Pb ages (95 $\pm$ 2 Ma, Pedersen *et al.* 2010; 94 $\pm$ 1 Ma, Sarma *et al.* 2010) from trondhjemites and plagiogranites, which give the age of the formation of the ocean floor at the spreading ridge, are similar to those of peri-Arabian Ophiolites formed above subduction zones from Cyprus to Oman. This suggests that formation and emplacement of the Andaman Ophiolite occurred in all probability in the Upper Cretaceous and possibly Paleocene.

The Upper Cretaceous–Paleocene thinly laminated and thin-bedded finer-grained sediments (see Chapter 7 for details), closely associated with the ophiolite and the Mithakhari Mélange, comprise slivers, bedded sequences and olistoliths of multicoloured mudstones, interbedded chert-limestones (limestone minor), thin-bedded radiolarian cherts, tuffaceous shales and metamorphic quartz-bearing siltstones (Bandopadhyay & Ghosh 1998), described as Oceanic Pelagic Sediments (OPS, Matsuda & Isozaki 1991).

The lower Palaeogene Mithakhari Mélange (major lithologies include conglomerates, gritty to fine-grained sandstones including bedded tuffs, shales and limestones) occurs as both coherent and chaotic units (Bandopadhyay 2012). Currently, there is a major gap in age control in that there is little biostratigraphic dating evidence for the Mithakhari Mélange units and therefore it is entirely possible that 'coherent and chaotic units' formed at different times. Were this shown to be the case in the future, it would negate treating these as a single stratigraphic unit. The coherent units show a fining-upwards succession starting with matrix-supported conglomerates followed by sand-rich units that include tuffaceous sandstones and tuffs. Sedimentary attributes suggest that the sandstone-shale couplets may not be true turbidites but belong to small-scale gravity flows (Mattern 2005). The clastic sediments have therefore been interpreted as slope basin deposits, and the reefoidal limestones as deposits formed in shallow water on top of slope basins perched on the accretionary slope. The detritus for the clastic rocks was sourced from a magmatic arc and accreted ophiolites. The enigmatic Lipa Black Shale (Table 6.1) has been interpreted as diagnostic of a euxinic environment within a trench-slope setting (Lipa Black Shale of Karunakaran *et al.* 1968), but despite an assiduous search in the field the authors have been unable to find an unequivocal exposure of this unit to verify this. There were two periods of widespread euxenic conditions in the world's oceans during the Cretaceous. The Aptian (*c.* 120 Ma) event is too early as it predates formation of Andaman ocean crust. This means that the Cenomanian–Turonian boundary at *c.* 93 Ma, which post-dates the U–Pb ages for formation of ocean crust, is the likely candidate. Although subduction has removed most of the evidence for this event, exposures of Cretaceous Tethys and the Cenomanian–Turonian euxinic event are found in outcrops of Tethyan marine sediments (equivalent to locations on the northern edge of the Indian plate) in Tibet (Bomou *et al.* 2013). Furthermore, given that all the indicators point to mobilization of black shales in a mud diaper, it is misleading to consider the Lipa Black shale as a discrete stratigraphic unit.

The end of the Eocene and the beginning of the Oligocene is marked by the abundant supply of clastic material deposited as extensive and thick sand-rich turbidites (Andaman Flysch) on an open submarine fan. The exposed Andaman Flysch has been interpreted to form the floor of a pile of tectonic slices consisting of igneous members of the ophiolite suite, oceanic pelagic sediments, olistostromal argillites and ophiolite-derived clastic rocks (Ray *et al.* 1988; Sengupta *et al.* 1990; Acharyya 1992). More recent work by Allen *et al.* (2008) and Bandopadhyay (2012) established that the Palaeogene turbidite sandstones were derived from recycled orogenic sources together with a subordinate arc-derived contribution. Allen *et al.* (2008) used apatite fission track thermochronometry data to identify when these rocks were first uplifted at *c.* 20 Ma well after a post-emplacement uplift of the ophiolite and related rocks that took place during 60–40 Ma, calling into question the interpretations made by the earlier studies.

The Neogene Archipelago Group (see Chapter 11 for details) in its lower part consists of Lower Miocene foraminiferal mudstones overlain by chalk containing several intervals of white claystones (Karunakaran *et al.* 1968); the upper part consists of sandstones, mudstones, calcareous sandstones, siltstones, argillaceous limestones, chalk and granular limestones, deposited in subtidal to intertidal shelf (Srinivasan & Azmi 1976*a*; Srinivasan & Chatterjee 1981). The white claystones were first identified as ash beds by Srinivasan (1980). Unfortunately, several subsequent studies did not mention the work of Srinivasan; instead the ash beds were claimed as a new finding in the work of Pal *et al.* (2002, 2005). Bandopadhyay & Ghosh (1995) described these beds as felsic tuffs of the Archipelago Group. Good sections of the tuff-bearing sedimentary formations can be found near Hubdeypur (11° 39′ 55″ N, 92° 38′ 20″ E), Bichdera (12° 30′ 20″ N, 92° 58′ 55″ E), Mile Tilek (11° 46′ 40″ N, 92° 40′ 10″ E) (Fig. 6.6) and the coastal area south of Manglutang (11° 30′ 20″ N, 92° 11′ 55″ E) (Fig. 6.9). Here, the narrow strip of interbedded mudstones and tuffs are underlain by western terrane Andaman Flysch, while to the east they are overlain by thrust units of the Mithakhari Ophiolite Mélange. The road section near Mile Tilek shows tectonically steepened sequences of off-white to light-greenish-white, very light and friable, bedded tuffs and dark fissile mudstones of lower Miocene age (Srinivasan 1988). Recently, Awasthi *et al.* (2015) dated the tuffs near

Mile Tilek using the $^{40}Ar/^{39}Ar$ method and claimed that the tuffs are much younger (late Pleistocene) in age. Previous work dating back to Karunakaran *et al.* (1965) assigned a Miocene age to the tuff-bearing sequences, presumably based on local biostratigraphic evidence, but locations differ meaning that outcrop need not be of the same age.

Field, petrological and geochemical studies on these tuffs (see Chapter 11 for details), which are widespread across the islands of Richie's Archipelago and also on South Andaman Island (recorded since Karunakaran *et al.* 1965), have shown the tuffs are part of the turbidite sequences consisting of locally cross-laminated beds of tuffs interbedded with mudstones of lower Miocene age (Karunakaran *et al.* 1965, and all subsequent studies of Srinivasan). These rocks have been subject to considerable alteration. The major-element chemistry of these inferred felsic tuffs does not match that of conventional felsic volcanic rocks; K_2O values are higher than Na_2O in all samples. The variable and fairly high loss on ignition (LOI) in most analyses >8 wt% (Pal *et al.* 2003, 2005) indicate chemical alteration, that is, reworked and weathered rock. On Havelock Island and in Hubdeypur adjacent to Mile Tilek tuffs are interbedded with shallow-marine sediments. These tuffs are therefore evidently reworked and altered. Biostratigraphic work on the entire Neogene sequence (Sharma & Srinivasan 2007) has indicated a lower Miocene age for the tuffs and the tuff-bearing sedimentary sequences. As noted above, not all of the tuffs in the different areas may have the same age; however, the evidence for alteration and reworking that we found in the rocks from the same outcrop at Mile Tilek studied by Awasthi *et al.* (2015) suggests that the proposed depositional age requires re-examination.

Ritchie's Archipelago and Little Andaman Island of the Andaman Group are formed from Neogene sedimentary rocks. Studies of the geology of Little Andaman Island are few. The first geological reference is contained in the reports of Gee (Gee 1927), which recorded outcrops in Jackson Creek and near Hut Bay (Fig. 1.1). After a long gap of nearly four decades, Srinivasan (1969, 1975) and Srinivasan & Singh (1980) published detailed descriptions of the geology, lithology and stratigraphy based on the study of smaller foraminifera. The geology of the island (Fig. 6.10) largely comprises dark-bluish-grey highly calcareous mudstone (Hut Bay Formation of Srinivasan 1975), chalk and limestone of Neogene age (Archipelago Group). Outcrops located in the south-western corner of the island expose Mithakhari sandstones and serpentinites, dolerite and volcanic rocks associated with ophiolite. Neogene sediments overlie these unconformably. The limestone beds overlie silty mudstones that yielded abundant and well-preserved planktic foraminifera typical of the *Globorotalia Siakensis* and *Globorotalia menardii* Zones (Havelockian Stage). The overlying limestone beds, which contain mollusc fossils, also produced *Neogloboquardrina acostaensis*, *N. Continuosa*, *Globorotalia menardii*, *Spheroidinellopsis seminulina* and *Clobigerinoides extremis*. The presence of *N. acostaensis* suggests that the beds belong to the Neogloboquadrina acostaensis Zone of the late Miocene (Neillian Stage).

Nicobar Islands

The geological studies of the Nicobar Islands are mainly confined to Car Nicobar, Great and Little Nicobar islands and a few smaller islands. The geology, geography and fauna of the Nicobar Islands were first studied by the British, sometimes in remarkable detail (Rink 1847; Hochstetter 1866; Ball 1870;

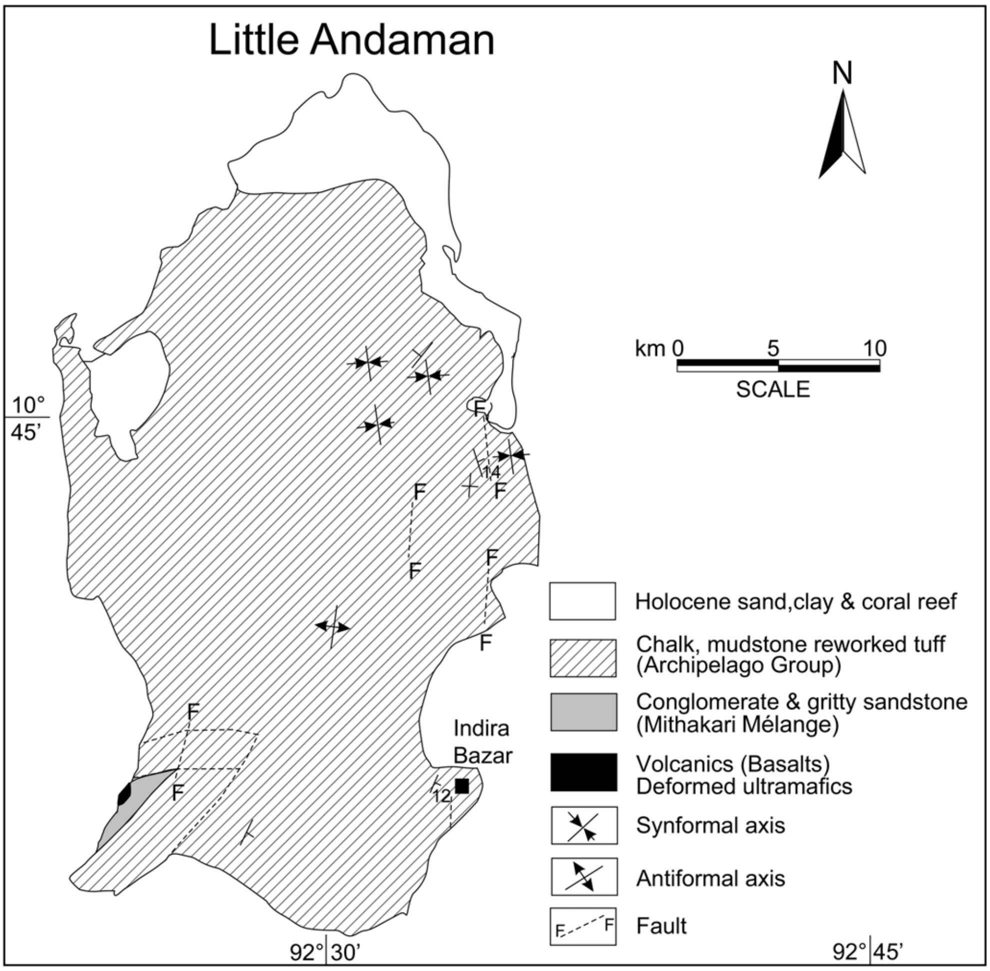

Fig. 6.10. Geological map of Little Andaman.

Tipper 1911; Gee 1927). The late 1950s and early 1960s saw the first efforts by the GSI at systematic mapping, and this continues to the present day. The first geological map was published by the GSI in 2012 (GSI Misc Publication no. 30, part XX, 2012). The Joint Scientific Expedition to Great Nicobar Island in 1966 is also noteworthy for making a comparison between the rock units of Great Nicobar Island with those of Andaman (Karunakaran *et al.* 1975). Geological units recognized on the Great Nicobar and Little Nicobar islands have been correlated with and named following the stratigraphic nomenclature of Andaman. Photogeology studies coupled with strategic ground-truthing fieldwork by GSI have helped to define the geology of the more inaccessible islands of the Nicobar Group (Biswas & Sarkar 1997; Das & Biswas 1997). The geology of Great Nicobar Island is summarized in Figure 6.11. Sharma & Srinivasan (2007) outlines four decades of work by Srinivasan and co-workers on the Neogene sedimentary rocks of Nicobar.

Great Nicobar Island comprises a highly folded terrane with a few longitudinal thrusts and several diagonal wrench faults. The ophiolite-Mithakhari belt is thrust over the Andaman Flysch in Cheruvai, Campbell and Andersen bays (Karunakaran *et al.* 1975). Deep-marine turbidite sandstones (Andaman Flysch) covers almost the entire width and length of the Great and Little Nicobar islands (Fig. 6.11). Basalts of ophiolite suite and conglomerates-sandstones of the Mithakhari Mélange that almost cover the entire island of Katchal are a minor component. Following the 2004 mega-thrust earthquake, the outcrop geology changed due to tilting of the islands. As a consequence, most of the ophiolite is no longer well exposed. Pillow basalts similar to those seen on South Andaman are exposed on the northern coast of Campbell Bay. The islands of Car Nicobar, Chowra, Teressa, Camorta and Nancowry (Fig. 1.1) are predominantly made up of fossiliferous Neogene chalk, claystones, diatomaceous earth, fine-grained quartzose sandstones marlstones, foraminiferal mudstones and bioclastic and reefoidal limestones. Ophiolite-related rocks occur in small outcrops in the northern part of Teressa and Nancowry islands, the southern part of Camorta Island (located just north of the Nancowry Islands) and virtually over the whole of Tillangchong and Bompoka islands (Fig. 1.1). The rocks are chiefly made up of basalts; however, occurrences of serpentinized ultramafic rocks and diorite-plagiogranite-agglomerate have been reported from Tillangchong Island by Biswas & Sarkar (1997). Other rock types reported by these authors include conglomerates, and sandstones of the Mithakhari group, with olistolithic blocks of cherty limestones, calcified serpentinites and a few outcrops of meta-sedimentary rocks (quartzite, quartz-sericite schist and banded chert). Recent geochemistry studies of basalts from Bompoka Island of the Nicobar Group show a back-arc basin basalt affinity similar to the pillow basalts on South Andaman (Jafri & Sheikh 2013). It is important to note that the ophiolites in the Nicobar Islands are dominated by basalts, with virtually no occurrences of ultramafic or mafic rocks of mantle affinity.

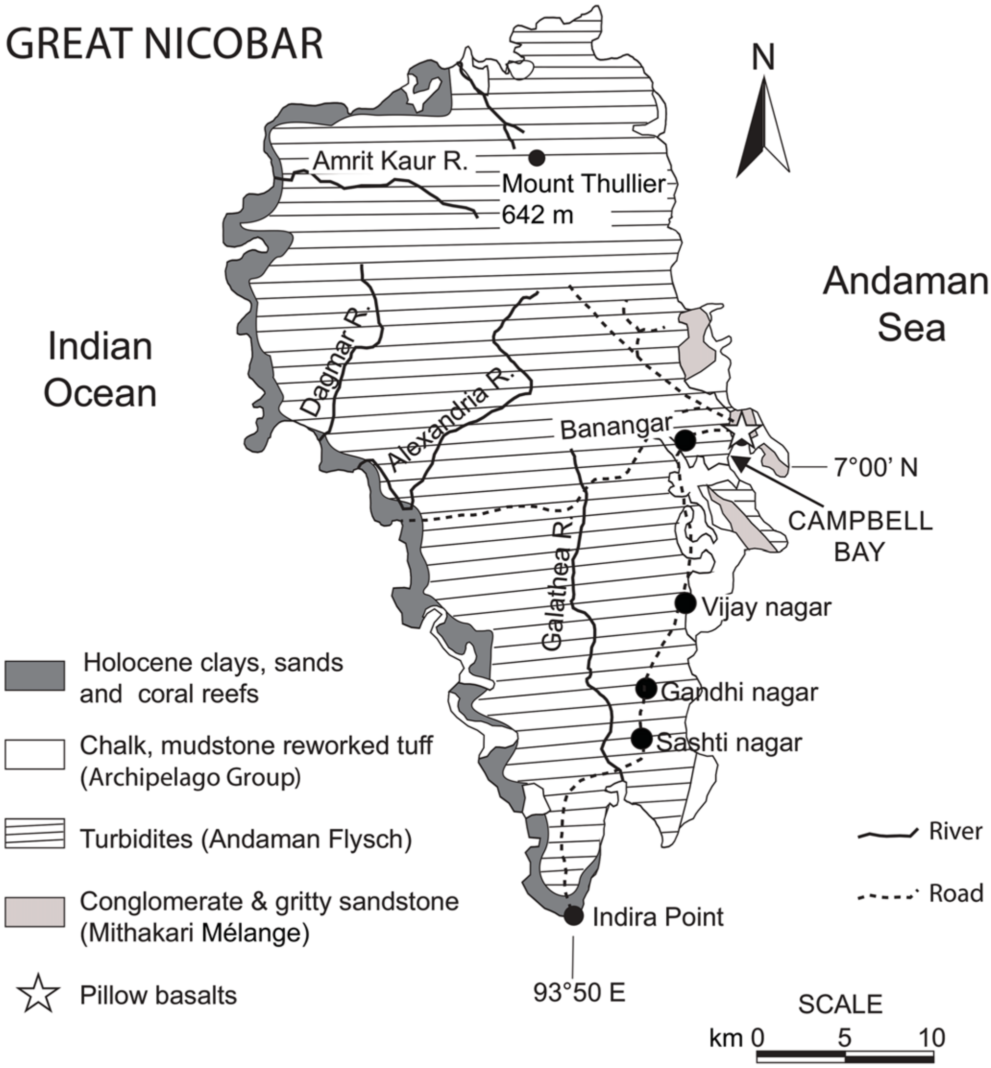

Fig. 6.11. Geological map based on post-tsunami outcrops of Great Nicobar modified and adapted from the 2010 survey map of the island.

Quaternary and active arc volcanism

Active, dormant and extinct Quaternary and active volcanoes form an inner volcanic arc that extends from south of Sumatra to north Myanmar, for example Mount Popa (Fig. 6.1). Of the inner arc volcanic belt within the Andaman Sea, Barren Island is an active volcano while the volcano that forms Narcondam Island is dormant. Ever since the first landing and geological mapping by Hobday & Mallet (1885), these volcanic islands have been regarded within the context of the geological framework of Andaman–Nicobar accretionary and subduction system as summarized here and detailed further in Chapter 12.

The sub-aerial volcanic islands of the Narcondam and Barren islands belong, along with other submarine volcanoes, to a chain that runs parallel to the accretionary wedge. The southern end of the volcanic arc is located in Sumatra and contains 34 volcanoes. The same chain of volcanoes extends further east into other islands of Indonesia as part of a separate volcanic arc linked to subduction of the Indian Plate beneath Eurasia. About 80% of these volcanoes are either active or have had eruptions in the Holocene (Siebert *et al.* 2010). Barren Island represents a composite volcanic system; it was believed that this volcano dated back to the Pleistocene (Shanker *et al.* 2001), and recent isotopic dating has supported this view (Ray *et al.* 2013*a*). A reappraisal of the volcanic eruptions and eruptive history of the Barren Volcano (Bandopadhyay *et al.* 2014) recognized a caldera-forming mafic stratovolcano that evolved, in historical times, into a scoria cone forming a basaltic volcano. By contrast, the dormant Narcondam Volcano represents a composite andesitic volcano, with evidence of repeated dome collapses and formation of pyroclastic surge flows (Pal *et al.* 2010). The nature and style of volcanism in these two volcanoes has been attributed to the difference in the basement rocks below the volcano, with the probability of the existence of continental or transitional crust below Narcondam and basaltic oceanic crust below Barren Island.

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