British Lower Jurassic Stratigraphy

M.J. Simms
Department of Geology,
Ulster Museum, Belfast

N. Chidlaw
Department of Earth Sciences,
University of Bristol

N. Morton
School of Earth Sciences,
Birkbeck, University of London

and

K.N. Page
School of Earth, Ocean and Environmental Science,
University of Plymouth

with contributions from

P. Hodges (Department of Geology, National Museums and Galleries of Wales, Cardiff)
M.J.Oates (BG Group plc, Reading)
N. Trewin (Department of Geology and Petroleum Geology, University of Aberdeen)

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Acknowledgements

Work began on selecting sites for the Lower Jurassic Stratigraphy part of the Geological Conservation Review more than a quarter of a century ago; in fact it was one of the first GCR subject 'Blocks' to be tackled by the GCR unit of the Nature Conservancy Council (NCC). Although some of the Lower Jurassic site reports that were drafted for the NCC during the site selection phase in the late 1970s and 1980s are not accredited in the GCR archive, it is known that several experts were consulted and involved both in GCR site selection, and report preparation, at that time including Philip Copestake, Tony Hallam, Phil Palmer, David Whiteside and Desmond Donovan. The authors of the present volume are indebted to these workers, and indeed to all of those who made a contribution to this early phase of the evaluation of British Hettangian–Pliensbachian sites for the GCR.

Although the majority of sites were selected for the GCR in the 1980s, since that time re-evaluation and more recent proposals have been translated into a revised GCR site list, as represented by the text presented here. So whereas some original GCR sites were re-evaluated and found wanting, others have been added to the GCR list. Thanks go to all of those who have helped in this updating work. Undoubtedly some readers will lament the exclusion of their favourite site, but stratigraphy, like any other science, is an ever-developing pursuit with new discoveries being made, and geological models subject to ongoing modification such that some sites increase in research value. Therefore, it is possible that further sites worthy of conservation will be identified in future years.

My own obsession with the Lias Group (often to the neglect of my school work) began in the early 1970s as new estates and pipe-trenches exposed the fossiliferous clays near my home. By the mid-1980s I had the opportunity to indulge my passion still further through my PhD research on Lower Jurassic echinoderms. My first involvement, albeit fleeting, with the Geological Conservation Review was a little earlier, in 1982, when I accompanied David Whiteside on a site assessment visit to Newnham (Wilmcote) Quarry. I have only a vague memory of the quarry – but much clearer recollections of the decrepit state of Dave's Morris Traveller! Fifteen years later, in 1998, I was contracted to prepare the final manuscript for the Lower Jurassic Stratigraphy GCR and was encouraged by JNCC to subcontract sections of the work to several others with appropriate areas of expertise; their names now appear as authors where they have written or substantially contributed to the site account. Many others have been generous with their help both

Acknowledgements

Access to the countryside

This volume is not intended for use as a field guide. The description or mention of any site should not be taken as an indication that access to a site is open. Most sites described are in private ownership, and their inclusion herein is solely for the purpose of justifying their conservation. Their description or appearance on a map in this work should not be construed as an invitation to visit. Prior consent for visits should always be obtained from the landowner and/or occupier.

Information on conservation matters, including site ownership, relating to Sites of Special Scientific Interest (SSSIs) or National Nature Reserves (NNRs) in particular counties or districts may be obtained from the relevant country conservation agency headquarters listed below:

Countryside Council for Wales,
Maes-y-Ffynnon,
Penrhosgarnedd,
Bangor,
Gwynedd LL57 2DW.

English Nature,
Northminster House,
Peterborough PE1 1UA.

Scottish Natural Heritage,
12 Hope Terrace,
Edinburgh EH9 2AS.

Preface

There is such a diversity of rocks, minerals, fossils and landforms packed into the piece of the Earth's crust we call 'Britain' that it is difficult not to be impressed by the long, complex history of geological change to which they are testimony. But if we are to improve our understanding of the nature of the geological forces that have shaped our islands, further unravel their history in 'deep time' and learn more of the history of life on Earth, we must ensure that the most scientifically important of Britain's geological localities are conserved for future generations to study, research and enjoy. Moreover, as an educational field resource and as training grounds for new generations of geologists on which to hone their skills, it is essential that such sites continue to remain available for study. The first step in achieving this goal is to identify the key sites, both at national and local levels.

The GCR, launched in 1977, is a world-first in the systematic selection and documentation of a country's best Earth science sites. No other country has attempted such a comprehensive and systematic review of its Earth science sites on anything near the same scale. After over two decades of site evaluation and documentation, we now have an inventory of over 3000 GCR sites, selected for around 100 categories covering the entire range of the geological and geomorphological features of Britain.

This volume, describing the British Lower Jurassic rocks of Great Britain, is the 30th to be published in the intended 43-volume GCR series. Not only does it contain the descriptions of key localities that will be conserved for their contribution to our understanding of the stratigraphy of rocks of this age, but also provides an excellent summary of the palaeontological and sedimentological features, and palaeogeographical significance to be found in them, and it outlines the research that has been undertaken on them. The book will be invaluable as an essential reference book to those engaged in the study of these rocks and will provide a stimulus for further investigation. It will also be helpful to teachers and lecturers and for those people who, in one way or another, have a vested interest in the GCR sites: owners, occupiers, planners, those concerned with the practicalities of site conservation and indeed the local people for whom such sites are an environmental asset. The conservation value of the sites is mostly based on a specialist understanding of the stratigraphical, palaeontological and sedimentological features present and is therefore, of a technical nature. The account of each site in this book ends, however, with a brief summary of the geological interest, framed in less technical language, in order to help the non-specialist. The

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first chapter of the volume, used in conjunction with the glossary, is also aimed at a less specialized audience. This volume is not intended to be a field guide to the sites, nor does it cover the practical problems of their ongoing conservation. Its remit is to put on record the scientific justification for conserving the sites.

This volume deals with the state of knowledge of the sites available at the time of writing, in 1998–2003, and must be seen in this context. Stratigraphy, like any other science, is an ever-developing pursuit with new discoveries being made, and existing models are subject to continual testing and modification as new data come to light. Increased or hitherto unrecognized significance may be seen in new sites, and it is possible that further sites worthy of conservation will be identified in future years.

There is still much more to learn and the sites described in this volume are as important today as they have ever been in increasing our knowledge and understanding of the geological history of Britain. This account clearly demonstrates the value of these sites for research, and their important place in Britain's scientific and natural heritage. This, after all, is the *raison d'être* of the GCR Series of publications.

N.V. Ellis
GCR Publications Manager
June 2003

Chapter 1

British Lower Jurassic stratigraphy:
an introduction

INTRODUCTION

M.J. Simms

The Lower Jurassic Series encompasses about 22 million years (Ma) of the geological record, from about 200 Ma to 178 Ma, a little more than a third of the total duration of the 58 Ma of the Jurassic Period as based on the most recent radiometric dates (Pálfy *et al.*, 2000a–c). The chronostratigraphically defined Lower Jurassic Series, incorporating the Hettangian to Toarcian stages (Figure 1.1), corresponds almost exactly to the lithostratigraphically defined Lias Group (but see later discussion on the base of the Jurassic System). The Lias Group crops out extensively in England, with a significant out-lying area in south Wales (Figure 1.2). The outcrop area of the Lias Group in Scotland is relatively small, comprising a remnant in the Solway Firth Basin, a small area in north-eastern Scotland (the **Dunrobin Coast Section** GCR site), and more extensive and better-documented outcrops in the Hebrides Basin of north-western Scotland. With few exceptions these deposits are fully marine and mark a striking contrast with the predominantly terrestrial deposits of the preceding Triassic System. They encompass a broad range of facies representing a correspondingly diverse range of environments. Most of these facies are fossiliferous, sometimes richly so, or yield exceptionally preserved material. Consequently they have been studied far more intensively than the Triassic sediments beneath.

Lower Jurassic strata in southern England figured in some of the earliest stratigraphical investigations anywhere in the world (Smith, 1797, MSS; Douglas and Cox, 1949) and many early 19th century collectors acquired some of the more spectacular fossils for which the Lower Jurassic Series was already noted as a result of the labours of Mary Anning and others (Lang, 1939). Although the coastal exposures of Dorset and Yorkshire clearly were important sources of fossil material and stratigraphical information, inland exposures also were a major source of information in these formative years of the sciences of geology and palaeontology. Until the mid-19th century numerous small quarries were opened along the Lower Jurassic outcrop to provide sources of building stone, bricks, cement and iron, and the materials were commonly used only locally in areas not well served by roads or rail. Even the coastal exposures were extensively modified by quarrying, for stone, lime, cement, alum and jet. Some quarries survived into the early 20th century in areas where transport links were poor, but most were abandoned as others, producing better-quality materials, assumed dominance of the market. Only a small number, such as that producing Ham Hill Stone, still thrive today providing material for a specialist market. Of the countless brickpits and cement works, very few large sites now still operate, such as **Blockley Station Quarry**.

The Industrial Revolution witnessed the establishment of many new quarries to exploit

				Radiometric dates (Ma)	
				Pálfy *et al.*	Harland *et al.*
Middle Jurassic	Aalenian				
				178.0 (+1.0/–1.5)	178.0 (+10.5/–10.5)
	Toarcian	Upper Lias			
				183.6 (+1.7/–1.1)	182.0 (+16.0/–14.0)
	Pliensbachian	Middle Lias			
Lower Jurassic			Lias Group	191.5 (+1.9/–4.7)	189.5 (+7.5/–7.5)
	Sinemurian				
		Lower Lias		196.5 (+1.7/–5.7)	203.5 (+7.5/–5.0)
	Hettangian				
				199.6 (+0.3/–0.3)	210.5 (+6.3/–8.8)
Upper Triassic	Rhaetian				

Figure 1.1 Chronostratigraphy and radiometric dates for the Lower Jurassic Series and its constituent stages. Based on Harland *et al.* (1990) and Pálfy *et al.* (2000c).
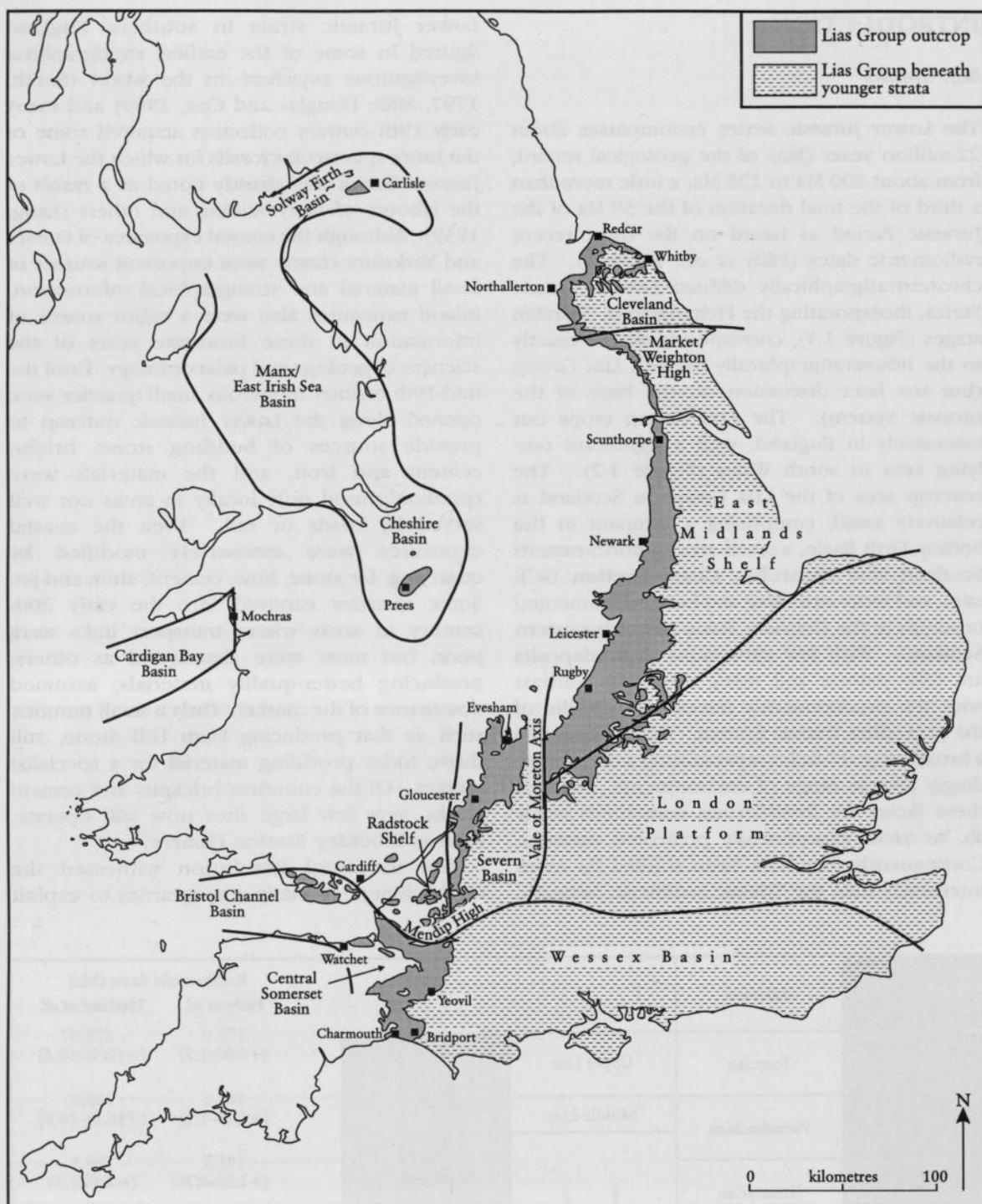
Figure 1.2 Outcrop and subcrop map for the Lias Group in England and Wales showing the location of the main sedimentary basins. After Cox *et al.* (1999).

the ironstones that are a conspicuous feature of the Lower Jurassic succession on parts of the Yorkshire coast, in the east Midlands and in the Hebrides. The scale of some of these excavations can be judged from figures cited by Whitehead *et al.* (1952), who noted that more than 500 million tons of Liassic ironstone had been worked up to 1945. The Yorkshire

succession for a while also supported a flourishing industry extracting alum from some of the Toarcian mudstones, while the growth in popularity of jet jewellery in the 19th century resulted in many small-scale excavations along this stretch of coast. The construction of the railways between the mid-19th and early 20th centuries also gave rise to many temporary exposures that added to our knowledge of the Lower Jurassic Series and its contained fauna (e.g. Gavey, 1853; Richardson, 1918). Economic changes in the latter part of the 19th century and early part of the 20th century saw the decline of the various quarrying industries. Generally the smaller pits became overgrown or flooded and the larger quarries often were used as landfill sites. By the mid-1970s many had all but vanished. Many important sites were never properly documented and received only cursory mention, if at all, in publications. Notable among these is the publication by Woodward (1893), which provides the only record of many sites for which nothing more was ever published. Indeed, many museum collections contain material from sites for which virtually nothing is known, although an inventory of a great many Lower Jurassic sites and their stratigraphical position, as deduced from museum material, was compiled some years ago by C.P. Palmer (pers. comm.).

THE ESTABLISHMENT OF THE JURASSIC SYSTEM AND THE STAGES OF THE LOWER JURASSIC SERIES

K.N. Page
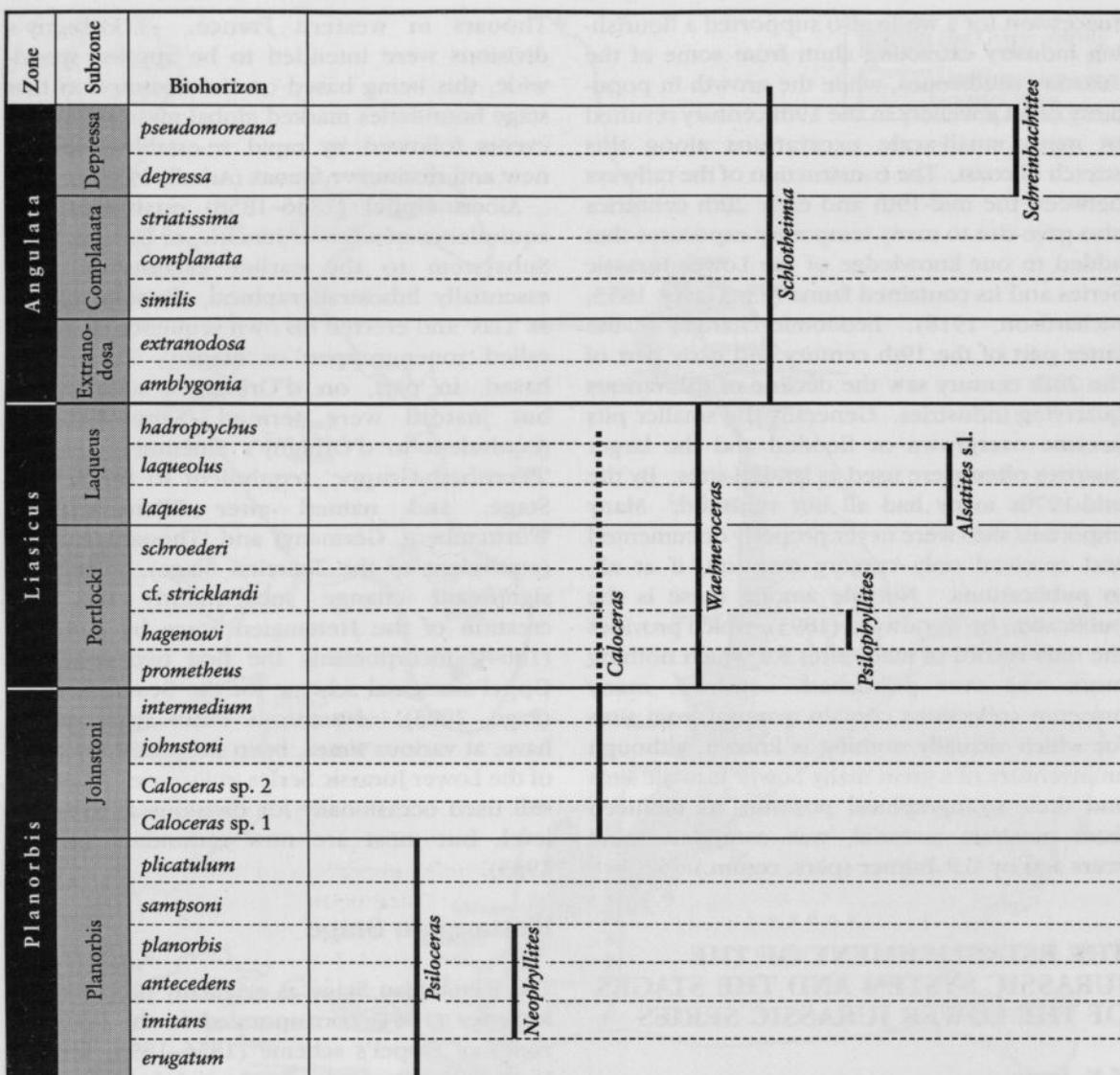
The term 'Jurassique' was introduced by Brongniart in 1829 for a distinct period of geological time first identified within the rocks of the Jura Mountains, in eastern France and Switzerland, by Alexander von Humbolt in 1795 (Torrens in Cope *et al.*, 1980a). However, it was not until the publication of Alcide d'Orbigny's *Palaeontologie Française, terrains Jurassique* (1842–1849), that the system was subdivided into stages (Arkell, 1933; Rioult, 1974; Page, 2003). D'Orbigny recognized three successive stages in the Lower Jurassic Series. The lowest was the Sinèmurien Stage, named after Semur-en-Auxois in Burgundy, eastern France. Above was the Liasien Stage, it's name derived from the old geological term 'Lias', and the third and youngest, the Toarcien Stage, was named after

Thouars in western France. D'Orbigny's divisions were intended to be applied worldwide, this being based on the assumption that stage boundaries marked global mass extinction events followed by rapid re-establishment of new and distinctive faunas (Arkell, 1933, p. 9).

Albert Oppel (1856–1858) established the equivalence of a Lower Jurassic, or Unterer Jura, Subsystem to the earlier established, and essentially lithostratigraphical, division known as 'Lias' and erected his own sequence of stages, called 'zonengruppen' or 'étagen'. These were based, in part, on d'Orbigny's subdivisions but instead were termed 'Semur-Gruppe' (equivalent to d'Orbigny's Sinèmurian Stage), 'Pliensbach-Gruppe' (equivalent to the Liasien Stage, and named after Pliensbach in Württemberg, Germany) and 'Thouars-Gruppe' (equivalent to the Toarcien Stage). The only significant change subsequently was the creation of the Hettangien Stage by Renevier (1864), incorporating the first two zones of Oppel's original scheme for the Semur-Gruppe (Page, 2003). Numerous other stage names have, at various times, been proposed for parts of the Lower Jurassic Series in Europe. A few are still used occasionally for divisions at substage level, but most are now redundant (Arkell, 1933).

Hettangian Stage

The Hettangian Stage as originally proposed by Renevier (1864) corresponded to the first two zones of Oppel's scheme (1856–1858) for the Jurassic System, namely those of *Ammonites (Psiloceras) planorbis* and *Ammonites (Schlotheimia) angulatus*. This interpretation remains essentially unchanged except for the addition, by Collenot (1869), of a Liasicus Zone for the lower part of the original *angulatus* Zone. Donovan (in Dean *et al.*, 1961) established the basic framework of subzones for the stage, with minor later additions by Elmi and Mouterde (1965) and Bloos (1979, 1983). This scheme was summarized diagrammatically by Mouterde and Corna (1991) and reviewed by Mouterde and Corna (1997). The sequence of zones, subzones and biohorizons currently recognized in the Hettangian Stage of northwest Europe, based on Mouterde and Corna (1991, 1997), Page (1994a), Page and Bloos (1998) and Bloos and Page (2000a), is summarized in Figure 1.3.

Zone	Subzone	Biohorizon	Ammonite genera ranges
Angulata	Depressa	pseudomoreana	Schlotheimia; Schreinbachites
Angulata	Depressa	depressa	
Angulata	Complanata	striatissima	
Angulata	Complanata	complanata	
Angulata	Complanata	similis	
Angulata	Extranodosa	extranodosa	
Angulata	Extranodosa	amblygonia	
Liasicus	Laqueus	hadroptychus	Waehneroceras; Psilophyllites; Alsatites s.l.
Liasicus	Laqueus	laqueolus	
Liasicus	Laqueus	laqueus	
Liasicus	Portlocki	schroederi	Caloceras
Liasicus	Portlocki	cf. stricklandi	
Liasicus	Portlocki	hagenowi	
Liasicus	Portlocki	prometheus	
Planorbis	Johnstoni	intermedium	
Planorbis	Johnstoni	johnstoni	
Planorbis	Johnstoni	Caloceras sp. 2	
Planorbis	Johnstoni	Caloceras sp. 1	
Planorbis	Planorbis	plicatulum	Psiloceras; Neophyllites
Planorbis	Planorbis	sampsoni	
Planorbis	Planorbis	planorbis	
Planorbis	Planorbis	antecedens	
Planorbis	Planorbis	imitans	
Planorbis	Planorbis	erugatum	

Figure 1.3 Sequence of zones, subzones and biohorizons for the Hettangian Stage, with the stratigraphical ranges of ammonite genera indicated (solid line – proven; dashed line – inferred ghost range). After Page (2002) and unpublished observations.

The base of the Hettangian Stage and the Jurassic System

Oppel (1856–1858) first established a zone of *Ammonites* (*Psiloceras*) *planorbis* to mark the base of the Jurassic System and this usage was finally stabilized at the first Jurassic colloquium in Luxembourg in 1962 (Mauberge, 1964). In north-west Europe, this chronozone marks the first occurrence of ammonites following the re-establishment of fully marine conditions towards the end of the Triassic Period.

The type locality of the index fossil for the Planorbis Zone, *Psiloceras planorbis* (J. de C. Sowerby, 1812–1846), and its lowest subzone, is on the coast of west Somerset near Watchet in south-west England, part of the **Blue Anchor–Lilstock Coast** GCR site. Subsequently, and almost inevitably, a type section for the subzone, and hence the Planorbis Zone, Hettangian Stage and the Jurassic System, was proposed in this district (Donovan *et al.* in Morton, 1971). There has been considerable discussion as to where exactly the boundary should be drawn in the

coastal sections in this area, especially as to whether the base of the Blue Lias Formation or the first occurrence of psiloceratid ammonites represents the most appropriate datum (Torrens and Getty in Cope *et al.*, 1980a; Ivimey-Cook *et al.*, 1980; Warrington and Ivimey-Cook, 1995; Benton *et al.*, 2002). The matter was finally resolved by the formal proposal for Global Stratotype Section and Point (GSSP) status of a section at St Audrie's Bay, east of Watchet (Warrington *et al.*, 1994). This proposal placed the base of the subzone and zone at the lowest recorded occurrence, at that time, of ammonites in Bed A21 of Palmer (1972; = beds 13–15 of Whittaker and Green, 1983). The subsequent discovery, by Hodges (1994) of ammonites at still lower stratigraphical levels at the proposed St Audrie's GSSP (in beds A18 and A19 of Palmer, 1972; = beds 8 and 9 of Whittaker and Green, 1983), and by Page and Bloos (1998; see also Bloos and Page, 2000a) farther along the coast and nearer Watchet, forced a revision of this definition. Warrington and Ivimey-Cook (1995) subsequently modified their original proposal and placed the base of the Jurassic System at the base of Bed A18 (= Bed 8 of Whittaker and Green, 1983). Characteristic Triassic ammonoids are entirely lacking in Britain, and the only British record to date of a supposedly late Triassic ammonite is that of an indeterminate and problematic psiloceratid from the Westbury Formation of the Penarth Group near Bristol (Donovan *et al.*, 1989).

By comparison with the remarkably complete and expanded Planorbis Subzone seen in the Wilkesley Borehole in Cheshire, north-west England (Page and Bloos, 1998; Bloos and Page, 2000a), the lowest ammonite fauna on the west Somerset coast, in Bed 8, was determined as *Psiloceras erugatum* (Phillips), a species well known from loose blocks at the **Normanby Stye Batts–Miller's Nab (Robin Hood's Bay)** GCR site in Yorkshire, but never confirmed previously in a surface exposure. Remarkably, the occurrence of this species below *P. planorbis* had already been noted by Donovan (in Poole and Whiteman, 1966) in the Wilkesley Borehole, but subsequently had been overlooked in later works. Re-examination of higher levels in this borehole revealed additional faunas, dominated by *Neophyllites*, below *P. planorbis*. A similar sequence is also present in west Somerset with *Neophyllites* in the lower part of Bed 9, below

the first *P. planorbis* in the upper part of the same bed, and especially from Bed 13 to the basal part only of Bed 24 (Page and Bloos, 1998; Bloos and Page, 2000a).

More complete sequences of ammonite faunas are known from uppermost Triassic (Rhaetian Stage) to lowermost Jurassic successions elsewhere in the world, and two have been proposed as candidates for GSSPs; in Nevada, USA (Guex, 1980, 1982; Guex *et al.*, 1997) and in northern Peru (von Hillebrandt, 1994, 1997). It remains to be seen whether a 'New World' definition for the base of the Jurassic System could be accepted in the face of historical reasons for defining it in Europe. However, it is clear that the current state of knowledge is inadequate to correlate these sections accurately with any in Europe (Bloos and Page, 2000a; Page, in press).

Sinemurian Stage

The zonal sequence of the Sinemurian Stage, with the Bucklandi Zone at the base and the Raricostatum Zone at the top, remains essentially the same as that originally proposed by Oppel (1856–1858), once Renevier's (1864) Hettangian Stage is separated from it. Occasionally, especially in French publications, the Upper Sinemurian Substage is referred to as 'Lotharingian', after Lorraine, in eastern France (Page, 2003). Subdivision of the stage into zones and subzones, started by Oppel (1856), developed through the work of Lang and Spath, primarily on the Dorset coast (Lang *et al.*, 1923; Lang, 1924; Spath, 1924, 1942; Lang and Spath, 1926). The work of S.S. Buckman (1909–1930) was also significant in incorporating considerable information from the Yorkshire coast, especially Robin Hood's Bay. The basic scheme, refined by Donovan (in Dean *et al.*, 1961) is still widely used. There have been only minor modifications since, arising primarily through the re-naming of a few subzones following the identification of senior synonyms of the index species. Further subdivision of the stage into zonules and biohorizons is based largely on the work of Corna (1987), Page (1992), Dommergues (1993), Dommergues *et al.* (1994), Page (1995), Corna *et al.* (1997), Bloos and Page (2000b) and Page *et al.* (2000) as reviewed by Page (2002) and summarized in Figures 1.4 and 1.5.

Zone	Subzone	Biohorizon
Turneri	Birchi	cf. bordoti
		subturneri
		birchi
		pseudobonnardi
		obtusiformis
	Brooki	hartmanni
		brooki
		sulcifer
Semicostatum	Sauzeanum	cf. semicostatum
		alcinoeiforme
		Euagassiceras
		cf. resupinatum
	Scipionianum	pseudokridion
		acuticarinatum
	Lyra	alcinoe
		Paracoroniceras sp.
		bodleyi
		cf. charlesi
		lyra
Bucklandi	Bucklandi	multicostatum
		cf. scunthorpense
		isis
		aff. isis
		scylla
	Rotiforme	kridion
		caprotinum
		aff. rotiforme
		rotiforme
		deffneri
	Conybeari	silvestrei
		conybeari
		elegans
		rotator
		rouvillei
		rotarius
		conybearoides
		Metophioceras sp. B
		quantoxense

Ammonite genera (stratigraphical ranges indicated): Schlotheimia, Vermiceras, Metophioceras, Epammonites, Coroniceras, Arietites, Cymbites, Arnioceras, Paracoroniceras, 'Paramioceras', Agassiceras, Euagassiceras, Caenisites, Microderoceras, Epophioceras, Promicroceras, Charmasseiceras / Sulciferites

Figure 1.4 Sequence of zones, subzones and biohorizons for the lower part of the Sinemurian Stage, with the stratigraphical ranges of ammonite genera indicated (solid line – proven; dashed line – inferred ghost range). After Page (2002) and unpublished observations.
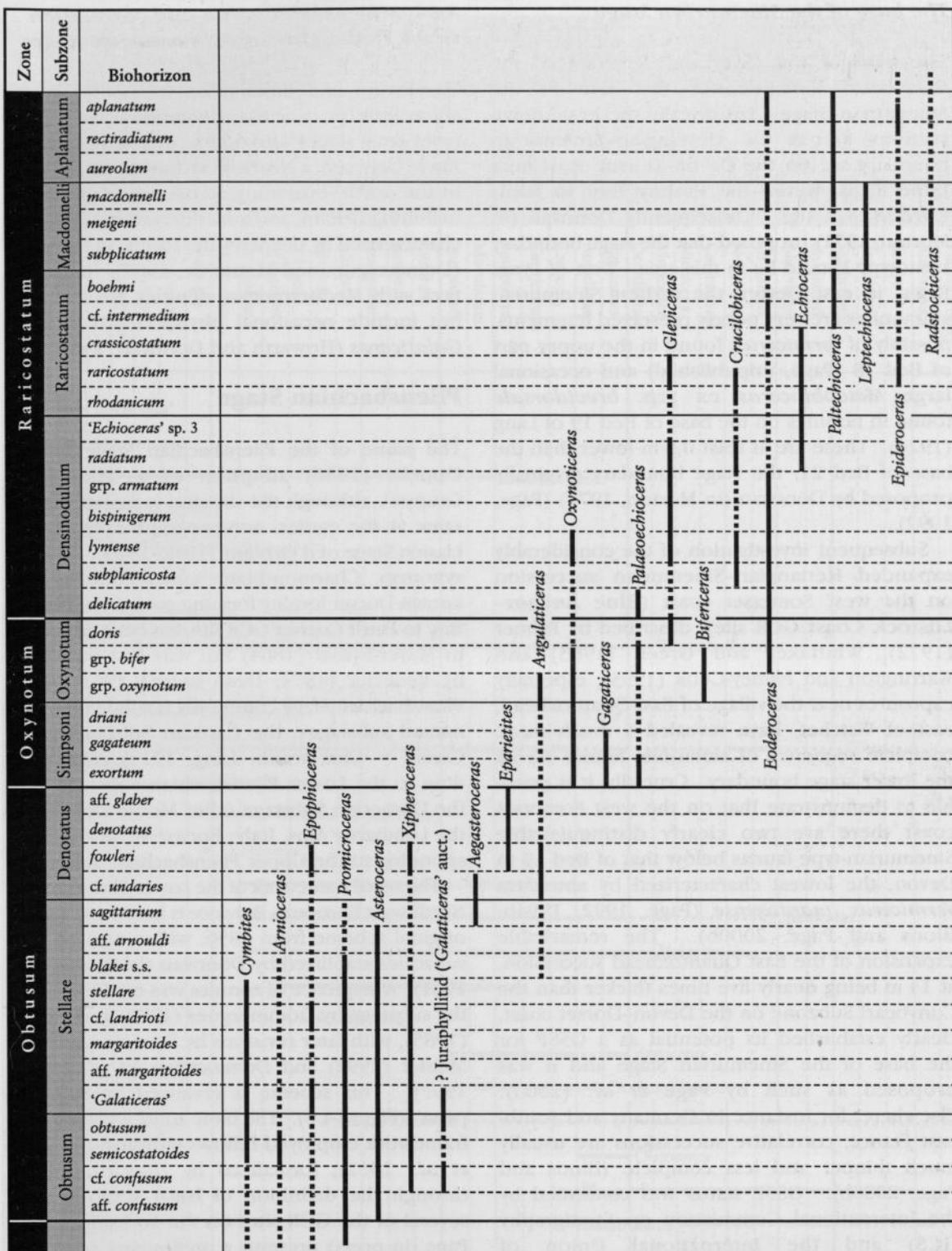
Figure 1.5 Sequence of zones, subzones and biohorizons for the upper part of the Sinemurian Stage, with the stratigraphical ranges of ammonite genera indicated (solid line – proven; dashed line – inferred ghost range). After Page (2002) and unpublished observations.

British Lower Jurassic stratigraphy: an introduction

The base of the Sinemurian Stage

The base of the Conybeari Subzone of the Bucklandi Zone defines the base of the Sinemurian Stage. Historically the best-known sections across the Hettangian–Sinemurian boundary are on the Devon–Dorset coast near Lyme Regis, within the **Pinhay Bay to Fault Corner** GCR site. Consequently Donovan (in Morton, 1971) proposed that the stage boundary stratotype should be in this area. West of Lyme Regis, in east Devon, the earliest Sinemurian ammonites are very poorly preserved fragments, possibly of *Vermiceras*, found in the upper part of Bed 18 (Page, unpublished) and occasional large *Metophioceras* ex grp. *brevidorsale* found in nodules on the base of Bed 19 of Lang (1924). These are at least 0.6 m lower than the base of Bed 21, the stage boundary originally proposed by Donovan (in Morton, 1971) (Page, 1992).

Subsequent investigation of the considerably expanded Hettangian–Sinemurian succession on the west Somerset coast (**Blue Anchor–Lilstock Coast** GCR site), described by Palmer (1972), Whittaker and Green (1983) and Warrington and Ivimey-Cook (1995), especially exposures near the village of East Quantoxhead, east of Watchet, have revealed a much more complete sequence of ammonite faunas across the lower stage boundary. Crucially, it is possible to demonstrate that on the west Somerset coast there are two clearly distinguishable Sinemurian-type faunas below that of Bed 19 in Devon, the lowest characterized by abundant *Vermiceras quantoxense* (Page, 1992, 1994b; Bloos and Page, 2000b). The remarkable expansion of the East Quantoxhead succession, at 14 m being nearly five times thicker than the Conybeari Subzone on the Devon–Dorset coast, clearly established its potential as a GSSP for the base of the Sinemurian Stage and it was proposed as such by Page *et al.* (2000). Elsewhere, for instance in Germany and southeast France, correlative successions are usually much thinner and less complete (Bloos and Page, 2000b). GSSP status was confirmed by the International Commission on Stratigraphy (ICS) and the International Union of Geological Sciences (IUGS) in 2000, and the site represents the first formalized Jurassic stage stratotype in Britain, as reviewed by Page (2002).

Ammonite provincialism and correlation in the Hettangian and Sinemurian stages

Hettangian and Sinemurian ammonite faunas show little provincialism compared with those from later stages although a distinction can be made between a North-west European Province in the north, extending across much of Europe including Britain, and a Mediterranean Province, characterized by deeper-water forms, in the south (Dommergues and Mouterde, 1987). In Britain taxa with Mediterranean affinities are very rare but include occasional phylloceratids such as *Galaticeras* (Howarth and Donovan, 1964).

Pliensbachian Stage

The name of the Pliensbachian Stage follows Oppel's (1856) adoption of a 'Pliensbach-Gruppe', although the division is essentially the same as the earlier, non-geographically named, Liasien Stage of d'Orbigny (1842–1849). Another synonym, 'Charmouthian', named after the well-known Dorset locality forming part of the **Pinhay Bay to Fault Corner** GCR site, has been attributed to Mayer-Eymar (1864) but was first published by Renevier (1874; Dean *et al.*, 1961). The Pliensbachian Stage commonly is subdivided into named substages; the Carixian Substage (after Carixa = Charmouth; Lang, 1914) corresponding to the Lower Pliensbachian Substage, and the Domerian Substage (after Monte Domaro in the Lombardy Alps, Italy; Bonarelli, 1894) corresponding to the Upper Pliensbachian Substage.

The zonal framework of the Lower Pliensbachian North-west European Province is based on Oppel's original scheme from 1856, with a sequence of subzones stabilized by Donovan (in Dean *et al.*, 1961). A sequence of zonules was established for the substage by Dommergues (1979) and Phelps (1985), with later revisions by Dommergues and Meister (1992) and Dommergues *et al.* (1991, 1997). This scheme is reviewed by Page (in press) (Figure 1.6). The basic zonal and subzonal framework employed follows Howarth (in Dean *et al.*, 1961), formalized by Howarth (1992) through the definition of basal stratotypes at several of the GCR sites on the Yorkshire coast. Page (in press) presents a preliminary sequence of biohorizons for the Upper Pliensbachian Substage in Britain, based largely on Howarth's meticulous and detailed faunal records for the region (1955, 1956, 1957, 1992).
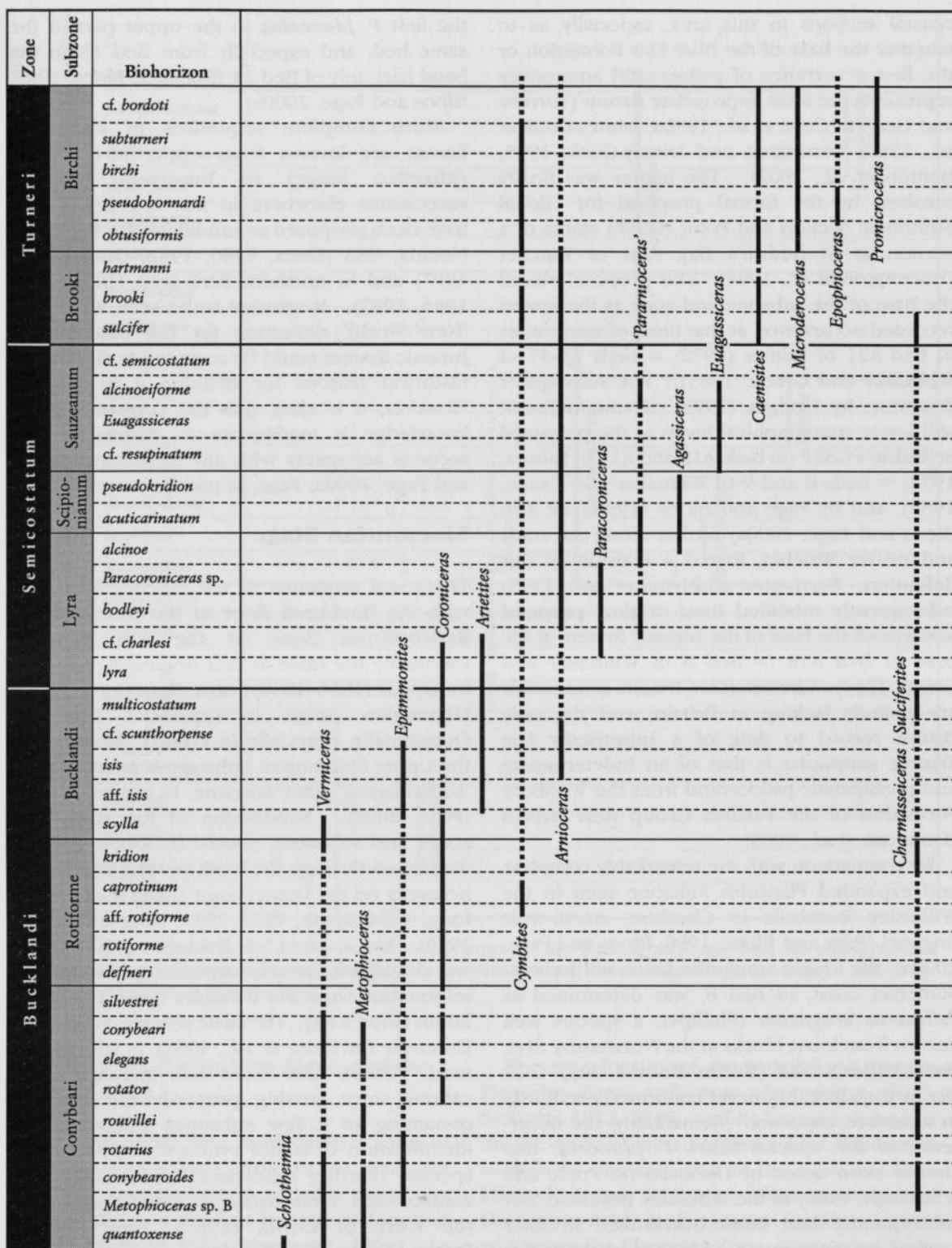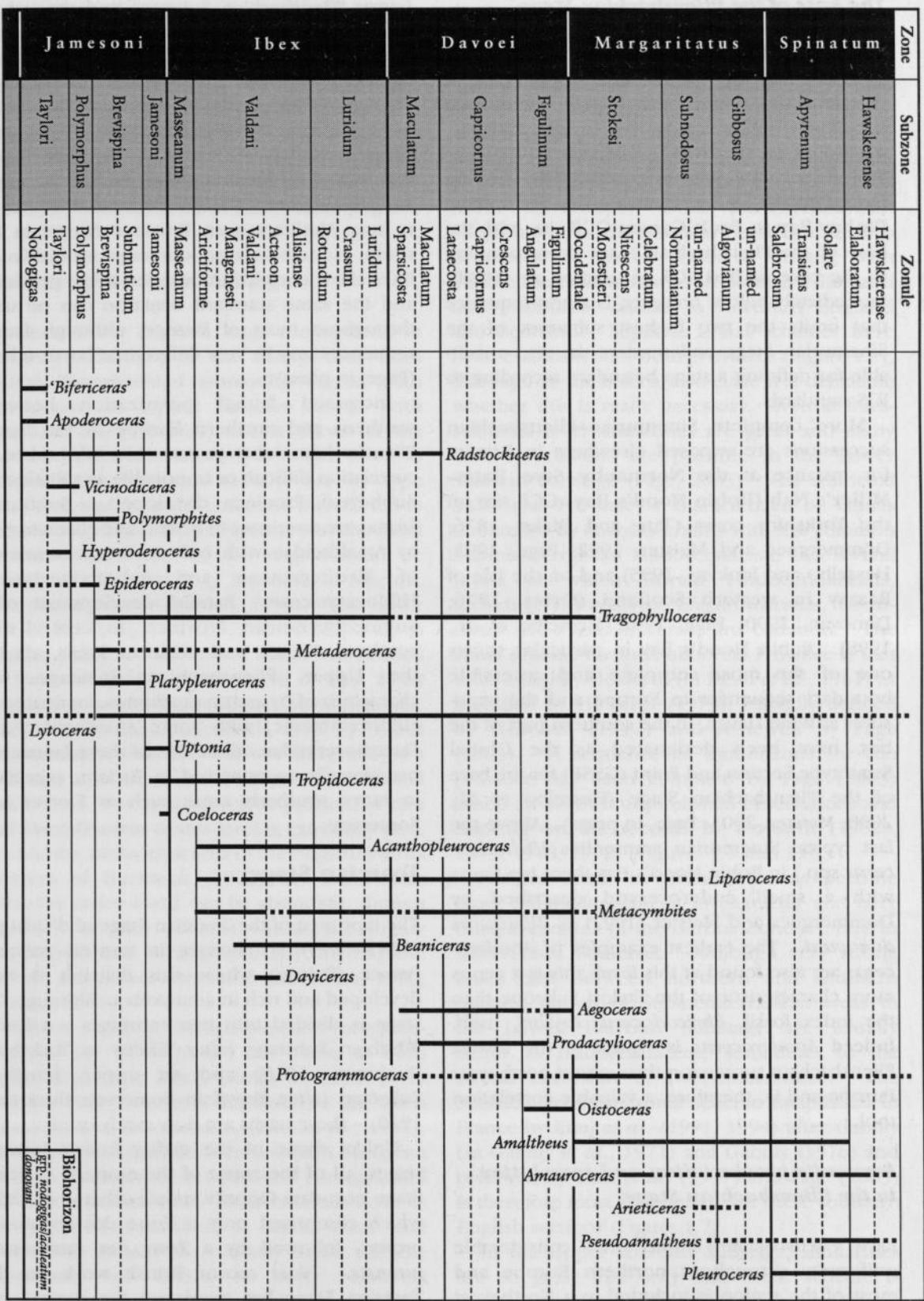
Figure 1.6 Sequence of zones, subzones and zonules for the Pliensbachian Stage, with the stratigraphical ranges of ammonite genera indicated (solid line – proven; dashed line – inferred ghost range). After Page (2002) and unpublished observations.

Zone	Subzone	Zonule
Jamesoni	Taylori	Nodogigas / Taylori
	Polymorphus	Polymorphus
	Brevispina	Brevispina / Submuticum
	Jamesoni	Jamesoni / Masseanum
Ibex	Masseanum	Masseanum / Arietiforme
	Valdani	Maugenesti / Valdani / Actaeon
	Luridum	Alisiense / Rotundum / Crassum / Luridum
Davoei	Maculatum	Sparsicosta / Maculatum
	Capricornus	Lataecosta / Capricornus
	Figulinum	Crescens / Angulatum / Figulinum
Margaritatus	Stokesi	Occidentale / Monestieri / Nitescens
	Subnodosus	Celebratum / Normanianum
	Gibbosus	un-named / Algovianum / un-named
Spinatum	Apyrenum	Salebrosum / Solare / Transiens
	Hawskerense	Elaboratum / Hawskerense

Genus ranges shown:

- 'Bifericeras'
- Apoderoceras
- Radstockiceras
- Vicinodiceras
- Polymorphites
- Hyperoderoceras
- Epideroceras
- Tragophylloceras
- Metaderoceras
- Platypleuroceras
- Lytoceras
- Uptonia
- Tropidoceras
- Coeloceras
- Acanthopleuroceras
- Liparoceras
- Metacymbites
- Beaniceras
- Dayiceras
- Aegoceras
- Prodactylioceras
- Protogrammoceras
- Oistoceras
- Amaltheus
- Amauroceras
- Arieticeras
- Pseudoamaltheus
- Pleuroceras

Biohorizon: grp. nodogigas/aculeatum donovani

British Lower Jurassic stratigraphy: an introduction

The base of the Pliensbachian Stage

Following Oppel (1856), the base of the Pliensbachian Stage is still taken as the base of the Jamesoni Zone, the lowest recognized subdivision of which is the Taylori Subzone. According to Donovan (in Morton, 1971) the Taylori Subzone was first recognized on the Dorset coast, near Charmouth, within the **Pinhay Bay to Fault Corner** GCR site, with the base of the Pliensbachian Stage corresponding to the base of Bed 105 of Lang *et al.* (1928). Immediately below, however, is a non-sequence that omits the two highest subzones of the Sinemurian Stage and renders the site unsuitable for defining a stage boundary according to ICS standards.

More complete Sinemurian–Pliensbachian successions are exposed elsewhere in Britain, for instance at the **Normanby Stye Batts– Miller's Nab (Robin Hood's Bay)** GCR site on the Yorkshire coast (Tate and Blake, 1876; Dommergues and Meister, 1992; Page, 1992; Hesselbo and Jenkyns, 1995) and on the Isle of Raasay in western Scotland (Oates, 1976; Donovan, 1990; Page, 1992; Hesselbo *et al.*, 1998). Robin Hood's Bay in particular shows one of the most complete and accessible boundary sequences in Europe and the exposures at Wine Haven, in the southern part of the bay, have been designated as the Global Stratotype Section and Point (GSSP) for the base of the Pliensbachian Stage (Hesselbo *et al.*, 2000; Meister, 2003; Page, in press). Above the last typical Sinemurian ammonites (*Paltechioceras* spp.) in Robin Hood's Bay there is a fauna with a small eoderoceratid described by Dommergues and Meister (1992) as *Bifericeras donovani*. The earliest examples of *Apoderoceras* are also found at this level; this is a genus more characteristic of the Taylori Subzone than the index fossil, *Phricodoceras taylori*, itself. Indeed *Apoderoceras* is typical of the lowest Pliensbachian succession throughout north-west Europe and is, therefore, a valuable correlation tool.

Ammonite provincialism and correlation in the Pliensbachian Stage

Early Pliensbachian faunas show considerable uniformity throughout northern Europe and most of the region is included in a North-west European Province. In the upper part of the Lower Pliensbachian Substage and throughout the Upper Pliensbachian Substage, however, the establishment of direct connections with Boreal regions resulted in a faunal spectrum developing across Europe from assemblages dominated by Boreal taxa in the northern areas (characterizing a Subboreal Province) through faunas dominated by Mediterranean faunas in central and western areas (Submediterranean Province) to true Mediterranean Province faunas in the south. Nonetheless, good inter-provincial faunal links allow correlation between these provinces and the same standard zonation can be used throughout most of Europe, although faunal sequences may be very different at horizon level (Page, in press).

Increased faunal polarization between southern and northern Europe in the Upper Pliensbachian Substage can make infra-subzonal correlation difficult or impossible as a distinctive Subboreal Province developed. Subboreal faunas are dominant in Britain and characterized by Amaltheidae with only rare representatives of Mediterranean and Submediterranean Hildocerataceae. Parallel development of a Submediterranean Province, in central and southern France and adjacent areas, during the Upper Pliensbachian Substage was characterized by ammonite faunas dominated by Hildocerataceae, with some Amaltheidae and Dactylioceratidae. Elements of these faunas are occasionally encountered in Britain, especially in more southerly areas such as Dorset and Somerset.

Toarcian Stage

The type area of the Toarcian Stage of d'Orbigny (1842–1849) is Thouars in central western France (Poitou) where this division is well developed and rich in ammonites. Although the stage is divided into two substages – a lower Whitbian Substage (after Whitby in Yorkshire; Buckman, 1910) and an upper Yeovilian Substage (after Yeovil in Somerset; Buckman, 1910) – these terms are now rarely used.

Unlike those of the earlier Lower Jurassic stages, all of the zones of the modern Toarcian Stage post-date Oppel's simple scheme of 1856, which comprised only a Zone des *Posidonia bronni*, followed by a Zone des *Ammonites jurensis*. Most recent British work on the Toarcian Stage has employed the basic zonal schemes compiled by Howarth and Dean (in

Dean *et al.*, 1961) (e.g. Cope *et al.*, 1980a). However this scheme has been considerably refined through work elsewhere in Europe, especially in France (e.g. by Gabilly *et al.*, 1971; Gabilly, 1976; Elmi *et al.*, 1991, 1994; Elmi, 1997). The results provide a new standard that should now be applied to British successions, as proposed by Page (2003), and which has been adopted in this volume (Figures 1.7 and 1.8).

The base of the Toarcian Stage

The base of the Toarcian Stage corresponds, in north-west Europe, to the change-over from typical Pliensbachian ammonite faunas with *Pleuroceras* to typical Toarcian faunas with abundant *Dactylioceras*, and is drawn at the base of the Tenuicostatum Zone. This zone, as proposed by Buckman (1910), has its type locality on the Yorkshire coast and this has led to various proposals or assumptions that the basal boundary stratotype of the stage should be defined in this area (e.g. Howarth in Morton, 1971; Cox, 1990; Howarth, 1992). The lower part of the Tenuicostatum Zone corresponds to a Paltus Subzone, the base of which was defined by Howarth (1992) as the base of Bed 26 at Kettleness, *or* the base of Bed 58 at Staithes. Both are in Yorkshire (Howarth, 1955, 1973) but only the latter (**Staithes to Port Mulgrave**) is a GCR site at present. In Yorkshire the subzonal index fossil, *Protogrammoceras paltum*, is rare and *Dactylioceras* at this level is extremely rare. In contrast, in the type area of the original *paltus* Hemera of Buckman (1922) on the Dorset coast the index fossil can be abundant, though confined to thin pockets within the highly condensed and stratigraphically incomplete Beacon Limestone Formation (Buckman, 1910; Jackson, 1926).

Farther south in Europe similar *Protogrammoceras* (or '*Paltarpites*') can occur at both higher and lower levels (Howarth, 1992, p. 7) and the first Toarcian *Dactylioceras* are often abundant and characteristic (Elmi *et al.*, 1997). Although correlation between southern European sections, for instance in Spain and Portugal, and the northern European Tenuicostatum Zone is not yet well-established, it seems clear that sections in Britain are unlikely to be suitable candidates for GSSPs as their relatively impoverished faunas have limited correlation potential.

Ammonite provincialism and correlation in the Toarcian Stage

Early Toarcian faunas show distribution patterns similar to those of late Pliensbachian times, reflecting the persistence of Boreal connections throughout the substage, and a Submediterranean to Subboreal transition is recognizable across north-west Europe. Unlike the Pliensbachian Stage, however, the boundary between the two provinces lay across southern Britain, with Submediterranean faunas in southern England and Subboreal faunas in northern England and Scotland. Separate zonal schemes have been established for both provinces (Figure 1.7), although as the links are so close it is debatable whether this is really necessary. Even at infra-subzonal level similarities are great and many cross-correlations are possible in the Lower Toarcian Substage (Page, 2003). The restricted Subboreal Province is characterized by faunas dominated by dactylioceratids with less common Submediterranean Hildocerataceae and several levels at which Boreal Hildocerataceans, including *Tiltoniceras*, *Elegantuliceras*, *Ovaticeras* and *Pseudolioceras*, are common. The zonal scheme for the Subboreal Province is that established by Howarth (in Dean *et al.*, 1961) as modified by Howarth (1973), formally defined by Howarth (1992) and reviewed by Page (2003). A sequence of biohorizons for the province has been compiled by Page (2003) based on his own unpublished observations and drawing on the records by Howarth (1962a, 1973, 1978, 1992) (Figures 1.7 and 1.8).

Farther south in Britain, faunas become more Submediterranean in character and later Dactylioceratids of the Bifrons Zone are rare in Dorset and Somerset. Although very strong links exist between northern and southern regions, faunas of Submediterranean areas in the Lower Toarcian Substage are usually richer in Hildocerataceae, sometimes to the virtual exclusion of Dactylioceratidae. The Submediterranean zonal scheme established in France by Elmi *et al.* (1991, 1994) after Gabilly (in Gabilly *et al.*, 1971) and Gabilly (1976) and reviewed by Elmi *et al.* (1997) and Page (2003) is therefore most appropriate for these southern English sections (Figure 1.7).

In the Upper Toarcian Substage, similarities are so great that only one zonal scheme is justifiable in north-west Europe (Figure 1.8). Rare Boreal links include occasional

Zone	Subboreal Province		Submediterranean Province	
	Subzone	Biohorizon	Zonule	Subzone
Tenuicostatum	Paltus	paltus	Paltus	Paltus
	Clevelandicum	crosbeyi / clevelandicum	Crosbeyi	'Semicelatum' (II)
	Tenuicostatum	tenuicostatum	Tenuicostatum	
	Semicelatum (I)	semicelatum / antiquum	'Semicelatum'	
Serpentinum	Exaratum	elegantulum / exaratum	Elegantulum	Elegantulum
	Falciferum	elegans / mulgravium / falciferum	Strangwaysi / Pseudoserpentinum	Falciferum
Bifrons	Commune	ovatum / commune / atheticum	Douvillei / Sublevisoni	Sublevisoni
	Fibulatum	turriculatum / braunianus / vortex	Lusitanicum / Tethysi / Apertum	Bifrons
	Crassum	crassum-bifrons / crassum-semipolitum	Bifrons / Semipolitum	

Stratigraphical ranges of ammonite genera (top to bottom):

- Dactylioceras
- Lytoceras
- Protogrammoceras
- Meneghiniceras
- Tiltoniceras
- Elegantuliceras
- Cleviceras
- Harpoceras
- Hildaites
- Phylloceras
- 'Nodicoeloceras'
- Ovaticeras
- Hildoceras
- Frechiella
- Pseudolioceras
- Peronoceras
- Zugodactylites
- Porpoceras
- Catacoeloceras
- 'Collina'
- Phymatoceras

Figure 1.7 Sequence of zones, subzones, biohorizons and zonules for the lower part of the Toarcian Stage, with the stratigraphical ranges of ammonite genera indicated (solid line – proven; dashed line – inferred ghost range). After Page (2002) and unpublished observations.

Zone	Variabilis			Thouarsense			Dispansum		Pseudo-radiosa		Aalensis	

Figure content (Figure 1.8):

Zone	Variabilis			Thouarsense			Dispansum		Pseudo-radiosa		Aalensis	
Subzone	Variabilis	Illustris	Vitiosa	Bingmanni	Striatulum	Fascigerum	Fallaciosum (?)	Insigne	Gruneri	Levesquei	Pseudoradiosa	Mactra	Fluitans
Zonule	Navis / Jugosa	Illustris / Phillipsi	Vitiosa	Bingmanni	Doerntense	Thouarsense	Fascigerum / Fallaciosum	Pachu / Cappucinum	Gruneri	Munieri / Insignisimilis	Pseudoradiosa	Tectiforme / Mactra	Celtica / Lugdunensis / Buckmani

Genera ranges:
- Hildoceras
- Haugia
- Catacoeloceras
- Denckmannia
- Hammatoceras
- Pseudogrammoceras
- Lytoceras
- Brodieia
- Podagrosites
- Osperlioceras
- Grammoceras
- Polyplectus
- Esericeras
- Pseudolioceras
- Pseudolillia
- Phlyseogrammoceras
- Gruneria
- Onychoceras
- Buckmanites
- Dumortieria
- Hudlestonia
- Pseudammatoceras
- Phylloceras
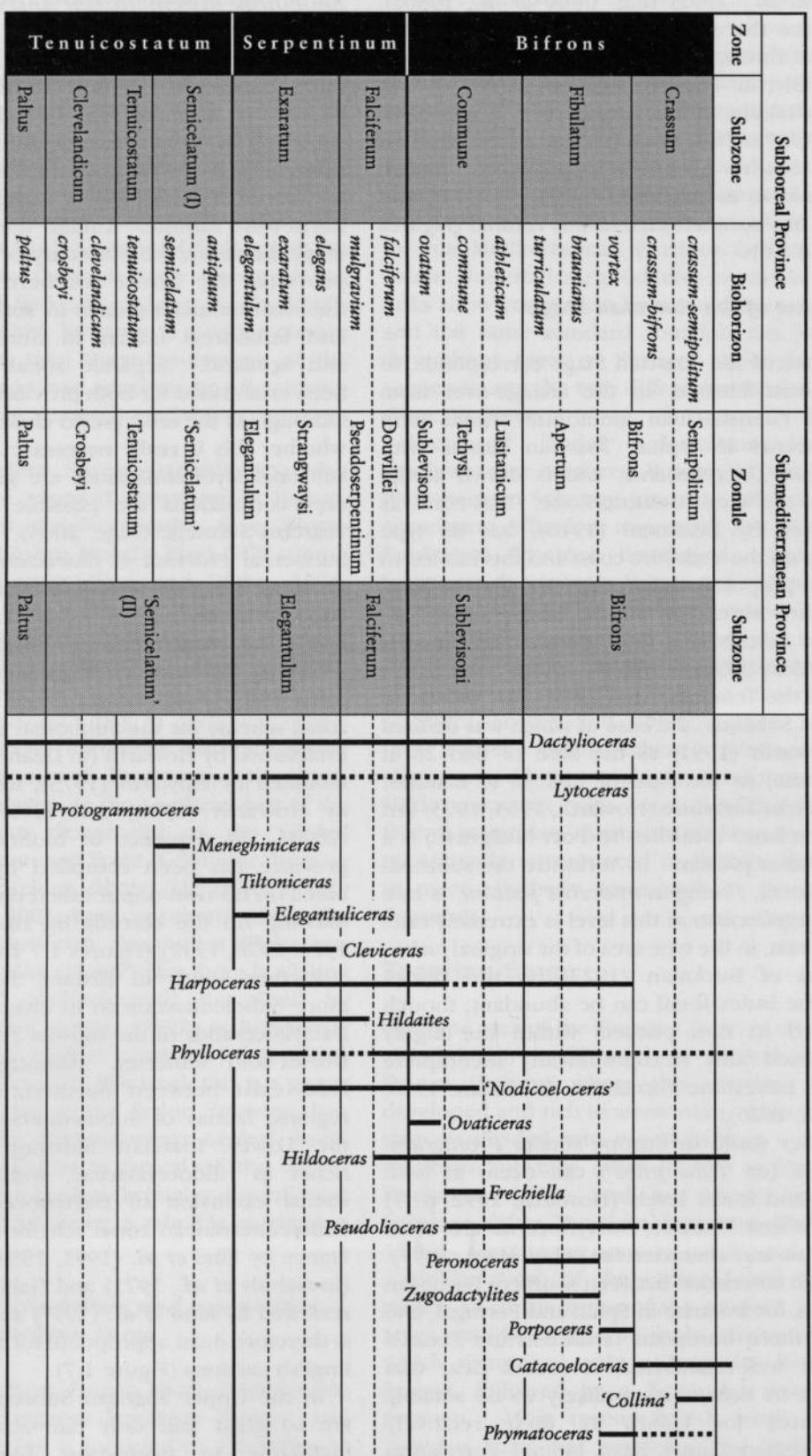- Erycites
- Paradumortieria
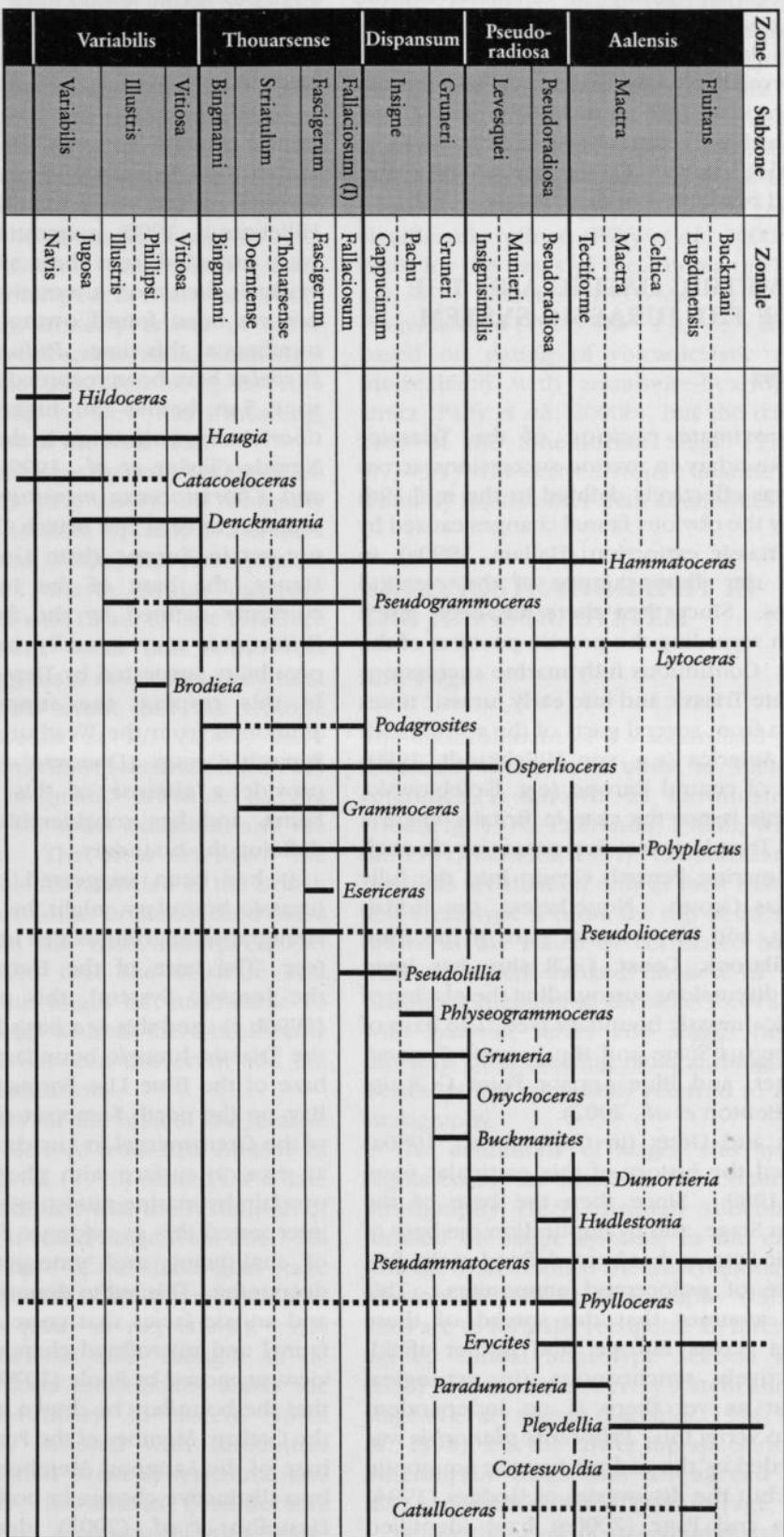- Pleydellia
- Cotteswoldia
- Catulloceras

Figure 1.8 Sequence of zones, subzones and zonules for the upper part of the Toarcian Stage, with the stratigraphical ranges of ammonite genera indicated (solid line – proven; dashed line – inferred ghost range). After Page (2002) and unpublished observations.

Pseudolioceras, mainly in northern Britain. Faunas are richer in more southerly areas, especially in Phymatoceratidae, but the bulk of the correlatively important Grammoceratinae (Hildoceratidae) are very widespread (Page, 2003). The basic zonal scheme of Dean (in Dean *et al.*, 1961) has been extensively refined (Page, 2003) and is adopted in this volume.

RADIOMETRIC DATING AND THE BASE OF THE JURASSIC SYSTEM

M.J. Simms

The approximate position of the Triassic–Jurassic boundary in marine successions across Europe was effectively defined in the mid-19th century by the obvious faunal changes caused by the end-Triassic extinction (Hallam, 1990a), in particular the disappearance of the ceratitid ammonites. Since then there has been much discussion regarding the precise position of the boundary. Continuous fully marine successions through late Triassic and into early Jurassic times are known from several parts of the world, such as South America (e.g. von Hillebrandt, 1990) and parts of central Europe (e.g. Golebiowski, 1990). This is not the case in Britain where a terrestrial Triassic succession passes up through the quasi-marine Penarth Group into the fully marine Lias Group. Nonetheless, the British succession, and in particular part of the **Blue Anchor-Lilstock Coast** GCR site, has been central to discussions surrounding the placing of the Triassic–Jurassic boundary (see 'The base of the Hettangian Stage and the Jurassic System', this chapter; and Blue Anchor Point GCR site report in Benton *et al.*, 2002).

Torrens and Getty (in Cope *et al.*, 1980a) summarized the history of this particular issue prior to 1980. Since then the base of the Hettangian Stage, and by implication the base of the Jurassic System, has been defined at the first appearance of psiloceratid ammonites. This definition assumes that the spread of these ammonites across Europe, and farther afield, was effectively synchronous (in geological terms) but as yet there is no independent evidence to verify this. *Psiloceras planorbis* was long regarded as the earliest Jurassic ammonite in Britain, but the discoveries of Hodges (1994) and Bloos and Page (2000a) have identified other psiloceratid ammonites below the first

P. planorbis at several sites. These discoveries may be construed as merely refining the precise position of the Triassic–Jurassic boundary, but other factors raise more serious questions. In general ammonites are rare or absent in the critical interval, between the last *Choristoceras* and the first *Psiloceras*, at most sites investigated throughout the world (e.g. Hallam, 1990b; von Hillebrandt, 1990), suggesting that ammonites were excluded from these sites either by some extrinsic factor or, alternatively, that they have not yet been found owing to their very low numbers at this time. *Psiloceras tilmanni* and *P. spelae* have been recorded in low numbers up to *c.* 5 m below the highest occurrence of *Choristoceras minutum* in the Muller Canyon of Nevada (Taylor *et al.*, 1999), while *Psiloceras* and *Choristoceras minutum* are also found together in Peru and British Columbia, although not yet in Europe (Jean Guex, pers. comm.). Hence, the base of the Jurassic System, as currently defined by the first appearance of *Psiloceras*, may actually be diachronous, a possibility suggested by Hesselbo *et al.* (2002). In this respect, the supposed psiloceratid ammonite from the Westbury Formation of the Penarth Group (Donovan *et al.*, 1989) may provide a glimpse of this elusive boundary fauna, and has considerable implications for defining the boundary.

It has been suggested that the Triassic–Jurassic boundary might be defined on lithostratigraphical grounds tied in to biostratigraphy (see 'The base of the Hettangian Stage and the Jurassic System', this chapter). Hallam (1990b,c) used this as a basis for suggesting that the Triassic–Jurassic boundary be placed at the base of the Blue Lias Formation in St Audrie's Bay, on the north Somerset coast, and the base of the Grenzmergel in Austria. At both localities an erosion surface with phosphatic nodules is overlain by marine mudstones. Hallam (1990b) interpreted this as evidence for a brief episode of shallowing and emergence followed by deepening. This led to deposition of condensed and anoxic facies that correlated with marked faunal and microfloral changes. An alternative view, proposed by Poole (1979, 1980, 1991), was that the boundary be drawn immediately above the Cotham Member of the Penarth Group at the base of the Langport Member, which is marked by a distinctive change in both facies and biota. Hesselbo *et al.* (2002) identified a globally correlatable isotope excursion within the

Cotham Member, which they linked with the immediate effects of the end-Triassic mass extinction, and proposed this as a suitable marker for the base of the Jurassic System. Certainly, adopting the first appearance of some fossil taxon to define the base of a system, and hence the top of the previous system, would appear to be fundamentally flawed in instances such as this where the dramatic change in biota between the two systems was due to a mass extinction. The defining event is the extinction, not the essentially arbitrary arrival of some element of the post-extinction fauna. Similarly it is midnight on the 31st December, not the arrival of the first bus on New Year's morning, that defines the start of the New Year.

Intriguingly, the isotope excursion of Hesselbo *et al.* (2002) lies just above an uniquely extensive seismite horizon, typically 1–2 m thick (Mayall, 1983; Simms, 2003a) that can be traced across the entire Penarth Group outcrop/subcrop from north-west Ulster to east Yorkshire and down to south Wales and south-west England. This suggests a causal link may exist between the seismic event and the isotope excursion. Hesselbo *et al.* (2002) have suggested massive volcanism associated with the Central Atlantic Magmatic Province as the ultimate cause for the mass extinction and the isotope excursion. The areal extent of the seismite is on a scale unparalleled in the British Phanerozoic and a volcanic or fault-related cause is improbable. On this basis, Simms (2003a) tentatively suggested that the seismite and associated tsunamite might be attributable to bolide impact, though without there necessarily being a direct link between this event and the end-Triassic mass extinction.

Radiometric dates for the base of the Jurassic System have been derived from sites outside of Britain. Harland *et al.* (1990) settled for a date of 210.5 Ma but accepted that the resolution of this was poor and it could range from 201.7 Ma to 216.7 Ma. The base of the Hettangian Stage has recently been dated both in terrestrial and marine sequences (Pálfy *et al.*, 2000a). The former is derived from sills 'thought to be feeders to basalt flows immediately above the Triassic–Jurassic boundary' in eastern North America but this, coupled with difficulties inherent in correlation between terrestrial and marine sequences, introduces considerable uncertainty to the accuracy of this date. However, another radiometric date for the base

of the Hettangian Stage, obtained from a tuff layer within a marine succession biostratigraphically dated using radiolaria (Pálfy *et al.*, 2000a), has given a date of 199.6 ± 0.3 Ma, which is close to the date for the non-marine sequence of approximately 201 Ma (Pálfy *et al.*, 2000a). The dating of the stage boundaries for the Lower Jurassic Series (Figure 1.1) has also been significantly refined (Pálfy *et al.*, 2000b,c). The dates for the bases of the Aalenian (178.0 Ma + 1.0, –1.5), Toarcian (183.6 Ma + 1.7, –1.1) and Pliensbachian (191.5 Ma +1.9, –4.7) stages were based on dating of volcaniclastic sediments intercalated with ammonite-bearing marine strata (Pálfy *et al.*, 2000b), but the date for the base of the Sinemurian Stage (196.5 Ma + 1.7, –5.7) was derived from a marine sequence dated by fossils other than ammonites.

CHRONOSTRATIGRAPHY IN THE JURASSIC SYSTEM

K.N. Page

The establishment of a standardized geological timescale using rock units as standards for reference is known as chronostratigraphy (Hedberg, 1976; Callomon, 1985b; Whittaker *et al.*, 1991; Salvador, 1994). Chronostratigraphical divisions are defined only at their base in a suitable stratotype section, the top of the unit being drawn at the actual or correlated base of the next equivalent ranked division of the scale. Chronostratigraphical divisions form a hierarchy with *systems*, *series* and *stages* being three divisions of decreasing rank, although the term 'series' is not commonly referred to in Jurassic stratigraphy.

The definitions of stages and systems are regulated by the International Commission on Stratigraphy (ICS) through subcommissions focused on single systems; in the case of the Jurassic System this is the International Subcommission on Jurassic Stratigraphy (ISJS). Their aims are to formally recognize an internationally agreed Global Stratotype Section and Point (GSSP) for the base of every system and for every stage of every system (Salvador, 1994; Remane *et al.*, 1996). For the Lower Jurassic Series only the Sinemurian Stage has an agreed GSSP, as discussed further below (and in Page, 2001).

Below the level of stage, subdivisions at the level of *chronozone* and ultimately *zonule* can

be used, although there is no formal regulation of these through the ISJS or the ICS. In the Jurassic System the frequent occurrence of ammonites and their wide geographical distribution has led to their use for correlating sequences of *standard zones*. As discussed at great length elsewhere (e.g. by Callomon, 1965, 1985b; Callomon and Donovan, 1974; Cox, 1990; Page, 1995), these 'standard zones' are chronozones and should therefore be treated as such – a point overlooked by some authors (e.g. in Whittaker *et al.*, 1991) who confuse Jurassic ammonite zones with biozones, where the use of fossils in correlation is not implicitly linked to a geological timescale. The use of the term 'zone' in a chronostratigraphical sense was first established for the Jurassic System by Albert Oppel (1856–1858) who developed a sequence of such divisions for the entire system. This convention continues today within the working groups of the ISJS.

Like stages, chronozones require definition at their bases in stratigraphical reference sections, or stratotypes, to establish full chronostratigraphical meaning. Although most Lower Jurassic standard ammonite zones are now defined in this way (e.g. in Cox, 1990; Howarth, 1992; Page, 1992; Page and Bloos, 1998), confusion does still exist, even in recent published literature and reviews. In addition, although the names of the chronozone units are derived from species names they are by convention quoted non-italicized (e.g. Jamesoni (Standard) Zone or Chronozone and not *Uptonia jamesoni* Zone).

Other fossil groups, especially microfossils, have been used to construct true biozonal schemes for the Jurassic System, but the resolution of these schemes is always inferior to the ammonite scale. Indeed, the latter is often used as a 'standard' against which other biozonal schemes are correlated. For this reason only the ammonite-based standard zonations for Europe will be considered further here. Zonal schemes for the Lower Jurassic Series based on microfossils and non-ammonite macrofossils are discussed in a later section.

High resolution stratigraphy – biohorizons and zonules

Jurassic standard zones (chronozones) are often divided into subzones, largely for historical reasons but also to maintain a degree of nomenclatural stability at zonal level (Figures 1.3–1.8). Smaller, infra-subzonal divisions, known as 'horizons', are also frequently used in Jurassic ammonite stratigraphy to further refine correlations. However, somewhat confusingly the term can refer to two conceptually different types of unit known more precisely as *zonules* or *biohorizons* (Page, 1995). *Zonules* (following Phelps, 1985, after Hedberg, 1976) are the smallest resolvable segments of a chronostratigraphical scale and should, therefore, be defined by a basal boundary stratotype, as for higher divisions. *Biohorizons*, however, are conceptually biochronological events, which were defined by Callomon (1985a,b) as 'a bed or series of beds characterized by a fossil assemblage within which no further stratigraphical differentiation of the fauna (or flora) can be made'. The much earlier term *hemera*, as used by S.S. Buckman (1902), would be the chronological equivalent of biohorizon (cf. Callomon, 1985a), i.e. as period is the time equivalent of system. A biohorizon is the smallest palaeontologically correlatable unit of geological time and, unlike a normal chronozone, is effectively defined at both the base and top. The duration of a biohorizon typically is very short, geologically, but a significant time gap may exist between each successive unit and is shown as an interval on any correlation diagram (e.g. in Page, 1992, 1995; Dommergues *et al.*, 1994). As the use of biohorizons is broadly analogous to events in event stratigraphy, they allow correlation of virtually isochronous time-lines between successions at different localities (Callomon, 1985a,b). By chronostratigraphical convention zonules should be quoted in a similar fashion to zones and subzones, i.e. with a non-italicized specific name (e.g. Planorbis Zonule), but biohorizons retain an italicized specific epithet (e.g. *planorbis* Biohorizon). In practice, however, many named zonules use, misleadingly, an italicized specific name and are referred to as 'horizons'; analysis of supporting text is necessary to clarify such ambiguities.

Biohorizonal and zonule schemes applicable to the Lower Jurassic Series in Britain are introduced below. They represent the ultimate in biostratigraphically resolvable chronology for the Jurassic System as the average zonule or biohorizon-plus-interval duration is potentially less than 200 000 years in the Lower Jurassic Series of north-west Europe (Page, 1995, 2003).

OUTCROP, SUBCROP AND STRUCTURAL FRAMEWORK OF THE LOWER JURASSIC SERIES IN BRITAIN

M.J. Simms

The main outcrop of the Lower Jurassic Series in Britain forms an almost unbroken strip of varying width extending from the east Devon and west Dorset coast, NNE through Somerset, Gloucestershire, the east Midlands and Humberside, to the coast of Cleveland and North Yorkshire. Significant outliers occur on either side of the Bristol Channel, in the Hebrides and adjacent west coast of Scotland, and in north-east Scotland (Figure 1.2; and Figure 8.1, Chapter 8), with others around Prees in Shropshire and Carlisle. The GCR sites described in this volume include representatives from the main outcrop and from the main outliers, with the exception of the Carlisle and Prees outliers where there are no permanent exposures.

To the east of its main outcrop the Lias has an extensive subcrop in England (Figure 1.2), which onlaps the London–Brabant Massif (Arkell, 1933; Donovan *et al.*, 1979). Investigation of both onshore and offshore outcrop/subcrop by drilling and geophysical methods, usually in association with hydrocarbon exploration, has revealed much about the nature, extent and structure of Lower Jurassic strata in Britain. Thick Lower Jurassic successions have been proven by boreholes in the North Sea, Hebrides Sea, Irish Sea, Bristol Channel and Cardigan Bay. The Mochras Borehole, on the edge of Cardigan Bay, proved more than 1300 m of Lias, the thickest Lower Jurassic succession yet encountered in the British Isles (Woodland, 1971).

To the north and west of the main outcrop there is evidence that much of the former cover of Lower Jurassic sediment has been lost through erosion. The Carlisle and Prees outliers are examples of erosional remnants of outcrops that formerly were much more extensive. Estimating the original depositional limits of the Lias is difficult. The presence of marginal facies, such as those exposed on the south Wales coast at the **Pant y Slade to Witches Point** GCR site, and adjacent to the Mendip Hills in the **Hobbs Quarry** and **Viaduct Quarry** GCR sites, provides evidence for the vicinity of shorelines at those specific times. However, such marginal facies are relatively rare and pass laterally and vertically up into offshore facies that provide little information on the limits

of deposition. Furthermore, the picture has been complicated by post-Jurassic faulting so that the present-day juxtaposition of Palaeozoic and Lower Jurassic outcrops cannot be taken as evidence for the location of shorelines during early Jurassic times. For example, in the Quantock Hills of Somerset, Devonian sandstones crop out within 1 km of coastal exposures of Lower Jurassic mudstones that contain no evidence of proximity to marginal deposits. Similarly, the presence of more than 1300 m of Lower Jurassic and 600 m of Tertiary sediments in the Mochras Borehole, adjacent to outcrops of Cambrian strata, testifies to the scale of post-Jurassic faulting at the margins of some basins.

Extensional stresses associated with the break-up of Pangaea in early Mesozoic times saw the development of several major sedimentary basins across Britain, each of which accumulated hundreds of metres of Lower Jurassic sediment as part of a total Mesozoic fill sometimes several kilometres thick. To a large extent the configuration of these various Mesozoic basins was determined by pre-existing faults, a concept already alluded to by Godwin-Austen (1856). These fractures originated during the Variscan, Caledonian or even earlier orogenies, and hence show orientations characteristic of these events. In several instances Mesozoic periods of subsidence represent only one episode in a sometimes complex history of basin subsidence and inversion (Chadwick, 1993). The fact that deposition was far from uniform across Britain during early Jurassic times was noted from the earliest days of geology; examples such as the highly condensed sequence in the Radstock district were often compared with the much thicker sequence in Dorset (e.g. Moore, 1867a). Subsequently, more subtle variations in thickness of the Lower Jurassic succession were noted across particular areas, for instance in the Market Weighton area of eastern England (Kendall, 1905) and in the north and mid-Cotswolds (Buckman, 1901). Attention seems often to have been focused on these persistent areas of reduced or interrupted sedimentation, which became known as 'axes of uplift' and were perceived as subdividing the troughs into distinct basins of deposition. Arkell (1933, pp. 59–87) provides a useful summary of the various 'axes' as they were recognized more than half a century ago, grouping them according to the major underlying structural trends that they seem to follow. Subsequently Hallam (1958) formulated the concept of 'swells', as rather broader positive features than the almost

two-dimensional 'axes' proposed by Arkell (1933), separating basins in which sedimentation was comparatively rapid. The concept was refined for the Pliensbachian to Bajocian interval by Sellwood and Jenkyns (1975), who highlighted the fact that 'basinal' facies often occurred within sediment sequences developed over these 'swells'. Their conclusions invoked considerable discussion (Hudson, 1976; Kent, 1976) but, simultaneously, Whittaker (1975) had proposed a fault-bounded rift-valley model for the Mesozoic basins in southern Britain. Whittaker's model predicted overlap of earlier by later Mesozoic strata, implying that faults in the lower, Triassic, parts of the succession would pass up into asymmetric folds in the higher, Jurassic, parts of the sediment pile. It was this concealment of the bounding faults of many basins that appears to have led to the notion of the rather ill-defined 'swells' of Hallam (1958) and Sellwood and Jenkyns (1975) and, in earlier times, the 'axes of uplift' of Buckman (1901) and others that were thought, ultimately, to have been determined by folding in the underlying basement. Subsequent research has largely verified Whittaker's predictions, with bounding faults identified at the margins of all of the major Mesozoic basins and other faults commonly subdividing these basins into smaller sub-basins by the development of graben or half-graben structures (e.g. Chadwick, 1985, 1986). Since then the development and widespread use of various geophysical techniques (e.g. Chadwick, 1985, 1986), coupled with refined interpretation of field observations (e.g. Jenkyns and Senior, 1991), has vastly increased our knowledge of the structure of these basins and their development through early Jurassic times.

On this basis several distinct early Jurassic depositional areas can be recognized in Britain, of which nine are covered by the selected GCR sites (Figure 1.2). These are the Wessex Basin, Bristol Channel/Somerset Basin, Mendip High and Radstock Shelf, Severn Basin, East Midlands Shelf, Market Weighton High, Cleveland Basin, Hebrides Basin and the Moray Firth Basin. Of those not represented in this GCR volume, the most significant onshore area is the Cheshire Basin. This contains an enormous thickness of Mesozoic sediment but Jurassic strata have been largely eroded away except in the Prees outlier, although even here the thickness of the Hettangian to Upper Pliensbachian succession is some 600 m. However, exposure is very poor and hence there are no sites suitable for GCR status.

PALAEOGEOGRAPHY

M.J. Simms

Britain lay between 30° and 40° north of the equator during early Jurassic times and occupied a key position in an epeiric seaway extending south-east into Tethys and north-east towards the Arctic (Figure 1.9). Although the break-up of Pangaea had commenced in Mid-Triassic times, about 230 Ma (Veevers, 1989), with rifting already well advanced by the start of the Jurassic Period, true ocean crust did not start forming in the north Atlantic until Toarcian times, about 180 Ma (Hallam, 1975). Hence throughout early Jurassic times the major landmasses of North America and Greenland never lay far to the north and west, with further extensive areas of land present to the north-east in Scandinavia. These may have formed a source of some of the terrestrial elements of the biota, such as plants, insects and dinosaurs, which are found occasionally in these marine sediments, though many may have originated from the various minor islands that must have dotted this shallow seaway.

In the most recently published detailed reconstruction of the palaeogeography during early Jurassic times Bradshaw *et al.* (1992) considered that much of Scotland, the London Platform and the extreme south-west of England were land areas (Figure 1.10). The Mendip Hills
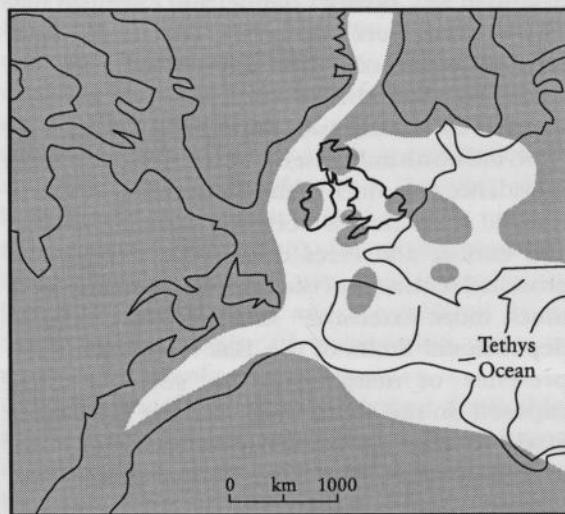

Figure 1.9 Generalized palaeogeographical reconstruction for the North Atlantic region during the Early Jurassic Epoch (light shading – sea; dark shading – land). After Scotese (2002).
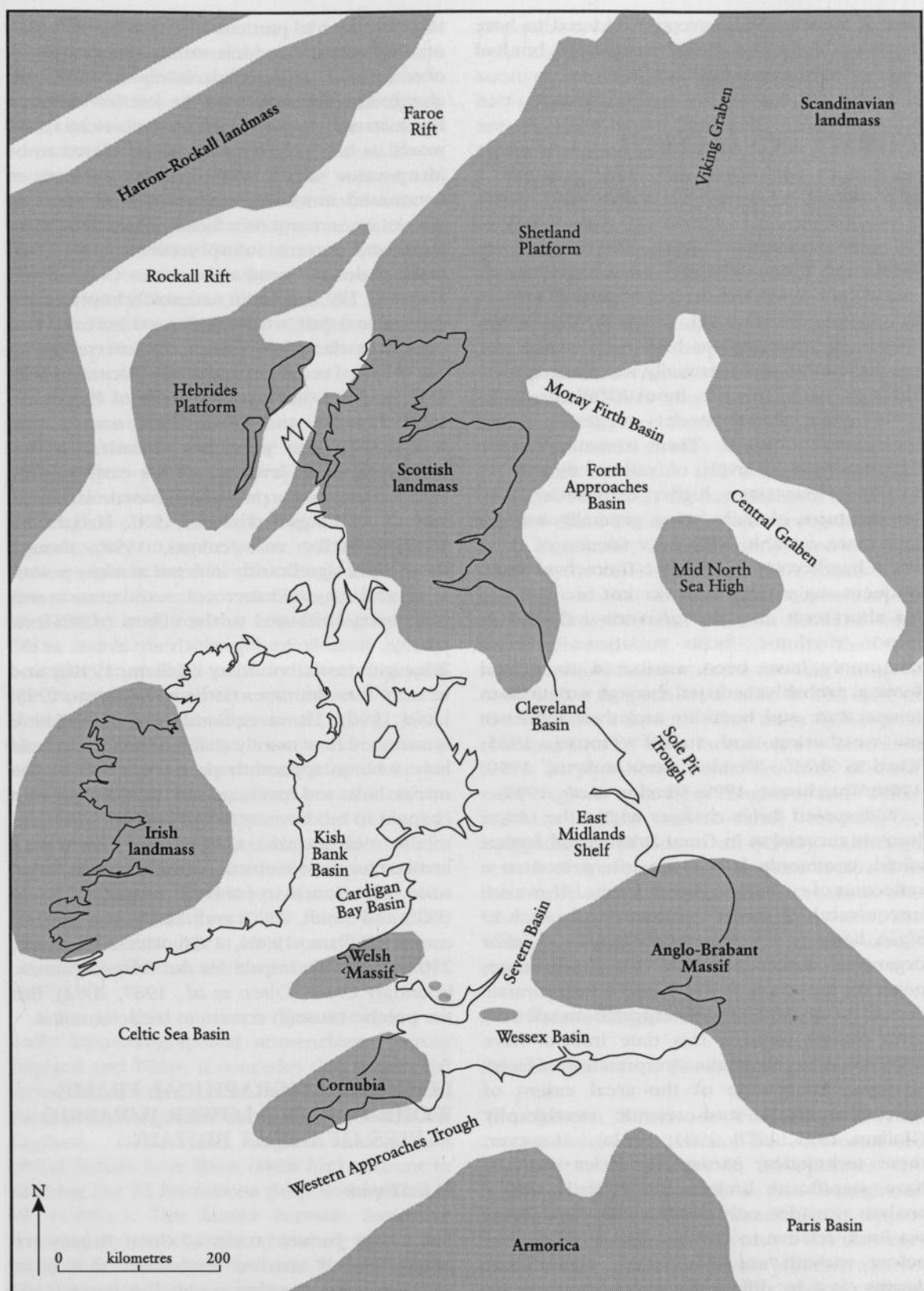
Figure 1.10 Palaeogeographical reconstruction for the British area during the Hettangian Stage of the Lower Jurassic Series (light shading – sea; dark shading – land). After Bradshaw *et al.* (1992).

and south-west Wales were considered to have been land for part of early Jurassic times but had become submerged by Toarcian times.

CLIMATE AND SEA LEVEL

M.J. Simms

Two environmental factors, climate and sea level, and their influence on Lower Jurassic facies, have been the subject of several reviews by Hallam (1981, 1984, 1985, 1992a, 1994). Britain is considered to have lain towards the southern edge of a seasonally wet climatic zone through early Jurassic times (Hallam, 1985, 1994) while climate models suggest a strong monsoonal influence. There is some evidence for atmospheric levels of carbon dioxide as much as four times higher than today, with temperatures globally being generally warmer and more equable with no evidence of Polar ice (Chandler *et al.*, 1992). There have been frequent suggestions over the last two decades for short-term climatic variations reflected in minor, rhythmic, facies variations. These commonly have been attributed to orbital forcing, probably mediated through variations in temperature and humidity and their influence on weathering and runoff (House, 1985; Weedon, 1986; Weedon and Jenkyns, 1990, 1999; Waterhouse, 1999; Weedon *et al.*, 1999).

Widespread facies changes within the Lower Jurassic succession in Great Britain, and farther afield, commonly have been interpreted as a reflection of eustatic sea-level change. However, unequivocal indicators of water depth, such as algae, hermatypic scleractinian corals and other organisms associated with the photic zone, generally are scarce in the British Lower Jurassic Series. Consequently, interpretations of sea-level change through this time interval have been based largely on the interpretation of facies changes, knowledge of the areal extent of successive units, and seismic stratigraphy (Hallam, 1975, 1978, 1981, 1992a). However, these techniques, particularly facies analysis, have significant limitations. Firstly, facies analysis provides only a qualitative measure of sea level, relative to the facies units above and below, without any quantitative component; depths cited by different authors for the same facies unit may vary by an order of magnitude. Secondly, and perhaps more significantly, the interpretation of particular facies is based largely on depositional models rather than empirical observation. As a result interpretations have changed significantly over the last few decades. For instance, marine black (organic-rich) shales would at one time have been considered to be 'deep-water' facies while erosion surfaces or condensed units were interpreted as 'shallow-water or emergent' facies (Arkell, 1933). However, current interpretations view many black shales as transgressive facies (Wignall and Maynard, 1993), without necessarily implying any particular depth, while condensed horizons and erosion surfaces are commonly interpreted as the result of sediment starvation associated with high sea level (compare the views of Haq *et al.*, 1987; Hesselbo and Palmer, 1992; and Hallam, 1999). In the past two decades several independent sea-level curves for early Jurassic times have been published based on these various techniques (Hallam, 1981; Haq *et al.*, 1987; Hesselbo and Jenkyns, 1998), though these differ significantly in detail at many points.

Several major Phanerozoic extinction events have been attributed to the effects of sea-level change, notable among which are events at the Triassic–Jurassic boundary (Hallam, 1990a) and in early Toarcian times (Little and Benton, 1995; Little, 1996). However, Smith *et al.* (2001) have questioned how merely changing sea level could have such an apparently profound effect on the marine biota and have suggested that the apparent changes in biodiversity in fact largely reflect bias in the rock record. Other factors have been invoked for these extinction events, such as large-scale volcanic activity for both the early Toarcian (Pálfy and Smith, 2000) and the Triassic–Jurassic events (Hallam, 1990a, 1996; Hesselbo *et al.*, 2002), or bolide impact for the Triassic–Jurassic boundary event (Olsen *et al.*, 1987, 2002), but the precise cause(s) remain to be determined.

LITHOSTRATIGRAPHICAL FRAMEWORK FOR THE LOWER JURASSIC SERIES OF GREAT BRITAIN

M.J. Simms

The Lower Jurassic rocks of Great Britain are predominantly marine mudstones that have been grouped together under the name 'Lias' since the early part of the 19th century. They form a distinctive succession between the mostly

red, non-marine sediments of the Triassic System, and the marine carbonates (in southern Britain), or predominantly non-marine sands (in northern Britain) of the Middle Jurassic Series. The Lias was deposited in a series of inter-connected sedimentary basins and shelf areas, producing local differences in the sedimentary successions. Nonetheless these local succes-sions can be correlated with some precision. At some stratigraphical levels the same lithostrati-graphical formation can be recognized across large areas of Britain. Examples are the Blue Lias Formation and the Marlstone Rock Formation/Member, both of which were already in use as lithostratigraphical terms in the early 19th century. During the 19th and 20th centuries many new names were introduced for local subdivisions within the Lias. These were often rather poorly defined, with imprecise boundaries and often based on a combination of lithological and palaeontological characters. Consequently in some areas several different names might be used for the same unit. Much of this nomenclature was rationalized by Cope *et al.* (1980a) and, for the Lias of England and Wales, was further revised by Cox *et al.* (1999). A similar rationalization of the lithostratigraphi-cal framework has been carried out for the Hebrides Basin (Hesselbo *et al.*, 1998, 1999; Morton, 1999a). These frameworks are now widely accepted and have been adopted in this volume (Figure 1.11). They are also to be adopted in the revised edition of the Geological Society of London's correlation guide for the Lower Jurassic Series, currently in preparation (K.N. Page, pers. comm.). Intra-basinal sub-divisions of these formations have yet to be rationalized although at least some have been, or will be, afforded member status (Cox *et al.*, 1999).

Although this approach has attempted to unify lithostratigraphical nomenclature across England and Wales, it concedes that substantial facies differences do exist between some areas, particularly between northern and southern England. Hence both temporal and geogra-phical factors have been taken into account in defining the 12 formations proposed by Cox *et al.* (1999). The Lower Jurassic Series in Scotland was not considered in their report, but most of the GCR sites there are located within the Hebrides Basin where recent work on the succession there has sought to establish a consistent lithostratigraphical framework

(Hesselbo *et al.*, 1998, 1999; Morton; 1999a, this volume). Details of lithologies within the litho-stratigraphical formations recognized on the east coast of Scotland are not included here but are described in the **Dunrobin Coast Section** GCR site report (see Chapter 7).

The Lias Group, as defined by Cox *et al.* (1999), encompasses the entire Lower Jurassic succession together with the uppermost beds of the Triassic System (the 'Pre-Planorbis Beds' of earlier accounts) and the lowermost part of the Middle Jurassic Series in those areas where the upper part of the Bridport Sand Formation is Aalenian in age. For the purposes of their litho-stratigraphical revision Cox *et al.* (1999) divided England and Wales into four main depositional areas; the Wessex Basin, including parts of Somerset and south Wales; the Severn (= Worcester) Basin and adjoining Bristol–Radstock Shelf area; the East Midlands Shelf; and the Cleveland Basin. They also recognized that other significant, though poorly exposed, out-crops in the Cheshire and Carlisle basins were not fully covered in their report, whereas off-shore successions and those in Scotland were specifically excluded. In this volume the litho-stratigraphical framework for the Lias Group of each region is given in a table at the start of the relevant chapter. The main lithological characteristics of each formation are described below, in alphabetical order for each of three main regions (southern England and Wales, northern England, and Scotland), following the nomenclature of Cox *et al.* (1999). Although certain of the formations are quite localized in their areal distribution, others, such as the Charmouth Mudstone Formation and the Whitby Mudstone Formation, extend across several basins.

Southern England and Wales

Beacon Limestone Formation

The Beacon Limestone Formation broadly corresponds to the 'Junction Bed' of Dorset and Somerset. In Dorset it incorporates the Marlstone Rock Member, a thin ferruginous oolitic and conglomeratic limestone of upper-most Pliensbachian to lowermost Toarcian age, and the Eype Mouth Limestone Member, a series of calcilutitic to conglomeratic pink to cream limestones with very little clastic material present. In the Ilminster area of Somerset the sequence is
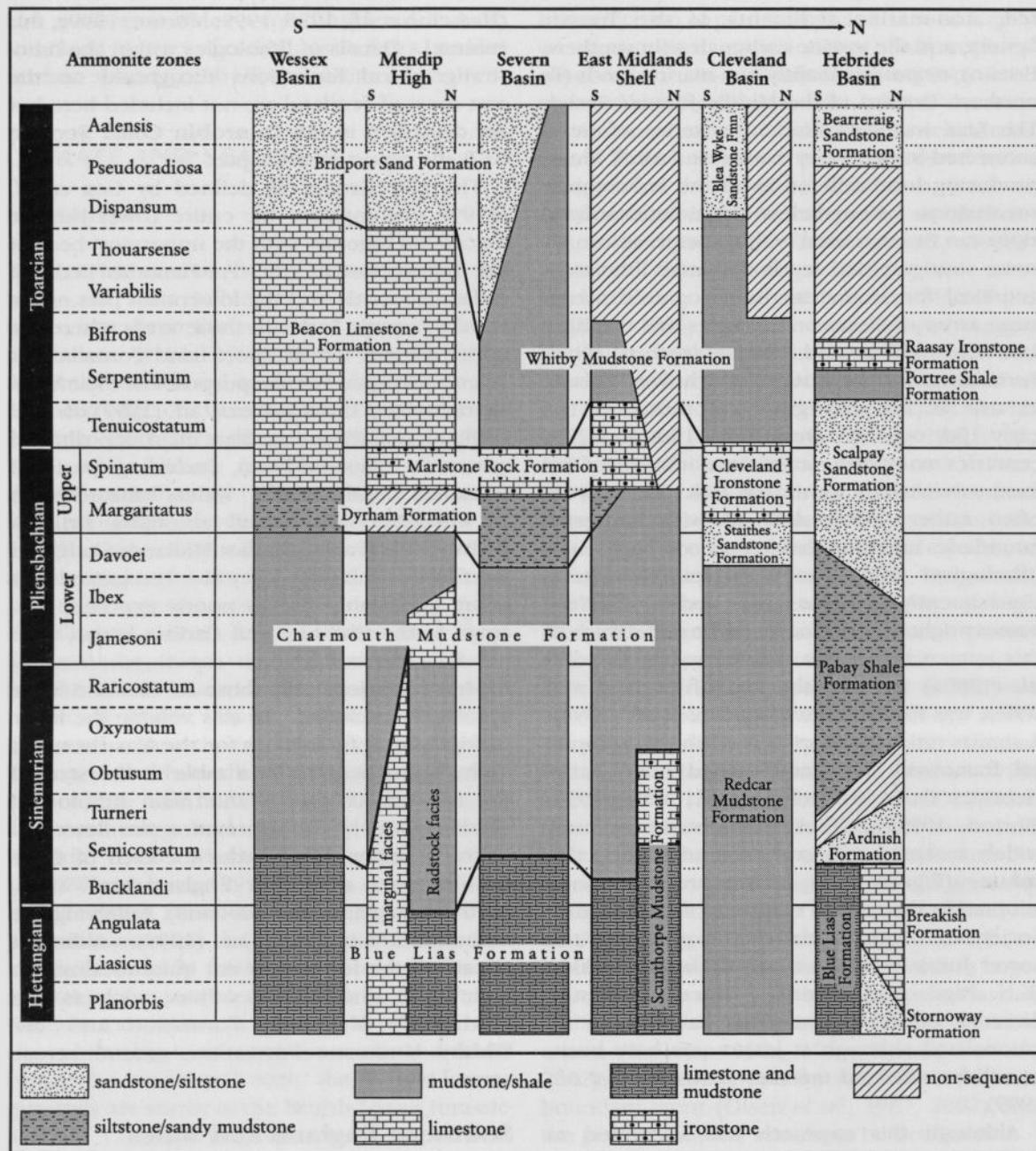
Figure 1.11 Lithostratigraphical nomenclature for the Lias Group in Britain showing the dominant lithologies of each formation. Thick lines indicate the formational boundaries. Based on Cox *et al.* (1999) and Morton (this volume).

more expanded and mudstones are locally a significant element within a sequence of argillaceous and conglomeratic limestones; this has been termed the 'Barrington Limestone Member'. A consistent characteristic of this formation is that it is a highly condensed sequence, with several ammonite zones reduced to a succession no more than a few metres in thickness and packed with ammonites. The most detailed accounts of this formation on the Dorset coast are by Jackson (1922, 1926) and Jenkyns and Senior (1991). There has been little recent work in the Ilminster area since that of Wilson *et al.* (1958).

Lower Jurassic lithostratigraphical framework

Blue Lias Formation

The Blue Lias Formation is perhaps the best known of all Lower Jurassic lithofacies. In its most characteristic development it consists of decimetre-scale alternations of argillaceous limestone and mudstone. These may show symmetrical cycles of limestone–marl–mudstone–marl–limestone (Hallam, 1964a). The limestones themselves vary from tabular to nodular and impersistent and may be massive or, less commonly, laminated; many are at least partly diagenetic in origin. The limestones may locally form only a minor component at some levels, notably in the Liasicus Zone of the Hettangian Stage. Adjacent to Palaeozoic highs the Blue Lias Formation lithofacies passes laterally into marginal facies dominated by bioclastic and skeletal limestones. The formation encompasses several ammonite zones, from the 'Pre-Planorbis Beds' into the Lower Sinemurian Substage. Member names have been proposed for various parts of the Blue Lias Formation across southern Britain. However, these have yet to be fully rationalized and currently there is considerable duplication. For instance names applied to the mudstone-dominated part of the succession in the Liasicus Zone include the Saltford Shale, St. Audrie's Shale and Lavernock Shale members. These various provisional member names are mentioned in the text, where appropriate, but have not been incorporated into the figures summarizing the lithostratigraphy for each region. Detailed accounts of the Blue Lias Formation can be found in Hallam (1960a) and Wobber (1965).

Bridport Sand Formation

The Bridport Sand Formation encompasses several older lithostratigraphical names for geographically defined units of similar facies; the 'Cotteswold Sands', 'Midford Sands', 'Yeovil Sands' and 'Bridport Sands'. The typical, and dominant, facies consists of yellow-weathering bioturbated silts and fine sands with many calcite-cemented beds or lenticles. Other facies may be developed locally, such as sandy mudstones near the base (the Down Cliff Clay Member), bioclastic limestones near the middle (the Ham Hill Limestone Member) or ironshot marls and limestone at the top (the Cotteswold Cephalopod Bed Member). These

units are of a broadly similar, late Toarcian, age but both the base and top are markedly diachronous, being younger in the south than in the north. Davies (1969) gives the fullest account of the lithologies in the Bridport Sand Formation.

Charmouth Mudstone Formation

The Charmouth Mudstone Formation is dominated by mudstones, from dark-grey laminated organic-rich shales to pale-grey calcareous mudstones. Argillaceous limestone beds form only a very minor component, although diagenetic carbonate or siderite nodules, or pyrite, may be common at some levels. There may be local developments of sandy or silty units a few metres thick. Several discrete members have been recognized on the Dorset coast but are less readily applicable inland. On the Radstock Shelf, north of the Mendip High, the succession is highly condensed into a series of thin limestones and clays only a few metres thick. The formation broadly corresponds to the Lower Lias Clay of many earlier accounts, and typically encompasses much of the Sinemurian Stage and Lower Pliensbachian Substage. Both the base and top are diachronous and often difficult to define precisely. The best recent account of the lithologies of this formation in its type area is by Hesselbo and Jenkyns (1995).

Dyrham Formation

The Dyrham Formation is dominated by grey to greenish-grey silty to sandy mudstone. There may be local developments of ferruginous limestone or sandstone beds, while diagenetic carbonate or siderite nodules, and sometimes large sandstone doggers, may also be present. The formation encompasses the upper part of the Lower Pliensbachian Substage and much of the Upper Pliensbachian Substage. The base is diachronous, whereas the top is drawn at the base of the Marlstone Rock Member/Formation. Hesselbo and Jenkyns (1995) provide a good account of Dyrham Formation lithologies on the Dorset coast. Details for the remainder of the outcrop can be found in the various regional guides for the [British] Geological Survey (e.g. Wilson et al., 1958; Edmonds et al., 1965) and in the unpublished thesis of Chidlaw (1987).

Marlstone Rock Formation

The Marlstone Rock Formation is a distinctive ferruginous limestone. It is typically oolitic, often sandy or conglomeratic, and generally is highly fossiliferous. Where it is closely associated with overlying condensed Toarcian limestones, as in the Beacon Limestone Formation of Dorset, the Marlstone Rock Formation is reduced to member status. It has long been recognized as marking the top of the Pliensbachian Stage, and of the Middle Lias, but in many places it extends into the basal Toarcian Stage. The base generally is sharply defined but it may be continuous with indurated sands of the upper part of the Dyrham Formation. Whitehead (1952), Edmonds *et al.* (1965), Hallam (1967a), Simms (1990a) and the unpublished thesis of Chidlaw (1987) all give good descriptions of lithologies in the Marlstone Rock Formation.

Northern England

Blea Wyke Sandstone Formation

The Blea Wyke Sandstone Formation consists of grey- or yellow-weathering argillaceous to silty sands and is confined to a restricted area of the Cleveland Basin, having been removed by pre-Aalenian erosion elsewhere in northern England. It encompasses only the uppermost part of the Toarcian Stage, with a gradational boundary with the Whitby Mudstone Formation below. Knox (1984) and Hesselbo and Jenkyns (1995) give the only recent accounts of this formation.

Cleveland Ironstone Formation

The Cleveland Ironstone Formation is characterized by rhythmic sequences of dark argillaceous siltstone and silty sandstone capped by relatively thin, but laterally persistent, beds of ooidal ironstone. It is confined to the Cleveland Basin, and encompasses a large part of the Upper Pliensbachian Substage. The lower boundary of the Cleveland Ironstone Formation is gradational from the Staithes Sandstone Formation below, and the upper boundary is sharply defined by the incoming of dark mudstones at the base of the Whitby Mudstone Formation. It was described in detail by Young *et al.* (1990a).

Redcar Mudstone Formation

The Redcar Mudstone Formation is dominated by grey fissile mudstones and siltstones, but thin beds of shelly limestone occur in the middle of the formation, and siderite concretions are prominent towards the top of the formation. It is confined to the Cleveland Basin, and has been subdivided into four members: the Calcareous Shale, Siliceous Shale, Pyritous Shale and Ironstone Shale members. It encompasses much of the Lower Lias from the Hettangian Stage through to the upper part of the Lower Pliensbachian Substage, and as such can be correlated with the Blue Lias and Charmouth Mudstone formations of southern England. Facies within this formation have been described by van Buchem and McCave (1989) and Hesslbo and Jenkyns (1995).

Scunthorpe Mudstone Formation

The Scunthorpe Mudstone Formation is dominated by grey mudstones with thin argillaceous limestones and calcareous siltstones. It is confined to the northern part of the East Midlands Shelf, south of the Market Weighton High. In Humberside, the upper part of the formation consists of an ooidal and richly bioclastic ironstone, more than 10 m thick called the 'Frodingham Ironstone Member'. It is succeeded abruptly by the Charmouth Mudstone Formation. The Scunthorpe Mudstone Formation encompasses the Hettangian (and 'Pre-Planorbis Beds' below) and much of the Sinemurian (up to the Obtusum or Oxynotum zones) stages. The Frodingham Ironstone Member was described in considerable detail by Young *et al.* (1990b), but other parts of the Scunthorpe Mudstone Formation have more rarely been exposed and received only passing mention (e.g. Hallam, 1968a).

Staithes Sandstone Formation

The Staithes Sandstone Formation is dominated by argillaceous silty sandstones, often intensely bioturbated and with a range of small-scale sedimentary structures, with several metre-scale beds of laminated cleaner-washed sandstone in the upper part. It is confined to the Cleveland Basin, and both the upper and lower boundaries are gradational. The formation encompasses the

upper part of the Lower Pliensbachian Substage and lower part of the Upper Pliensbachian Substage. Lithological descriptions of this formation can be found in Brenchley *et al.* (1991).

Whitby Mudstone Formation

The Whitby Mudstone Formation is dominated overwhelmingly by dark-grey mudstones that are commonly laminated. Diagenetic carbonate, or less commonly, siderite or pyrite, nodules are common at certain levels. It broadly corresponds to the 'Upper Lias Clay' of many earlier accounts. It encompasses most or all of the Lower Toarcian Substage and a varying amount of the Upper Toarcian Substage, passing upwards into the sandier facies of the Blea Wyke Sandstone Formation or, in the Severn Basin, the Bridport Sand Formation. In the Wessex Basin it is replaced by the highly condensed Beacon Limestone Formation. Many published accounts exist of the lithologies and diagenesis of this formation in its type area. Good summaries and references to more detailed descriptions can be found in Hesselbo and Jenkyns (1995) and Rawson and Wright (1995).

Scotland (Hebrides Basin only)

Ardnish Formation

The Ardnish Formation is dominated by sandstones and sandy siltstones that are often highly micaceous and ferruginous. The formation corresponds to the upper part of the succession formerly included within the Broadford Beds of earlier accounts, and the lower part of an expanded Pabay Shale Formation as was defined by Hesselbo *et al.* (1998). Hence it can be correlated with the upper part of the Blue Lias Formation and lower part of the Charmouth Mudstone Formation, the lower part of the Frodingham Ironstone Member of the Scunthorpe Mudstone Formation, or part of the Redcar Mudstone Formation. Morton (1999a) separated it as a lithologically distinct formation between the traditional 'Pabba Shales' and the upper unit of his more restricted 'Broadford Beds', now re-named the Breakish Formation. The lithologies are described by Morton and Hudson (1995) and Hesselbo *et al.* (1998).

Bearreraig Sandstone Formation

The Bearreraig Sandstone Formation falls largely in the Middle Jurassic Series but its lowermost unit, the Dun Caan Shale Member, consists of bioturbated mudstones and is of uppermost Toarcian age (Morton and Hudson, 1995).

Blue Lias Formation

The Blue Lias Formation consists of alternating mudstones and limestones. It is of identical facies to the Blue Lias Formation of south-west England and so the same name has generally also been used in Scotland. This succession, found in Mull and Movern, encompasses the Hettangian Stage and Lower Sinemurian Substage. The formation passes laterally, through intermediate sandy limestones and shales, into the more lithologically varied Breakish Formation. Hesselbo *et al.* (1998) provide a summary of lithologies.

Breakish Formation

The Breakish Formation is dominated by limestones, often richly bioclastic and with corals and oolites at some levels. Mudstones and coarser clastic material form only a minor component. The formation corresponds to the lower part of the Broadford Beds of early accounts, and the 'Broadford Formation' of Hesselbo *et al.* (1998), and can be correlated with the lower part of the Blue Lias, Redcar Mudstone or Scunthorpe Mudstone formations of other regions. Good summaries of the facies are given by Morton and Hudson (1995) and by Hesselbo *et al.* (1998).

Pabay Shale Formation

The Pabay Shale Formation is dominated by silty and sandy mudstones, siltstones, and some sandstone, with the two main developments of sandstone recognized as distinct members within the formation. It largely corresponds to the Charmouth Mudstone Formation farther south. Lithologies are described in Morton and Hudson (1995) and in Hesselbo *et al.* (1998).

Portree Shale Formation

The Portree Shale Formation consists of dark-grey, or black, laminated to organic-rich mudstones, much like its correlative the Whitby Mudstone Formation farther south. It

corresponds to part of the Lower Toarcian Sub-stage. The formation was described by Morton and Hudson (1995), but is rarely exposed.

Raasay Ironstone Formation

The Raasay Ironstone Formation comprises a chamositic or sideritic, often oolitic, ironstone no more than a few metres thick in the middle of the Lower Toarcian Substage, and gradational from shaly limestones with chamosite ooliths seen in the upper part of the Portree Shale Formation. There is a brief description in Morton and Hudson (1995)

Scalpay Sandstone Formation

The Scalpay Sandstone Formation consists of an upward-coarsening sequence of siltstones to massive fine-grained sandstones. It extends from the middle of the Lower Pliensbachian Substage through to the basal Toarcian Stage, and hence encompasses the Dyrham and Marlstone Rock formations and Staithes Sandstone and Cleveland Ironstone formations of other regions. Descriptions can be found in Morton and Hudson (1995).

Stornoway Formation

The Stornoway Formation encompasses continental red-beds of late Triassic to earliest Jurassic age in some areas. The facies represented are described by Morton and Hudson (1995).

BIOSTRATIGRAPHY OF INVERTEBRATE MACROFOSSILS AND MICROFOSSILS

M.J. Simms and P. Hodges

The criteria for using particular fossil groups as biostratigraphical index fossils are well known. Such fossil species must have existed for a relatively short period of time, and hence be found through only a limited vertical thickness of rock; they must have a wide geographical distribution to allow correlation between widely separate sites; they must be relatively independent of facies, again to allow correlation between widely separated sites and different palaeoenvironments; they must be common and

easy to collect; and they must be readily identifiable to species level. Within the British Lower Jurassic succession various macrofossil taxa, particularly ammonites, have been used for this purpose since the earliest days of geology (Smith, 1797, MSS). Other macrofossil groups have also been shown to have some stratigraphical use in the Lower Jurassic Series, especially where their stratigraphical distribution can be tied in to the ammonite biostratigraphy. Neaverson (1955) summarized the stratigraphical ranges of some of the more important non-ammonite taxa. Range charts or zone/ subzone specific lists for various taxonomic groups or stratigraphical intervals have also been published, and can provide a useful source of information, particularly for groups that have received no recent taxonomic treatment (Melville, 1956; Hallam, 1961, 1987a; Whittaker and Ivimey-Cook, 1972; Ivimey-Cook, 1978, 1982; Hauff and Hauff, 1981; Dommergues, 1997).

Over the last few decades the needs of the hydrocarbon-exploration industry have led to the development and refinement of a range of bio-stratigraphical schemes based on microfossils. Most commercial boreholes produce only rock chips rather than cores and hence macrofossils of any sort are seldom identifiable. Under such circumstances biostratigraphical correlation is achieved through the use of various microfossil groups, each with particular advantages and drawbacks. None of the microfossil biostrati-graphical schemes has attained a resolution comparable to that provided by ammonites, and the criteria used to define microfossil zones and subzones commonly are less rigorous than those for ammonites. However, used together these microfossil zonal schemes can provide a reason-able level of stratigraphical precision.

Macrofossils

Ammonites

K.N. Page

Ammonite biostratigraphy and chronostrati-graphy and the British Lower Jurassic Series
The importance of ammonites in the biostrati-graphical subdivision of the British Lower Jurassic Series is unparalleled. They possess all of the essential attributes of ideal zonal index fossils; genera and species typically have a wide

geographical distribution, are largely facies independent, are often common and easily identified, and evolved rapidly such that successive taxa represent geologically short periods of time. The stratigraphical range of most of the ammonite genera found in Britain is summarized in Figures 1.3–1.8. The principal limitations of ammonites are that they are exclusively marine and that their aragonitic shells are prone to dissolution in deep-water environments or through diagenesis. Since Oppel (1858) first established his biozonal scheme for the Jurassic System there has been increasing refinement of the ammonite zonal scheme so that today we can recognize successive Jurassic ammonite faunas with an average duration of only 120 000 years (Callomon, 1995; Page 1995). With their great reliability and superb potential for high-resolution correlation, ammonite-correlated zones are established as the backbone of Jurassic stratigraphy, providing a standard against which all other biostratigraphical schemes are compared. Not surprisingly, therefore, their use in Jurassic correlation has meant that they have transcended biostratigraphical method and ammonite zones are now used as chronostratigraphical units to define the bases of actual named units of geological time; namely the Hettangian, Sinemurian, Pliensbachian and Toarcian stages of the Lower Jurassic Series.

British successions and localities have contributed significantly to the establishment of this role through the work both of British authors and visiting Europeans. For instance, the seminal works of d'Orbigny (1842–1849) and Oppel (1856–1858), which established the basic sequence of Jurassic stages and their mainly ammonite-correlated zones, were primarily syntheses of information from France, Germany and Britain. Indeed, five of d'Orbigny's *étages* and four of Oppel's *Étagen*, though none of them from the Lower Jurassic Series, were named after English locations (Arkell, 1933, pp. 8–17).

William Smith's work in England began the process of establishing the sequence of guide fossils for the Jurassic System for Britain, culminating in his *Stratigraphical System of Organised Fossils* of 1817. A remarkably early, and long-forgotten, study showing the value of a bed-by-bed approach to sampling and the correlation potential of ammonites, was that of Louis Hunton (Hunton, 1836; Arkell, 1933,

pp. 14–15). His work on the Middle and Upper Lias of North Yorkshire and Cleveland was based on the **Boulby Quarries** GCR site and, remarkably, remains the most detailed published stratigraphical description of the latter locality. The significance of this work would not have been lost on one of Hunton's contemporaries, Martin Simpson, who was based at Whitby Museum from 1837 and began to describe extensive ammonite collections from the district, including notes on their stratigraphical occurrence (Simpson, 1843, 1868). These same Yorkshire sections, and their contained fossil faunas, had already been described by John Phillips (1829), a nephew of William Smith who applied Smith's undescribed stratigraphical methods. Throughout the 19th century these Yorkshire coast sections remained fundamental to the development of Lower Jurassic biostratigraphy in Britain (e.g. in Tate and Blake, 1876; Fox-Strangways, 1892) and certainly were more influential in this respect than correlative sections in Dorset.

It was work in Germany, however, by Quenstedt (1856–1858) and Oppel (1856–1858) that refined that theory and method of Jurassic biostratigraphy (Arkell, 1933, pp. 8–17). Remarkably, Oppel's basic Hettangian to Pliensbachian zonal sequence is broadly the same as that used today, although zonation of the Toarcian Stage has been significantly refined, a process contributed to by Thomas Wright (1860a, 1878–1886) in his review and subsequent monograph of British Lower Jurassic ammonites. The latter work was the first attempt to provide a systematic overview of ammonite taxonomy and faunal successions in Britain, although it must now be viewed in conjunction with Donovan's synoptic supplement of 1954.

The next major advance was based on detailed bed-by-bed, layer-by-layer documentation of British strata and marked a major conceptual leap in the use of ammonites as stratigraphical guide fossils, the full significance of which has only really been appreciated in the last 30 years or so. S.S. Buckman's early work concentrated on determining the sequence of ammonite faunas in the mainly Aalenian–Bajocian Inferior Oolite Group of his home district of Dorset and Somerset. He soon realized that the existing ammonite zones could be subdivided further into many distinctive horizons, each with its own unique

and correlatable ammonite fauna. He coined the term '*hemera*' for these subdivisions and, through his thoughtful analysis of geochronology and biostratigraphical theory, the science of 'high-resolution' stratigraphy was born (e.g. Buckman, 1887–1907, 1902; Arkell, 1933, pp. 17–25). He even established the concept of biozones (Buckman, 1902). However, except for the uppermost Toarcian Stage, which was encompassed by his work on the Inferior Oolite Group (Buckman, 1887–1907), his interpretation of Lower Jurassic ammonite faunas was more theoretical. Although he created many hemerae for the subsystem (e.g. in 1909–1930), not all were based on actual field observation of specimens *in situ*. Inevitably stratigraphical sequencing errors crept in, providing ammunition for the critics of his method and even forcing him to publish some of his results privately. Nonetheless, the value of many of the units he established can be judged from the use of many of the same index ammonite taxa for the ammonite biohorizons of Page (1992, 2003).

The meticulous bed-by-bed collecting of ammonites by Lang, largely identified by Spath, from the Lower Lias of the Dorset coast (Lang, 1914, 1917, 1924, 1932, 1936; Lang *et al.*, 1923, 1928; Lang and Spath, 1926) complemented the largely theoretical chronology of Buckman (1898) by establishing high-resolution sequences of zones in the field, mainly in the Sinemurian and Pliensbachian stages. As with Buckman's hemera, however, these units were largely overlooked in later generalized syntheses of Lower Jurassic ammonite zones. Spath continued to contribute to the understanding of the British Lower Jurassic Series himself, through various important works (Spath, 1924, 1925a–h, 1926a–d, 1942, 1956).

In the 1950s and 1960s major advances were made in documenting Lower Jurassic ammonite sequences in other areas in Britain. Howarth investigated the Upper Pliensbachian Substage of Yorkshire, Dorset and north-west Scotland (Howarth, 1955, 1956, 1957, 1958) and the Lower Toarcian Substage of Yorkshire and Northamptonshire (Howarth, 1962a, 1973, 1978, 1992), while Donovan worked on the Hettangian and basal Sinemurian stages of the Bristol–Bath area (Donovan, 1952a,b, 1956). It was their work in the 1950s that ultimately led to the publication of the then-definitive work on

the standard zonal framework for the entire Lower Jurassic Series of north-west Europe (Dean *et al.*, 1961). Ammonite faunas from the remainder of the Sinemurian Stage and the Lower Pliensbachian Substage have received rather less coverage although monographic treatments of some taxa have been published, such as the Juraphyllitidae (Howarth and Donovan, 1964) and the Echioceratidae (Getty, 1972, 1973) to name but two.

Subsequent refinement of the ammonite stratigraphy of the British Lower Jurassic Series has concentrated largely on establishing rigorously defined, high-resolution, correlation schemes using 'horizons', including 'faunal horizons' or *biohorizons*, as pioneered by Callomon in the Middle and Upper Jurassic series (e.g. Callomon, 1985a,b) or *zonules* (*sensu* Phelps, 1985), the 'horizons' of French authors (Page, 1995). These are incorporated into Figures 1.3–1.8 of this volume. Biohorizon schemes have been proposed for the British Hettangian Stage (Page and Bloos, 1998; Bloos and Page, 2000a,b), for the Sinemurian Stage (Page, 1992; Dommergues *et al.*, 1994; Bloos and Page, 2000a) and for the Lower Toarcian Substage (Page, 2003). A system of zonules for the British Lower Pliensbachian Substage was proposed by Phelps (1985) while zonule schemes for the Upper Pliensbachian and Upper Toarcian substages follow Page (2003), based on Dommergues *et al.* (1997) and Elmi *et al.* (1997), respectively.

Despite the numerous revisions, compilations and refinements of the last 150 years or so, the ammonite-based zonation for the north-west European Lower Jurassic Series is still heavily dependent on British reference sections. At least 9 of the 22 zones, and around 35 of the 61 subzones still use an index fossil based on a type specimen from a British or Northern Irish locality. Inevitably, therefore, these sections will continue to play a key role in Lower Jurassic stratigraphy on a global scale as stratotypes for each unit are proposed and internationally agreed.

Ammonoid provincialism in the Lower Jurassic Series of Europe

Like any group of organisms, ammonoids show distinctive geographical distribution patterns, reflecting ecological and physical controls on individuals and populations. These patterns are

characterized as biogeographical provinces and the inevitable consequence of using ammonites for correlation purposes is that every province, almost by definition, will have a different scheme of standard zones. These differences inevitably make inter-provincial correlations at zonal, and especially subzonal and horizon, level difficult.

Representatives from up to three contemporaneous faunal provinces can be recognized at various levels in the Lower Jurassic Series of Britain (Page, 1996) and are summarized below:

1. *North-west European Province*: The province is typical of much of the shelf seas of Europe from Hettangian to Early Pliensbachian times and again in Late Toarcian times, when great faunal uniformity characterized most of the region. Faunal affinities are almost entirely from southern or Tethyan areas (i.e. from a *Mediterranean Province*) and direct connection to an Arctic or Boreal Sea is lacking (except perhaps in earlier Late Toarcian times). Zonal schemes of the North-west European Province are well developed reflecting the long history of research on the area.

2. *Subboreal Province*: The establishment of direct marine connections with the circum-polar Boreal Sea in Late Pliensbachian and Toarcian times enabled some mixing of Arctic Province faunas and the previously separated faunas of north-west Europe (Figure 1.9). The abundance of Boreal taxa alongside forms with more southerly affinities distinguishes the province in northern Britain. A standard zonation is well established and correlates fairly well with more southerly areas as a result of faunal overlap.

3. *Submediterranean Province*: The province developed in parallel with the Subboreal Province in late Pliensbachian times in regions between the former and the southern European Mediterranean Province. Boreal taxa usually are infrequent and an independent zonation is used in the Lower Toarcian Substage, but with significant links to that of Subboreal areas. Typical Mediterranean Province faunas are never developed in Britain, although a few genera and species typical of the province (e.g. Phylloceratina and Lytoceratina) do

turn up occasionally, mainly in the Pliensbachian and Toarcian stages, interestingly associated with both Submediterranean and Subboreal faunas.

Belemnites

M.J. Simms

Belemnites are the only nektonic group of invertebrate macrofossils, other than ammonites, that have been proposed as biostratigraphical index fossils for the Lower Jurassic Series. Records of belemnites from the Carboniferous Period are questionable, the first definite appearance being in upper Triassic or lower Jurassic strata of Europe. However, their potential as biostratigraphical index fossils in the Lower Jurassic sequence is limited by several factors. They are rare in the Hettangian Stage and do not become abundant until the mid-Sinemurian Stage. They may have been facies-dependent to some extent, with several species apparently affected by benthic anoxia in early Toarcian times (Simms, 1986; Doyle, 1990–1992); and the identification of individual species can be difficult, being based largely on subtle variations in guard morphology. However, belemnites have the advantage that they are abundant at some stratigraphical levels and their tough calcitic guards have a very high preservation potential, even in environments where the aragonitic shells of ammonites are destroyed or poorly preserved.

The belemnite biostratigraphy of the Lower Jurassic Series of north-west Europe was reviewed by Doyle and Bennett (1995), incorporating earlier work by Stoyanova-Vergilova (1977) and Doyle (1990–1992). In a more recent study, Combémorel (1997) attempted direct correlation between the established ammonite zonation and a series of proposed belemnite zones and subzones (Figure 1.12). The Hettangian Stage is characterized by the rare genus *Schwegleria*, although in Combémorel's scheme this genus is confined to the Planorbis Zone. The Sinemurian Stage is dominated by species of *Nannobelus*, a genus first appearing in latest Hettangian times. Combémorel (1997) includes the entire Sinemurian Stage in his *Nannobelus acutus* Zone. Only the index species is present in the Lower Sinemurian sequence but *Nannobelus oppeli* and *N. alveolatus* appear in the Upper Sinemurian sequence

	Ammonite zones		Belemnite zones and subzones (Combémorel, 1997)		Belemnite biozones (Doyle and Bennett, 1995)
Toarcian	Aalensis			*Acrocoelites bobeti*	
	Pseudoradiosa		*Brevibelus breviformis* and *Acrocoelites curtus*		*Brevibelus breviformis*
	Dispansum				
	Thouarsense				
	Variabilis		*Acrocoelites wrighti*		*Dactyloteuthis* spp.
	Bifrons		*Acrocoelites ilminsterensis*	*Acrocoelites striolatus*	*Acrocoelites vulgaris* and *Simpsonibelus dorsalis*
	Serpentinum			*Acrocoelites trisulculosus*	*Acrocoelites trisulculosus*
	Tenuicostatum		*Passaloteuthis bisulcata*		
Pliensbachian	Upper	Spinatum	*Parapassaloteuthis zieteni*		*Passaloteuthis bisulcata*
		Margaritatus			
	Lower	Davoei	*Hastites clavatus*	*Pseudohastites apicicurvata*	*Pseudohastites apicicurvata*
		Ibex			
		Jamesoni		*Coeloteuthis dens* and *Coeloteuthis excavatus*	
Sinemurian	Raricostatum				
	Oxynotum		*Nannobelus acutus*	*Nannobelus oppeli*	*Nannobelus* spp.
	Obtusum				
	Turneri				
	Semicostatum			*Nannobelus acutus*	*Nannobelus acutus*
	Bucklandi				
Hettangian	Angulata		Zone d'intervalle		*Schwegleria* spp.
	Liasicus				
	Planorbis		*Schwegleria*		

Figure 1.12 Proposed belemnite biozonation schemes for the Lower Jurassic Series of north-west Europe. Based on Doyle (1990–1992), Doyle and Bennett (1995) and Combémorel (1997).

and allow division of this zone into two subzones. Belemnites are abundant in the Upper Sinemurian sequence and particularly from the Pliensbachian Stage onwards. Lang (in Lang *et al.*, 1928) demonstrated the biostratigraphical resolution that could be achieved within the Lower Pliensbachian Substage, listing the stratigraphical range (by bed number) of 26 nominal

species found within the Belemnite Marl Member of the **Pinhay Bay to Fault Corner** GCR site. Although some of these nominal taxa must be no more than ecophenotypic, ontogenetic or sexual variants, nonetheless, there does appear to be some stratigraphical significance at the generic level. Thus slender elongate forms of *Pseudohastites* are particularly abundant in the lower part of the Jamesoni Zone (Taylori and Polymorphus subzones), *Clastoteuthis* in the upper Polymorphus Subzone, *Angeloteuthis* in the top Jamesoni and lower Ibex zones (Jamesoni to Valdani subzones) and *Hastites* in the Ibex and Davoei zones. However, both *Hastites* and slender forms of *Pseudohastites* are known to extend higher in the succession while the robust forms of *Pseudohastites*, such as *Pseudohastites apicicurvata* itself, range throughout the Lower Pliensbachian Substage. Combémorel (1997) recognized a single zone of *Hastites clavatus* in the Lower Pliensbachian sequence, divisible into two subzones. Typical species additional to the zonal/subzonal index fossils include *Nannobelus armatus*, *Passaloteuthis elongatus* and, in the Davoei Zone, *Hastites charmouthensis*. Doyle (1990–1992) considered the *Passalotheuthis bisulcata* Biozone to correspond broadly to the Upper Pliensbachian Substage and basal Toarcian Stage, but in Combémorel's scheme this species is taken as the zonal index fossil only for the Tenuicostatum Zone and the Upper Pliensbachian Substage is encompassed by the zone of *Parapassaloteuthis zieteni*, with *Pseudohastites longiformis* also characteristic.

Belemnite diversity is higher for the Toarcian Stage than for earlier stages, allowing for greater refinement of belemnite biozonation. By mid-Toarcian times the Belemnitinae were replaced by the more diverse Megateuthidinae. Doyle (1990–1992) proposed five belemnite biozones for the Toarcian Stage, based on a combination of the ranges of the biozonal index fossils and of other species, and provided an indication of their correlation with the standard ammonite zones. Combémorel (1997) recognized four zones and three subzones but there is a reasonable correspondence between the two schemes. Combémorel (1997) cites characteristic species for each of his zones and subzones whereas Doyle (1990–1992) provides range charts for all species of belemnite found in the British Toarcian Stage.

Bivalves

P. Hodges and M.J. Simms

Bivalves occur in large numbers throughout the Lias and dominate the shelf fauna of the early Jurassic seas. Most bivalve species in the early Jurassic Period have relatively long stratigraphical ranges compared to ammonite species, and consequently they do not generally give the same degree of resolution. Furthermore, most bivalves are benthic and strongly facies dependent, which detracts from potential use in correlation between different facies. However, use can be made of the first and last occurrences of many bivalve species in the stratigraphical column, correlated with known ammonite zones. Some species are known to extend virtually unchanged through several zones, or even stages, of the Lower Jurassic Series (Hallam, 1987a) although certain bivalve groups do show distinct and well-documented evolutionary changes through early Jurassic times and hence do have a limited biostratigraphical significance. Of these the most notable is the ostreid genus *Gryphaea*, which Trueman (1922a) was the first to use in biostratigraphical correlation based on material from the **Pant y Slade to Witches Point** GCR site. Subsequent publications challenged his conclusion that *Gryphaea* evolved from *Liostrea*, proposing instead an origin from late Triassic gryphaeate oysters. Nonetheless *Gryphaea* does exhibit distinct morphological changes through early Jurassic times, with three distinct species recognized (Figure 1.13); *Gryphaea arcuata* from the (upper Hettangian to lower Sinemurian) Angulata Zone to Semicostatum Zone, *Gryphaea mccullochi* from the (lower Sinemurian to basal Lower Pliensbachian) upper Semicostatum Zone to lower Jamesoni Zone, and *Gryphaea gigantea* from the (Lower Pliensbachian to upper Toarcian) Ibex Zone to Pseudoradiosa Zone. The lineage exhibits not only a clear paedomorphocline but also an overall size increase through early Jurassic times (Hallam, 1968b, 1982; Johnson, 1994). Other bivalve taxa (*Entolium lunare* and *Pseudopecten equivalvis*) documented by Johnson (1994) also show similar size increases through time, though without significant change in shape comparable to that seen in the *Gryphaea* lineage. Hence it is the morphometric changes associated with the
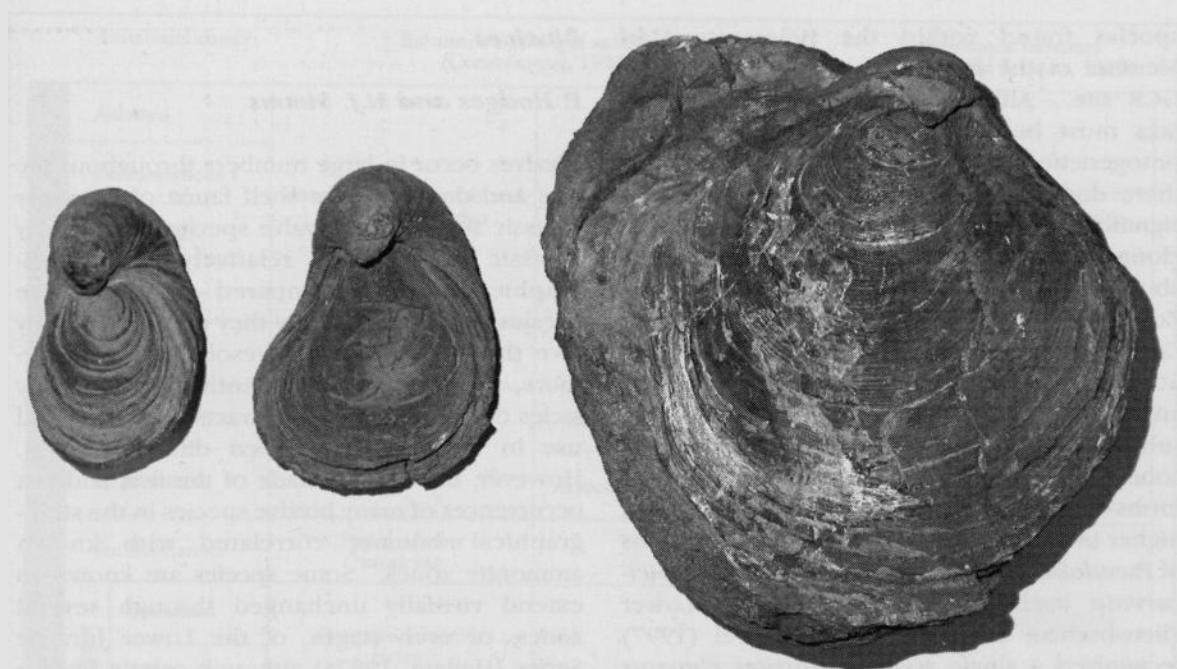
Figure 1.13 The *Gryphaea* evolutionary lineage, showing pronounced paedomorphosis and size increase. All specimens are from the Severn Basin. From left to right: *Gryphaea arcuata*, Bucklandi Subzone, Hock Cliff GCR site; *G. mccullochi*, Oxynotum Subzone, Bishops Cleeve; *G. gigantea*, Spinatum Zone, Bredon Hill. *G. gigantea* is 11.5 cm across.

Gryphaea paedomorphocline that are biostratigraphically significant. A few papers dealing with specific bivalve groups provide information on their stratigraphical distribution (Cox, 1963; Johnson, 1984), but many more taxa remain neglected. Lists and tables that give the stratigraphical range of many bivalve taxa are included in the descriptions of several boreholes (Melville, 1956; Whittaker and Ivimey-Cook, 1972; Ivimey-Cook, 1978, 1982) and other general accounts of the Lower Jurassic Series (Hallam, 1960a, 1961).

Detailed investigation by Peter Hodges of the bivalve faunas in several boreholes drilled by the British Geological Survey, and from coastal exposures in south-west Britain, indicate that some species are stratigraphically useful, particularly where ammonites are absent. His observations, summarized below, and in Figure 1.14, are published here for the first time.

In south-west Britain the Pre-Planorbis Beds of the Lower Lias are dominated by the mussel *Modiolus* (*Modiolus*) *minimus*, which locally may cover the upper surfaces of limestone beds. They suggest very shallow-water, possibly intertidal, conditions. The last occurrence of *Modiolus* (*M.*) *minimus*, coincides with the first appearance of *Plagiostoma giganteum* and indicates a marked increase in water depth. This relationship can be demonstrated at the **Pant y Slade to Witches Point** GCR site, in south Wales, where the Blue Lias Formation shows an eastwards transition along the coast from shallow-water marginal facies to deeper water offshore facies. It is also possible to pick out the occurrence of various bivalve species that coincide with these deepening water conditions. In the immediate vicinity of the Carboniferous Limestone Jurassic 'island' at Ogmore-by-Sea large numbers of the oyster *Terquemia difformis* occur with *Chlamys* (*Chlamys*) *valoniensis*. In the deeper-water facies east of Dunraven Bay these species disappear and are replaced by *Plagiostoma giganteum* and *Pinna* (*Pinna*) *similis*, which can be seen on the limestone beds exposed at low tide.

Throughout south-west Britain, the first occurrence of *Plagiostoma giganteum* precedes the first occurrence of the ammonite genus *Psiloceras* (Hodges, 1994). In the absence of ammonites, it can be used as a biostratigraphical

Biostratigraphy of invertebrate macrofossils and microfossils

Figure 1.14 Range chart for 27 common species of Rhaetian to Pliensbachian bivalve. From data compiled by Peter Hodges. See text for details.

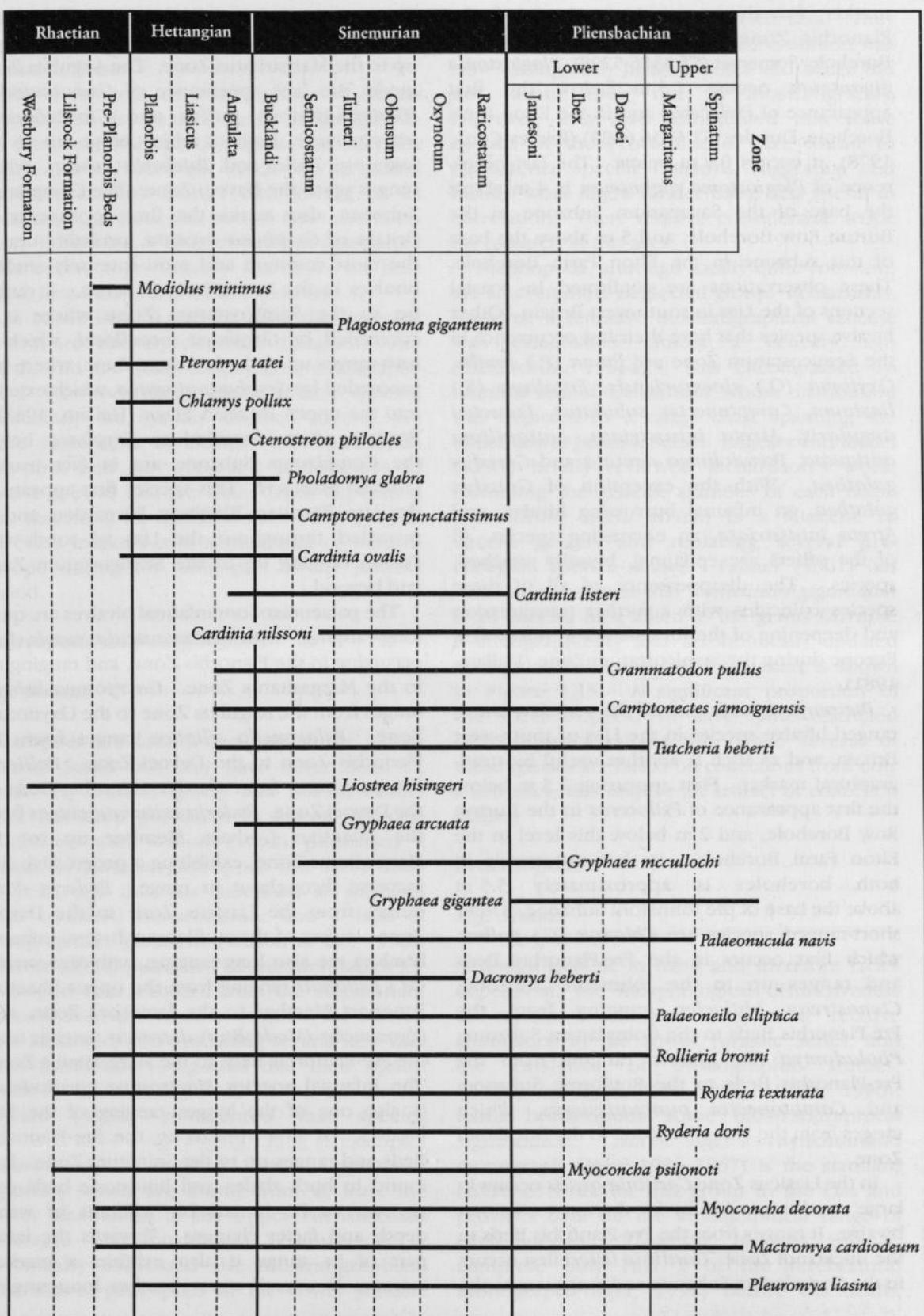marker for the approximate base of the Planorbis Zone. In the BGS Burton Row Borehole, Somerset (ST 3356 5208), *Plagiostoma giganteum* occurs 1.5 m below the first appearance of *Psiloceras* and in the Elton Farm Borehole, Dundry (ST 5636 6589) (Ivimey-Cook, 1978), it occurs 0.8 m below. The last occurrence of *Plagiostoma giganteum* is 4 m above the base of the Sauzeanum Subzone in the Burton Row Borehole, and 5 m above the base of this subzone in the Elton Farm Borehole. These observations are confirmed in coastal sections of the Lias in south-west Britain. Other bivalve species that have their last occurrence in the Semicostatum Zone are *Pinna* (*P.*) *similis*, *Oxytoma* (*O.*) *sinemuriensis*, *Entolium* (*E.*) *liasinum*, *Camptonectes subulatus*, *Eopecten angularis*, *Atreta intusstriata*, *Antiquilima antiquata*, *Pseudolimea dentata* and *Gresslya galathea*. With the exception of *Gresslya galathea*, an infaunal burrowing bivalve, and *Atreta intusstriata*, an encrusting species, all of the others are epifaunal, byssally attached, species. The disappearance of all of these species coincides with a further transgression and deepening of the Jurassic sea in north-west Europe during the Semicostatum Zone (Hallam, 1981).

Pteromya tatei is one of the very few short-ranged bivalve species in the Lias of south-west Britain, and as such is another useful biostratigraphical marker. First appearing 2.5 m below the first appearance of *Psiloceras* in the Burton Row Borehole, and 2 m below this level in the Elton Farm Borehole. Its last occurrence in both boreholes is approximately 3.5 m above the base of the Johnstoni Subzone. Other short-ranged species are *Chlamys* (*C.*) *pollux*, which first occurs in the Pre-Planorbis Beds and ranges up to the Johnstoni Subzone; *Ctenostreon philocles*, ranging from the Pre-Planorbis Beds to the Complanata Subzone; *Pholadomya* (*P.*) *glabra*, ranging from the Pre-Planorbis Beds to the Rotiforme Subzone; and *Camptonectes punctatissimus*, which ranges from the Planorbis Zone to the Bucklandi Zone.

In the Liasicus Zone *Cardinia ovalis* occurs in large numbers and is by far the most common bivalve. It ranges from the Pre-Planorbis Beds to the Bucklandi Zone. *Cardinia listeri* first occurs in the Complanata Subzone and ranges up to the

Raricostatum Zone while *Cardinia nilssoni* first occurs in the Sauzeanum Subzone and ranges up to the Margaritatus Zone. The Angulata Zone marks the first appearance of *Grammatodon* (*Grammatodon*) *pullus* and *Camptonectes jamoignensis*, both of which range up to the Jamesoni Zone, and *Tutcheria heberti*, which ranges up to the Davoei Zone. The Complanata Subzone also marks the first appearance in Britain of *Gryphaea arcuata*, probably one of the most common and most intensely studied bivalves in the Lower Jurassic Series. It ranges up to the Semicostatum Zone where it is succeeded by *Gryphaea mccullochi*, which in turn ranges up to the Jamesoni Zone, where it is succeeded by *Gryphaea gigantea*, which extends into the upper Toarcian Stage (Hallam, 1968b). Bivalves often identified as *Gryphaea* below the Complanata Subzone are in fact usually *Liostrea hisingeri*. This species first appears in the late Rhaetian Westbury Formation and is recorded throughout the Lias of south-west Britain ranging up to the Semicostatum Zone and beyond.

The palaeotaxodont infaunal bivalves are quite long-ranging, with *Palaeonucula navis* first occurring in the Planorbis Zone, and ranging up to the Margaritatus Zone. *Dacryomya heberti* ranges from the Angulata Zone to the Oxynotum Zone. *Palaeoneilo elliptica* ranges from the Planorbis Zone to the Davoei Zone. *Rollieria bronni* ranges from the Pre-Planorbis Beds to the Davoei Zone. *Ryderia texturata* ranges from the Rhaetian Cotham Member up to the Margaritatus Zone, exhibiting a progressive size increase throughout its range. *Ryderia doris* ranges from the Liasicus Zone to the Davoei Zone. A few of the isofilobranch semi-infaunal bivalves are also long-ranging, with *Myoconcha* (*M.*) *psilonoti* ranging from the upper Rhaetian Langport Member to the Jamesoni Zone, and *Myoconcha* (*Modiolina*) *decorata* ranging from the Pre-Planorbis Beds to the Margaritatus Zone. The infaunal species *Mactromya cardiodeum* is also one of the longest-ranging of the Lias bivalves. It first appears in the Pre-Planorbis Beds and ranges up to the Spinatum Zone. It is found in both shales and limestone beds and appears to be remarkably tolerant of water depth and facies changes. Towards the latter part of its range it also exhibits a marked increase in overall size. Another long-ranging

infaunal species is *Pleuromya liasina*, which ranges from the Planorbis Zone up to the Spinatum Zone.

The dominance of some species at certain horizons can also be used locally as stratigraphical markers. This can be demonstrated by the bivalve genus *Posidonia*, which can be picked out as a distinct marker bed, owing to its abundance, in both the Burton Row and Elton Farm boreholes. This *Posidonia*-dominated shale occurs approximately 5 m above the base of the Lyra Subzone in both boreholes.

In conclusion, it can be seen that infaunal bivalves are relatively tolerant of changes in water depth, and are quite long-ranging stratigraphically. However, the epifaunal bivalve species, particularly the byssally attached species, are more susceptible to changes in water depth. The first and last recorded occurrences of bivalve species that are water-depth dependant can, therefore, be useful as chronostratigraphical event markers over a wide area of western Europe during the early part of the Jurassic Period.

Gastropods and scaphopods

M.J. Simms

Gastropods are locally common in the Lower Jurassic Series but they have never been an intensively studied group and no substantial work has been published in several decades. Hudleston and Wilson (1892) published a census of Jurassic gastropods but more than 40 years ago this was described as suffering from outdated nomenclature and a lack of stratigraphical precision (Wilson *et al.*, 1958). Melville (1956) published distribution tables for gastropod taxa recorded from the Sinemurian, Pliensbachian and Toarcian stages of the Stowell Park Borehole, also describing several new taxa from there, but recognized that their significance for correlation remained to be assessed. Hallam (1961) commented that species appeared to be long-ranging, citing as examples *Pleurotomaria anglica* and *Cryptaenia expansa*, which are found from at least the Lower Sinemurian to the Upper Pliensbachian substages. McDonald and Trueman (1921) specifically addressed the biostratigraphical potential of gastropods in the Lower Jurassic

Series but discussed only selected taxa. They noted that, in general, gastropod evolution was slow during early Jurassic times and hence did not favour their use in biostratigraphy. However, they also commented that some species of the Procerithidae were found to characterize specific horizons, suggesting that further work might render these taxa useful in correlation. There remains considerable scope for research in this area.

Scaphopods, although locally quite common, are an even more neglected group. Remarkably, however, a tentative biostratigraphical scheme was established almost a century ago (Richardson, 1906a). This encompassed 16 nominal taxa of '*Dentalium*' whose distribution was depicted in a range chart spanning the entire Lower Jurassic Series. Engeser and Riedel (1992) briefly reviewed Richardson's work, discussing the generic affinities of each taxon (*Dentalium sensu stricto* is a Miocene to Recent genus) and replacing several preoccupied species names. Palmer (2001) has since demonstrated that *Dentalium giganteum* is an annelid tube allied to the genus *Ditrupa*. A stratigraphically and taxonomically updated version of Richardon's (1906a) chart is shown in Figure 1.15. A significant proportion of the species appear to have quite restricted stratigraphical ranges but, since several of these species are based on collections from only a few sites, this may be an artifact of collection failure.

Brachiopods

M.J. Simms

Although benthic in habit and therefore facies dependent, the morphological distinctiveness of certain brachiopod taxa, their relative abundance in the Lower Jurassic Series, and the existence of monographic studies, notably by Ager (1956–1967, 1956b, 1990), lends brachiopods some biostratigraphical significance. Derek Ager's rhynchonellid monograph (Ager, 1956–1967) is the standard reference work for this group in the Lias and provides data on the stratigraphical range of each species. However, he was able to complete only Part 1 of the terebratulid monograph (Ager, 1990) before his death,

		Zone	
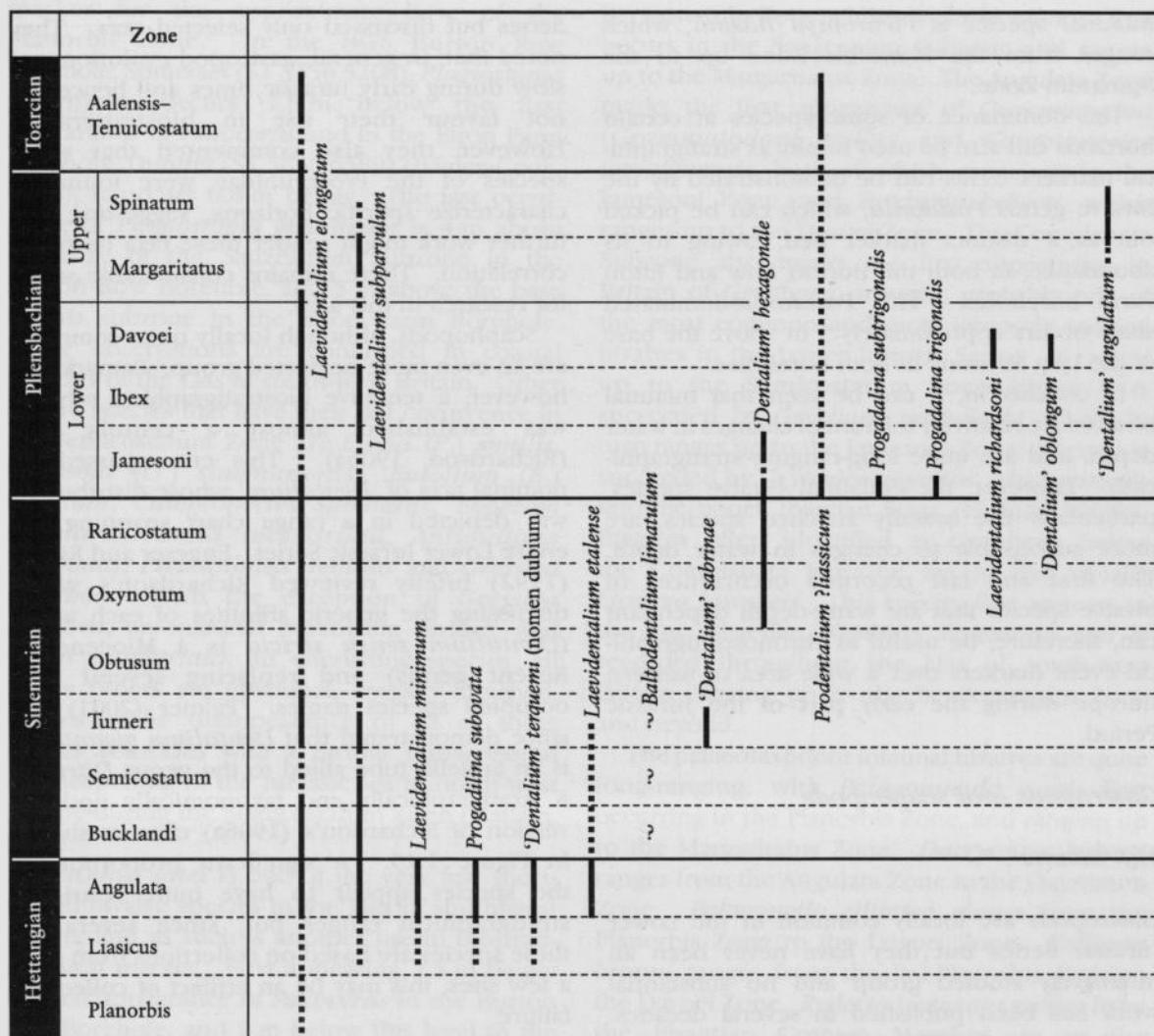
Figure 1.15 Range chart for Lower Jurassic scaphopods. Data from Richardson (1906a); with taxonomy revised by Engeser and Riedel (1992).

whilst a proposed monograph on the genus *Spiriferina* never came to fruition. Nonetheless, in the terebratulid monograph and an earlier publication (Ager, 1978) he provided a valuable overview of Lower Jurassic brachiopod biostratigraphy, based both on his own work and that of others. He concluded that rhynchonellids were the most useful group on account of their greater diversity and more rapid evolution, though, with few exceptions, individual species ranges extend through several ammonite zones (Figure 1.16). For the terebratulids Ager (1990) noted that they were extremely facies-restricted and he attempted subdivision only to stage level.

The biostratigraphical potential of other brachiopod taxa is poorly known, though some have been discussed in earlier publications. Davidson (1851–1852, 1876–1878) described a diverse range of Lower Jurassic species and provided a table showing the stratigraphical distribution of all of the taxa in his monograph, although the stratigraphical resolution of this was low and divided only into the Lower, Middle and Upper Lias, and the 'Passage beds, Midford Sands'. Neaverson (1955) briefly described the application of species of terebratulid, rhynchonellid and *Spiriferina* in Lower Jurassic biostratigraphy, and Revert and Tchoumatchenco (1973) included *Spiriferina*

Biostratigraphy of invertebrate macrofossils and microfossils

Hettangian			Sinemurian						Pliensbachian					Toarcian							
									Lower			Upper									Zone
Planorbis	Liasicus	Angulata	Bucklandi	Semicostatum	Turneri	Obtusum	Oxynotum	Raricostatum	Jamesoni	Ibex	Davoei	Margaritatus	Spinatum	Tenuicostatum	Serpentinum	Bifrons	Variabilis	Thouarsense	Dispansum	Pseudoradiosa	Aalensis	

Calcirhynchia calcaria

Cirpa fronto

Cirpa langi

Cuneirhynchia dalmasi

Cuneirhynchia oxynoti

Furcirhynchia cotteswoldiae

Furcirhynchia furcata

Furcirhynchia ilminsterensis

Furcirhynchia melvillei

Gibbirhynchia amalthei

Gibbirhynchia curviceps

Gibbirhynchia gibbosa

Gibbirhynchia micra

Gibbirhynchia muirwoodi

Gibbirhynchia northamptonensis

Gibbirhynchia thorncombiensis

Gibbirhynchia tiltonensis

Grandirhynchia grandis

Grandirhynchia laevigata

Holcorhynchia standishensis

Homoeorhynchia acuta

Homoeorhynchia capitulata

Homoeorhynchia cynocephala

Maxillirhynchia implicata

Nannirhynchia pygmaea

Piarorhynchia juvensis

Piarorhynchia radstockensis

Piarorhynchia rostellata

Prionorhynchia quinqueplicata

Prionorhynchia serrata

Pseudogibbirhynchia moorei

Pseudogibbirhynchia jurensis

Quadratirhynchia quadrata and spp.

Rhynchonelloidea lineata

Rimirhynchia anglica

Rimirhynchia elevata

Rimirhynchia tardata

Rudirhynchia fallax

Rudirhynchia huntcliffensis

Rudirhynchia rudis

Scalpellirhynchia scalpellum

Squamirhynchia squamiplex

Stolmorhynchia bouchardii

Tetrarhynchia dunrobinensis
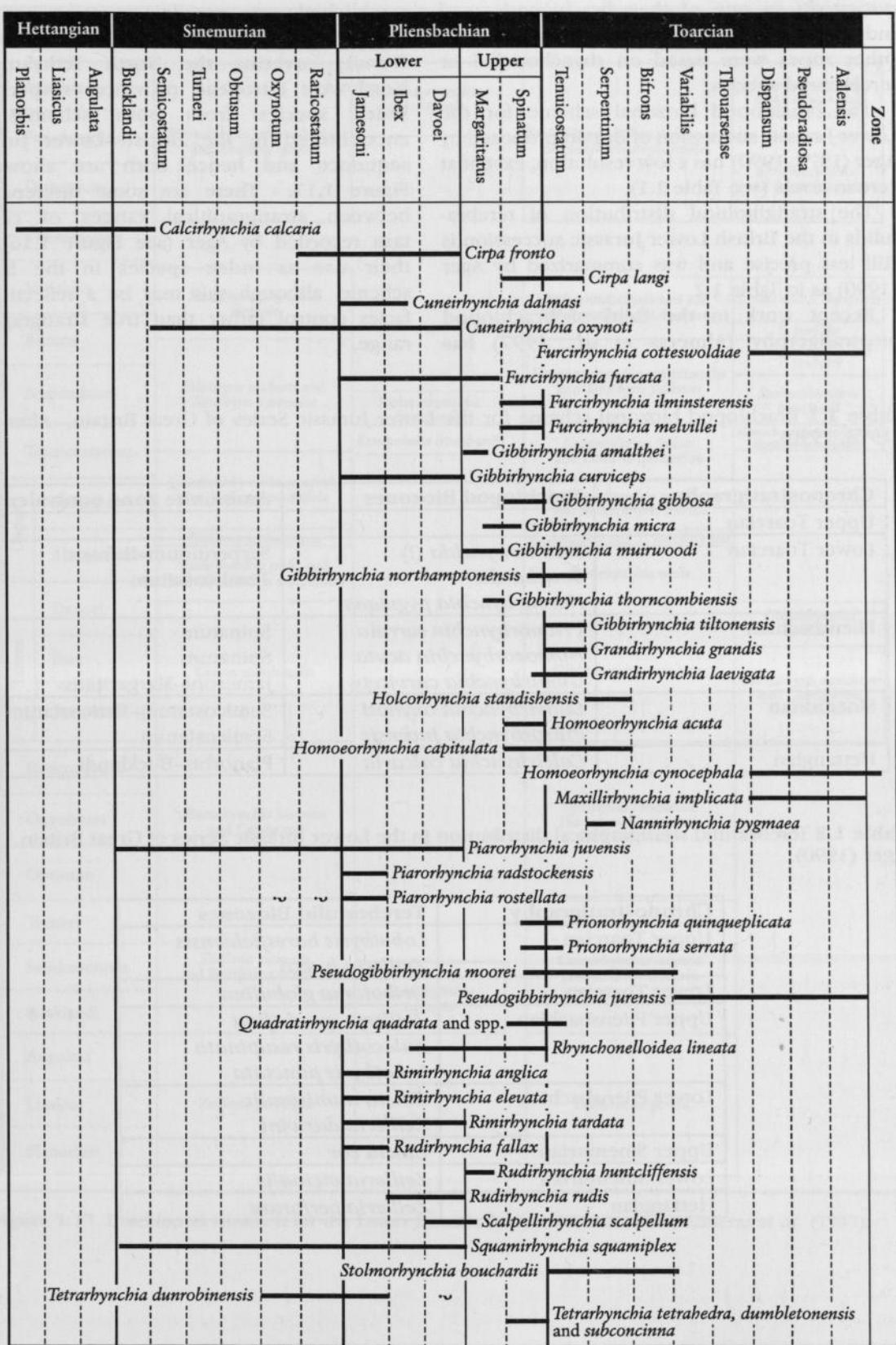
Tetrarhynchia tetrahedra, dumbletonensis and subconcinna

Figure 1.16 Stratigraphical distribution of rhynchonellid brachiopods in the Lower Jurassic Series of Britain. Data mainly from Ager (1956–1967).

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quenstedti as one of their brachiopod zonal index fossils for the Sinemurian Stage, though other zones were based on rhynchonellid or terebratulid species.

The brachiopod biozonal scheme for the Lower Jurassic succession of Britain proposed by Ager (1978, 1990) has a low resolution, except at certain levels (see Table 1.1).

The stratigraphical distribution of terebratulids in the British Lower Jurassic succession is still less precise and was summarized by Ager (1990) as in Table 1.2.

Recent work in the field of brachiopod biostratigraphy (Alméras *et al.*, 1997) has

established two parallel zonation schemes for the Lower Jurassic succession of France, covering the North Tethyan and North-west European provinces respectively. Index species from both schemes are encountered in the British Lower Jurassic sequence and hence both are shown in Figure 1.17. There are some discrepancies between stratigraphical ranges of certain taxa recorded by Ager (see Figure 1.16) and their use as index species in the french scheme, although this may be a reflection of facies control rather than true stratigraphical range.

Table 1.1 Brachiopod biozonal scheme for the Lower Jurassic Series of Great Britain. After Ager (1978, 1990).

Chronostratigraphy	Brachiopod Biozones	Ammonite zone equivalents
Upper Toarcian	none	
Lower Toarcian	*Stolmorhynchia* (?) *bouchardii* *Nannirhynchia pygmaea*	Serpentinum–Bifrons Tenuicostatum
Pliensbachian	*Prionorhynchia serrata* *Homoeorhynchia acuta* *Gibbirhynchia curviceps*	Spinatum Spinatum Jamesoni–Margaritatus
Sinemurian	*Cuneirhynchia oxynoti* *Piarorhynchia juvensis*	Semicostatum–Raricostatum Semicostatum
Hettangian	*Calcirhynchia calcaria*	Planorbis–Bucklandi

Table 1.2 Terebratulid stratigraphical distribution in the Lower Jurassic Series of Great Britain. After Ager (1990).

Chronostratigraphy	Terebratulid Biozones
Upper Toarcian	*Lobothyris haresfieldensis* *Zeilleria lycetti*
Lower Toarcian	*Orthotoma globulina*
Upper Pliensbachian	*Zeilleria quadrifida* *Aulacothyris resupinata* *Lobothyris punctata*
Lower Pliensbachian	*Cincta numismalis* *Zeilleria darwini*
Upper Sinemurian	*Cincta cor*
Lower Sinemurian	*Zeilleria vicinalis*
Hettangian	*Zeilleria perforata*

Ammonite zones			North-west European brachiopod zones and subzones		North Tethyan brachiopod zones and subzones	
Toarcian		Aalensis	*Stroudithyris infraoolithica and Zeilleria lycetti*	*Homoeorhynchia cynocephala*	*Stroudithyris infraoolithica and Stroudithyris stephanoides*	*Homoeorhynchia cynocephala* and *Zeilleria lycetti*
		Pseudoradiosa				*S. infraoolithica and S. stephanoides*
		Dispansum				
		Thouarsense				
		Variabilis	*Pseudogibbirhynchia jurensis*		*Sphaeroidothyris vari and Sphaeoroidothyris decipiens*	*S. vari and S. decipiens*
		Bifrons	*Telothyris jauberti and Telothyris pyrenaica*		*Homoeorhynchia meridionalis and Telothyris jauberti*	*S. perfida*
						H. meridionalis and T. jauberti
		Serpentinum		*Stolmorhynchia bouchardi*		*Stolmorhynchia bouchardi*
		Tenuicostatum		*Koninckella bouchardi*	*Leospiriferina falloti and Zeilleria quadrifida*	*Nannirhynchia pygmaea and Koninckella bouchardi*
Pliensbachian	Upper	Spinatum	*Quadratirhynchia quadrata and Zeilleria quadrifida*		*Quadratirhynchia quadrata and Aulacothyris iberica*	
		Margaritatus	*Zeilleria sarthacensis*		*G. amalthei and Z. sarthacensis*	
			Rudirhynchia rudis and Scalpellirhynchia scalpellum		*Rudirhynchia rudis*	
	Lower	Davoei	*Cincta numismalis*		*Gibbirhynchia curviceps*	*Gibbirhynchia curviceps*
		Ibex				*Cuersithyris davidsoni and Cuersithyris radstockensis*
		Jamesoni				
Sinemurian		Raricostatum	*Piarorhynchia juvensis and Cincta cor*		*Spiriferina betacalcis, Piarorhynchia juvensis and Cincta cor*	
		Oxynotum				
		Obtusum				
		Turneri				
		Semicostatum	*Zeilleria vicinalis and Spiriferina walcotti*		*Cuneirhynchia oxynoti and Zeilleria vicinalis*	
		Bucklandi		*Calcirhynchia calcaria*		
Hettangian		Angulata	*Zeilleria perforata*		*Zeilleria perforata*	
		Liasicus				
		Planorbis				

Figure 1.17 Brachiopod zonation for the Lower Jurassic Series of France. After Alméras *et al*. (1997).

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Crinoids

M.J. Simms

Lower Jurassic crinoids are, for the most part, strongly facies dependent and hence are poorly suited for use as biostratigraphical index fossils. However, individual species within the order Isocrinida are widely distributed, often common and sufficiently distinctive for identification of fragmentary material. This led Oppel (1856–1858) to use one species, *Isocrinus* (= '*Pentacrinus*') *tuberculatus* in his biostratigraphical subdivision of the Lower Jurassic Series, corresponding roughly to the Turneri Zone of the modern schemes (Dean *et al.*, 1961). Crinoids have not otherwise been used in Lower Jurassic biostratigraphy but the monographic treatment of this group by Simms (1989) provides all of the data necessary to establish a crinoid biostratigraphy in parallel with that for ammonites and other groups (Figure 1.18). Representatives of the order Millericrinida generally are very rare within the British Lower Jurassic succession and restricted to hardground environments. At present the known geographical and stratigraphical distribution of this group reflects little more than the
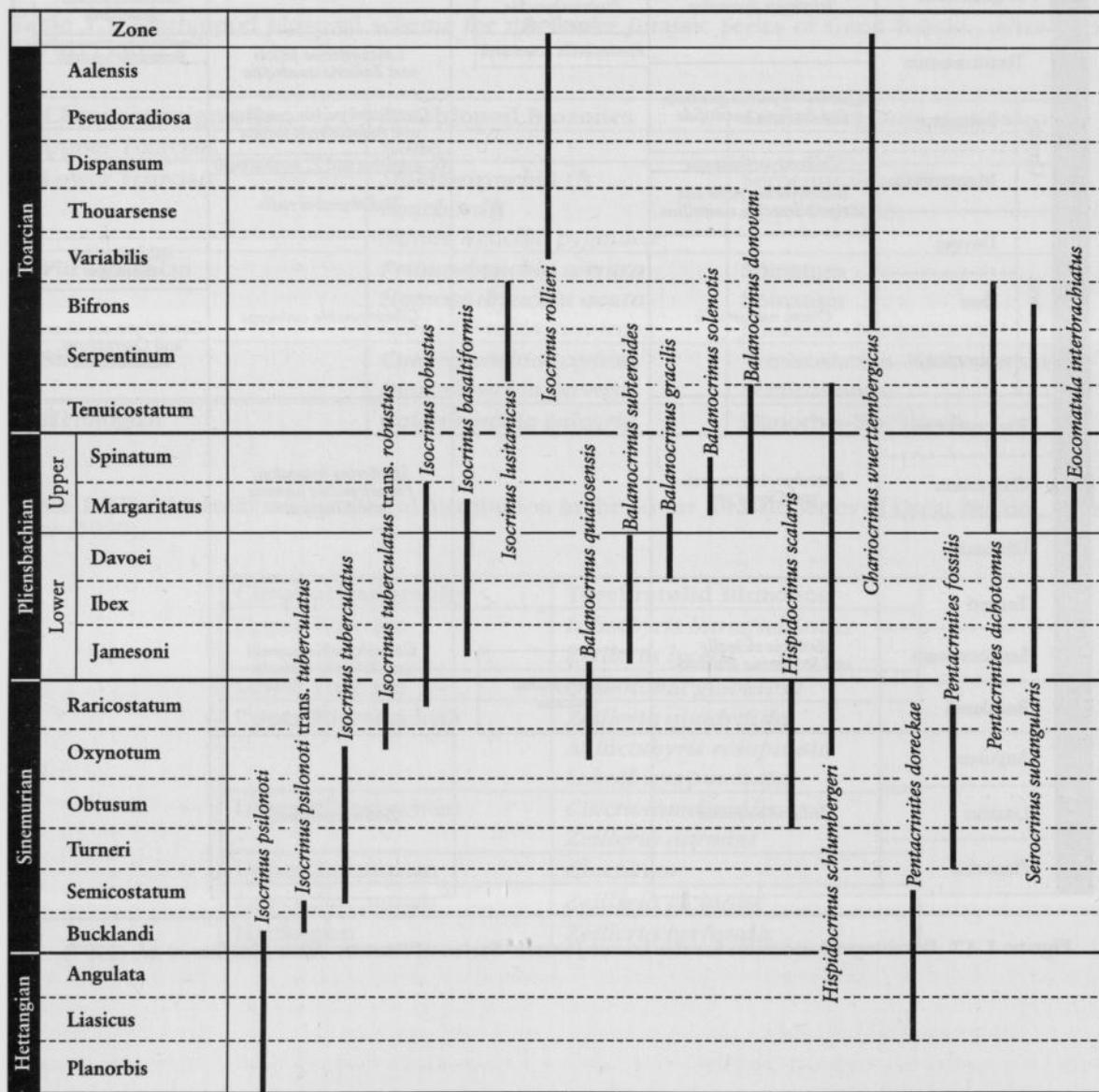

Figure 1.18 Stratigraphical range chart for Lower Jurassic isocrinid crinoids. After Simms (1989).

occurrence of such environments rather than any underlying phylogenetic pattern that might provide the basis for a biostratigraphical scheme. Furthermore, the shape and articulation surfaces of isolated columnals, even within local populations, appear highly polymorphic (Simms, 1989) and this provides a further hindrance to identification. However, representatives of the order Isocrinida are, for the most part, considerably more abundant than millericrinids, far less environmentally restricted and easier to identify to species level using even fragmentary material.

Isocrinus tuberculatus has a stratigraphical range substantially greater than the Turneri Zone, spanning the Semicostatum to Oxynotum zones. Several common species provide a similar biostratigraphical resolution, though others, such as *Hispidocrinus schlumbergeri*, extend through several stages and hence are of limited use. Most species of each lineage appear suddenly in the fossil record, without forms transitional from their presumed ancestors; this is particularly evident in the genus *Balanocrinus* (Simms, 1985, 1988). However, transitional morphotypes between *Isocrinus psilonoti* and *I. tuberculatus*, and between *I. tuberculatus* and *I. robustus* are known and provide a slightly enhanced level of biostratigraphical resolution, since they occupy relatively restricted stratigraphical ranges in the Bucklandi and Semicostatum zones and the Oxynotum and Raricostatum zones respectively.

Although most Lower Jurassic crinoid species are exclusively benthic, two genera of the Pentacrinitidae, *Pentacrinites* and *Seirocrinus*, were pseudoplanktonic in habit and hence are facies independent. Other attributes that render them potentially useful as biostratigraphical index fossils are an exceptionally wide geographical distribution (Simms, 1986) and a distinctive morphology (Simms, 1989). However, although abundant at certain localized horizons, they are in general extremely rare and have a highly disjunct distribution even within their known stratigraphical range.

Holothurians

M.J. Simms

With rare exceptions fossil holothurians are found only as disarticulated, usually microscopic, sclerites whose precise taxonomic

affinities can seldom be determined easily. Indeed, frequently it is not even clear that a particular sclerite morphospecies actually originated from a holothurian! Knowledge of Lower Jurassic holothurians has increased through the work of Gilliland (1992, 1993) but this also highlighted the limitations inherent in any biostratigraphical scheme using this group. Rioult (1961) published a subdivision of the Lower Jurassic Series based on holothurian sclerites in which he recognized three morphospecies associations that defined the Hettangian and Sinemurian stages, the Pliensbachian and lowermost Toarcian (Tenuicostatum Zone) stages, and the remainder of the Toarcian Stage. Gilliland (1992) concluded that only the lower two sclerite assemblage zones of Rioult (1961) were still recognizable, in modified form, as below. The biostratigraphical resolution that can be achieved using holothurian sclerites is poor by comparison with many other fossil groups, and likely to remain so.

Hettangian–Sinemurian stages: *Binoculites terquemi*, *Cucumarites mortenseni* and *Mortensenites circularis*

Pliensbachian–lowermost Toarcian stages; *Theelia crassidentata*, *T. mortenseni*, *T. rigauda*, *Myriotrochites* (= *Stueria*)? *costifera*, *Ambulacrites* (= *Stichopites*) *terquemi* and *A. (S.) polymorpha*. Also characterized by a predominance of wide-armed *Staurocumites bartensteini* and early growth stages of *Binoculites jurassica*.

Other echinoderms

M.J. Simms

Articulated specimens of the three other echinoderm classes represented in the Lower Jurassic Series are rare but fragmentary material often is common and frequently is morphologically distinctive. However, there have been no detailed monographic investigations since the publications of Thomas Wright (1857–1880) and the lack of modern taxonomic treatments is a major hindrance to identification. Coupled with this they exhibit strong facies dependence, and so clearly have a very limited application in biostratigraphy.

Asteroids are poorly known and intact specimens are very rare, although isolated ossicles are not uncommon in washed mudstones. Little can

be said about the stratigraphical distribution of species or even genera until a thorough investigation of such disarticulated material has been undertaken. Intact ophiuroids are similarly rare and generally confined to particular horizons, the Starfish Bed in the Stokesi Subzone of the **Pinhay Bay to Fault Corner** GCR site being perhaps the best-known example (Goldring and Stephenson, 1972). In a study of disarticulated ophiuroid ossicles from Jurassic clays, Hess (1960, 1962, 1964) described various Lower Jurassic taxa and their approximate stratigraphical ranges. These studies may provide a basis for the future development of an ophiuroid biostratigraphy for the Lower Jurassic but the current state of knowledge is inadequate to draw any firm conclusions about the stratigraphical distribution of this group.

Echinoids are also rare as intact specimens in the British Lower Jurassic Series, though significantly less so than either of the other two echinoderm groups. Disarticulated echinoid plates and spines are common but little has been published on this group in recent years. Unpublished observations (Simms, 1987) suggest that most taxa are fairly long-ranging. For instance *Miocidaris lobatum* ranges at least from the Planorbis Zone to the Semicostatum Zone, whereas higher in the succession *Eodiadema minuta* extends from the Oxynotum Zone to at least the Davoei Zone. Thierry *et al.* (1997) tabulated the stratigraphical distribution of 32 echinoid species in the Lower Jurassic succession of France, but only a small proportion of these are taxa known to occur in the British Lias. Most of the species included in their table have poor stratigraphical resolution; most precision is no better than stage or substage level and only four species are confined to individual ammonite zones.

Corals

M.J. Simms

The predominantly argillaceous sediments of the Lower Jurassic succession in Britain do not favour the growth of hermatypic colonial corals, and even solitary corals, presumably ahermatypic, generally are far from common. They occur in abundance at only a few sites, such as on the **Ob Lusa to Ardnish Coast** GCR site on the Isle of Skye, and the **Pant y Slade to Witches Point** GCR site in south Wales. There

has been no modern monographic treatment of the group since that of Duncan (1867a) and the tabulated data of Negus (1991) provides only a tripartite division of the Lower Jurassic Series into Lower, Middle and Upper Lias. Even with more precise information on the stratigraphical distribution of coral species in the Lower Jurassic Series it is unlikely that their value as biostratigraphical index fossils would be significant owing to the overwhelming facies control that they suffer, their relatively slow rate of evolution, and difficulties of identification for many species. However, certain coral-bearing horizons do have a value as local marker bands that in some instances can be traced over distances of several tens of kilometres; examples include the Coral Band containing abundant *Stylophyllopsis rugosa* in the Raricostatum Zone of Gloucestershire and Worcestershire (Richardson, 1918), and a limestone bed (Bed 28 of Trueman, 1930) containing profuse *Montlivaltia guettardi* in the Conybeari Subzone of the **Pant y Slade to Witches Point** GCR site in south Wales (Wobber, 1968a).

Microfossils

M.J. Simms

Foraminifera

All Early Jurassic foraminifera were benthic in habit and hence facies controlled. Nonetheless, they are often abundant and diverse in Lower Jurassic mudstones and many species have limited stratigraphical ranges. They also have been documented and described for more than a century and a half (Strickland, 1846), substantially longer than any other microfossil group known from the Jurassic Period. Several GCR sites have been important sources of material from these earliest papers right up to the present time (e.g. Tate and Blake, 1876; Richardson, 1908; Macfadyen, 1941; Barnard, 1950; Hylton, 1998). Lower Jurassic foraminiferal assemblages comparable with those found in Britain have been studied in many other parts of Europe. Bartenstein and Brand (1937) were the first to appreciate the stratigraphical significance of foraminifera in the Lower Jurassic Series and paved the way for all subsequent zonation schemes. Various regional zonal schemes have been proposed, reflecting facies control and/or provincialism, most recently that

by Ainsworth *et al.* (1998a) who recognized 10 foraminifera zones within the Lower Jurassic Series in the southern part of the Wessex Basin, spanning the interval from late Rhaetian to earliest Bajocian times. Copestake and Johnson (1989) summarized the stratigraphical ranges of 62 taxa, based on samples that included many of the Lower Jurassic GCR sites, and defined 16 foraminifera zones (JF1–JF16) for the Lower Jurassic Series (Figure 1.19); the boundaries of these were defined by a combination of first and last appearances and by other foraminiferal 'events', such as flood occurrences. They noted that, in general, new appearances were associated with transgressions while extinctions were associated with regressions. As expected from their benthic habit, foraminifera were largely absent from anoxic facies, with the prolonged and widespread Toarcian anoxic event causing a major turnover among this group.

Ostracods

Most early Jurassic ostracods were benthic in habit and hence strongly influenced by facies. However, they are often abundant and appear to have evolved rapidly. In consequence, biostratigraphical ostracod zonation schemes for the Lower Jurassic Series of north-west Europe have been widely used. Very few publications on Lower Jurassic ostracods pre-date 1960 and it was not until 1975 that any attempt was made to establish a biozonation scheme, with Michelsen (1975) subdividing the Hettangian to Pliensbachian interval of the offshore Danish Embayment while Bate and Coleman (1975) established a biozonation for part of the Toarcian Stage of the east Midlands. The zonation for the Hettangian to Lower Pliensbachian interval was further refined by Park (1987) based on records from the southern North Sea Basin. More recent biozonation schemes include those established by Boomer (1991), based on material from the exceptionally thick succession in the Mochras Borehole, and by Ainsworth *et al.* (1998a) for the southern part of the Wessex Basin (Figure 1.19). These schemes extend through all or much of the Lower Jurassic interval although Boomer (1991) noted that a direct comparison between ostracod faunas of the Mochras Borehole and those from elsewhere in north-west Europe was not always possible. At certain stratigraphical levels these differences

are acute but at others, notably the Hettangian and Toarcian intervals, the correspondence is much closer. The difficulty of establishing a single ostracod biozonation for the whole of north-west Europe is evident from the diversity of zonal schemes that have been proposed for different areas across the region and undoubtedly reflects the strong facies dependence of this group and perhaps also a certain degree of endemism. Within the Lower Jurassic Series, biostratigraphical resolution using ostracods typically is of the order of two to three ammonite zones. The Hettangian to lowermost Toarcian interval is dominated by the Metacopina, Cypridacea, Cytheracea and Bairdiacea. The Metacopina are important in Hettangian, late Sinemurian, late Pliensbachian and earliest Toarcian times, while the Cypridacea and Cytheracea assume dominance during mid-Sinemurian and early Pliensbachian times. Widespread anoxia in the Serpentinum Zone caused the extinction of the Metacopina, with the remainder of the Toarcian Age being dominated by the Cytheracea, with the Platycopina also important locally. There is a progressive increase in ostracod diversity through early Jurassic times following the onset of marine conditions across much of Britain in the late Triassic Period, with some 50–60 species recorded for the late Toarcian Age (Boomer, 1991). Minor fluctuations in abundance, diversity and taxonomic composition can, in many cases, be linked directly to facies changes associated with eustatic change or the development of anaerobic/dysaerobic conditions (Boomer and Whatley, 1992).

Dinoflagellates

The diversity of dinoflagellates is low in the Rhaetian and Lower Jurassic succession, with fewer than 20 species recognized in total. Their use in biostratigraphical correlation of the Jurassic System has been discussed particularly by Woollam and Riding (1983), Riding (1984a), Riding and Thomas (1992) and Ainsworth *et al.* (1998a). Because of their low diversity in the Lower Jurassic Series, biostratigraphical resolution is rather poor, with each dinoflagellate cyst subzone corresponding to between two and four ammonite zones (Figure 1.19). Woollam and Riding (1983) recognized four dinocyst zones within the Lower Jurassic Series; the *Dapcodinium priscum* Zone (Pre-Planorbis

Figure 1.19 Microfaunal and microfloral biostratigraphy for the British Lower Jurassic Series. Foraminifera after Copestake (1989); ostracods after Ainsworth et al. (1998a); dinoflagellates after Riding and Thomas (1992); miospores after Koppelhus and Batten (1996); calcareous nannofossils after Bown (1987).

Stage	Substage	Ammonite zone	Foraminifera zones/subzones	Ostracod zones	Dinoflagellate cyst zones/subzones	Miospore zones	Calcareous nannofossil zones/subzones
Hettangian		Planorbis	JF1	OJ1	Dapcodinium priscum	Pinuspollenites–Trachysporites	Schizosphaerella punctulata JL1
Hettangian		Liasicus	JF1	OJ1			
Hettangian		Angulata	JF2 / JF3	OJ1			Parhabdolithus liasicus JL2 — Parhabdolithus marthae JL2a / Mitrolithus elegans JL2b
Sinemurian		Bucklandi	JF4 a / b	OJ2			
Sinemurian		Semicostatum	JF5	OJ2			Crepidolithus crassus JL3
Sinemurian		Turneri	JF5	OJ2	Liasidium variabile		
Sinemurian		Obtusum	JF6	OJ3		Cerebropollenites macroverrucosus	
Sinemurian		Oxynotum	JF7	OJ3			
Sinemurian		Raricostatum	JL8	OJ3			
Pliensbachian	Lower	Jamesoni	JF9 a / b	OJ4	Mendicodinium reticulatum		Biscutum novum JL4 — Crepidolithus pliensbachensis JL4a
Pliensbachian	Lower	Ibex	JF11 / JF10 b	OJ5			Crepidolithus granulatus JL4b
Pliensbachian	Lower	Davoei	JF11 a	OJ6			
Pliensbachian	Upper	Margaritatus	JF12 a / b	OJ7	Luehndea spinosa		Lotharingius hauffi JL5 — Crepidolithus cavus JL5b
Pliensbachian	Upper	Spinatum	JF13	OJ8			Biscutum finchii JL5a
Toarcian		Tenuicostatum	JF14	OJ9	Nannoceratopsis gracilis	Callialasporites–Perinopollenites	Carinolithus superbus JL6
Toarcian		Serpentinum	JF14	OJ9			Discorhabdus ignotus JL7
Toarcian		Bifrons	JF15	OJ9			
Toarcian		Variabilis	JF15	OJ9			Biscutum intermedium JL8
Toarcian		Thouarsense	JF16	OJ9			
Toarcian		Dispansum	JF16	OJ9			
Toarcian		Pseudoradiosa	JF16	OJ9			
Toarcian		Aalensis	JF16	OJ9			

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Beds to Turneri Zone), *Liasidium variabile* Zone (Obtusum to Davoei zones), *Luehndea spinosa* Zone (Margaritatus and Spinatum zones), and the *Mancodinium semitabulatum* Zone (Tenuicostatum Zone to top Aalenian). Ainsworth *et al.* (1998a) recognized only two zones within the Lower Jurassic Series but subdivided them into 11 distinct biostratigraphical units (subzones and 'zonules'). However, the 'zonules' were based largely on changes in abundance of particular species recorded from boreholes in the English Channel, events that remain unproven outside of the southern Wessex Basin. Nonetheless, the index species are common throughout Britain and hence potentially have much wider application. Fenton and Fisher (1978) claimed that the ranges of some Middle Jurassic taxa might be discordant between different areas, although this is perhaps less likely in the generally more open-marine conditions that prevailed during early Jurassic times.

Pollen and spores

Pollen and spores comprise just two elements of the larger collective termed 'palynomorph', which encompasses a range of chitinous microfossil material of which dinoflagellages are another important group (see Batten, 1996a, for a full discussion of palynomorphs and palynofacies). They are of enormous value in biostratigraphy since potentially they allow correlation between non-marine environments in which they originate, and in which often they are the only biostratigraphically useful fossils, and marine sequences, which commonly are much better dated using a variety of fossil groups. However, palynomorphs are subject to latitudinal zonation and provincialism, and may have diachronous ranges, so correlation over long distances may be unreliable. Some proposed miospore zones are applicable only within individual sedimentary basins, limiting any wider application, while they are often difficult to identify. Batten (1996b) has highlighted the need to consider palynofacies in all such biostratigraphical investigations since this reflects the proximity of terrestrial vegetation, the sedimentary environment, and subsequent diagenesis.

Although the Lower Jurassic succession across virtually the entire United Kingdom is marine almost throughout, and hence commonly yields abundant macrofossil dating evidence, miospores have proven important for correlation with non-marine successions, such as those of the Newark Supergroup of eastern North America, and in helping to identify the provenance of important fossil material for which original collection data are lacking (e.g. Martill *et al.*, 2000). Koppelhus and Batten (1996) reviewed the stratigraphical distribution of miospores for the Lower Jurassic interval and listed the ranges for many taxa in north-west Europe on which miospore zonation schemes have been based (Figure 1.19). The upper Rhaetian Stage is commonly characterized by an abundance of *Corollina* spp., which may comprise more than 90% of assemblages near the Triassic–Jurassic boundary. The lower Hettangian Stage typically contains a mixed assemblage with forms more common in Rhaetian strata, and soon to disappear altogether, alongside long-ranging forms. These latter taxa continue into upper Hettangian and Lower Sinemurian successions, which otherwise are distinguished from the lower Hettangian strata only by the absence of the Rhaetian relics. The Upper Sinemurian and Lower Pliensbachian succession yields a rather restricted flora, often with abundant *Corollina* spp. again, and the Pliensbachian Stage especially appears to be characterized over much of north-west Europe by an impoverished assemblage. The mid-Pliensbachian to earliest Toarcian succession is characterized by *Ceratosporites spinosus*, one of only a few short-ranging Lower Jurassic miospore taxa. Lower Toarcian palynomorph assemblages across much of north-west Europe are typically rich in amorphous organic matter and marine algae but associated miospores, such as *Chasmatosporites*, are mostly gymnospermous and of little biostratigraphical value. A range of taxa appear for the first time in the upper Toarcian Stage, allowing lower and upper Toarcian strata to be distinguished.

Calcareous Nannofossils

Coccolithophorid algae are the dominant calcareous nannofossil in the Jurassic System. The Early Jurassic Epoch was a time of major diversification for the group, from their first appearance in the fossil record in the Upper Triassic Series to six major families by the Pliensbachian Stage and more than 50 described species in the Toarcian Stage. In

a comprehensive review of Lower Jurassic calcareous nannofossils in north-west Europe, Bown (1987) standardized the biostratigraphical zonation scheme for the group (Figure 1.19) and summarized the ranges of individual species. He proposed eight zones, three of them being further subdivided into two subzones each, defined by first appearances of particular taxa though a few are tied to last occurrences. Biostratigraphical resolution is, in most cases, of the order of two to three ammonite zones but may be significantly less than one ammonite zone.

Other groups

Several other fossil groups have not been considered here since they form only minor or low-diversity components of most described faunas and their distributions are relatively poorly documented. They include benthic invertebrate groups such as bryozoa, annelids and arthropods, the nektobenthic nautiloids, vertebrates (fish and reptiles) and trace fossils. Ultimately some may prove to be of limited stratigraphical use, or at least display well-defined stratigraphical distributions. There is some evidence for this among vertebrates (Benton and Spencer, 1995) but the data is insufficient to establish any meaningful 'zonal' scheme at present. The rarity of intact material and the difficulty of identifying isolated bones and teeth would render any such schemes of limited use, although further work on isolated fish teeth may eventually establish them as of some value in stratigraphy.

EVENT STRATIGRAPHY IN THE BRITISH LOWER JURASSIC SERIES

M.J. Simms

Recent decades have seen the emergence of various techniques for refining the chronostratigraphy of sedimentary sequences independently of any fossil biota they might contain, or of identifying specific events within the succession. These include the use of stable isotopes, particularly of strontium (Jones *et al*., 1994) or carbon (Hesselbo *et al*., 2002), radiometric techniques (Pálfy *et al*., 2000a–c), identification of ejecta from bolide impacts or volcanic eruptions, sedimentary events associated with

tectonic activity, rhythmic or cyclic sedimentary sequences caused by climate change linked to Milankovitch cyclicity (House, 1985, 1986; Weedon, 1986; Weedon and Jenkyns, 1990, 1999; Weedon *et al*., 1999) and sea-level change (Hallam, 1981, 1988; Haq *et al*., 1988). Of these, most have only limited, if any, application within the British Lower Jurassic Series. Radiometric dating is, of course, crucial to defining the absolute dates for stratigraphical boundaries at stage level and above, but this has not been possible for any British site and hence stage boundary dates have been defined elsewhere. Analysis of strontium isotope ratios has been employed as just one of a suite of techniques used to define proposed GSSPs in the British Lower Jurassic Series (Hesselbo *et al*., 2000) but otherwise it has little general stratigraphical application at this level of resolution. Ejecta from bolide impacts, such as are well documented for the Cretaceous–Tertiary boundary (Smit, 1999) have not been found at any level in the British Lower Jurassic sequence, although an iridium anomaly has been reported from the terrestrial Triassic–Jurassic boundary in the Newark Supergroup of eastern North America and cited as tentative evidence for bolide impact at the end of the Triassic Period (Olsen *et al*., 2002). The most recent dating of the Manicouagan impact crater at 214 ± 1 Ma (Hodych and Dunning, 1992) places it almost within the range of the Triassic–Jurassic boundary as defined by Harland *et al*. (1990), but re-dating of the boundary close to 200 Ma (Pálfy *et al*., 2000a) eliminates any possible link between this impact and events at the Triassic–Jurassic boundary. Volcanic ejecta also have not be found in the British Lower Jurassic sequence despite the presence of extensive flood basalts in the Hettangian Stage of the Newark Supergroup on the eastern seaboard of North America (Tankard and Balkwill, 1989; Hesselbo *et al*., 2002), although this apparent absence may merely reflect a lack of intensive searching. Major tectonic events might be anticipated to show up in the sedimentary record but although there is clear evidence for local influence of tectonic activity on adjacent sediments (e.g. Jenkyns and Senior, 1991), more widespread event horizons of this type have yet to be found in the British Lower Jurassic Series. However, a major, uniquely extensive horizon of soft-sediment deformation occurs in the Cotham Member of the Penarth Group, a little below the

base of the Lias Group. This deformation, ascribed to seismic activity (Mayall, 1983) can be traced at the same level across the entire UK and appears to represent a seismic event of unique magnitude for the British Phanerozoic, possibly attributable to bolide impact (Simms, 2003a).

The only factors that appear to have had widespread, frequent and easily discernable effects on the sedimentary sequence are climate and sea level, although it can often be difficult to distinguish between the effects of the two. The link between orbitally induced climatic fluctuations and small-scale sedimentary cyclicity in the British Lower Jurassic sequence is now fairly well-established, with well-documented case studies from several GCR sites (House, 1986; Weedon, 1986; Weedon and Jenkyns, 1990, 1999; van Buchem *et al.*, 1994; Weedon *et al.*, 1999). Direct correlation of individual decimetre-scale units between Dorset and Yorkshire, a distance of more than 400 km, has even been attempted (Hesselbo and Jenkyns, 1995). However, although these Milankovitch-scale sedimentary rhythms may be common and widespread, they are by no means ubiquitous and other factors may effectively mask the climatic signal. Furthermore, although broad-scale correlation of the larger units may be relatively straightforward, correlation of individual beds in isolation from these larger units is greatly hampered by the presence of other, essentially indistinguishable, beds in close stratigraphical proximity. Essentially, these small-scale, climatically induced, sedimentary rhythms do represent extremely widespread event horizons. However, they appear to be preserved only in certain parts of the Lower Jurassic succession where their stratigraphical frequency is too high for individual beds to be especially useful as marker horizons. Although there have been claims that these climatically controlled sedimentary sequences offer potential for establishing a high-resolution absolute timescale (House, 1985), in truth the stratigraphical distribution of such sequences is far too disjunct for this to be realized at present.

That changes in sea level can effect the Lower Jurassic sedimentary sequences has been recognized for far longer than has the influence of climate change, being exemplified by sites such as **Pant y Slade to Witches Point**, south Wales, where there is a clear upward, and lateral, transition from marginal to 'offshore' facies. As discussed elsewhere in this volume, changes in relative sea level, as interpreted from the sedimentary sequence at a particular site, can be under the control of several factors. However, global or eustatic sea-level changes should be traceable across many sites over a very wide area and, as such, offer the potential for useful event horizons, if these can be identified. Consideration of the effects of rising or falling sea level on the style of deposition in the Lower Jurassic Series has been a subject of investigation for many decades. For instance Arkell (1933) wrote widely of the evidence for transgressions and regressions in the British Jurassic System while in a series of papers Hallam (1961, 1964b, 1978) discussed the patterns of cyclic sequences produced by eustatic changes. These lines of investigation led ultimately to the development of the concept of 'sequence stratigraphy' (e.g. Haq *et al.*, 1987; Vail *et al.*, 1991), with several orders of cycles discernable under ideal conditions. Critical to applying the sequence stratigraphy concept in the field is the identification of key surfaces within a given sedimentary cycle, of which there are three main types; sequence boundaries, transgressive surfaces, and maximum flooding surfaces. The precise sedimentary expression of any one of these varies according to position along a proximal–distal transect but the following criteria were used by Hesslbo and Jenkyns (1998) for their analysis of the British Lower Jurassic Series. They diagnosed a sequence boundary as an erosional unconformity or an abrupt basinward facies shift inferred to be its conformable correlative; a transgressive surface was indicated by an abrupt juxtaposition of deep-water facies over shallow; and a maximum flooding surface was indicated by stratigraphical condensation. Within the British Lower Jurassic sequence Hesselbo and Jenkyns (1998) were able to identify key surfaces for several second-order, or transgressive–regressive facies cycles, and a large number of third-order, or sequence cycles, with a significant number of the latter being correlatable across Britain. Second-order cycles are of durations comparable with stratigraphical stages or substages while third-order cycles are broadly comparable in duration to ammonite zones or subzones. The overall implication of the technique is that if these cycles are primarily under eustatic control then the key surfaces are effectively synchronous and, in geological terms, instantaneous. Consequently they can be

considered to represent event horizons that potentially can be correlated over very large areas. However, a significant constraint is that it is dependent on individual interpretation of sedimentary sequences in the field and it is quite possible for the same, apparently quite straight-forward, feature to give rise to quite different interpretations, with consequent significance for broader-scale correlation (e.g. Hesselbo and Palmer, 1992; Hallam, 1999).

Morton (1993) contends that within individual basins or broader regions the influence of tectonics may be greater than eustatic changes. Hence major sequence boundaries may be diachronous, in marked contrast to what is implied by eustatically determined sequence boundaries. This is 'genetic stratigraphy', in which gradationally changing packages of sediment are bounded by major abrupt changes of facies that often correspond to hiatuses or unconformities. These genetic sequences represent a record of the dynamic development and infill by sediment of a basin and hence are the basic unit for analysis of basin evolution. Inevitably these genetic stratigraphical sequences are not synonymous with stratigraphical sequences defined by eustatic events (e.g. Haq *et al.*, 1987; Vail *et al.*, 1991; Hesselbo and Jenkyns, 1998) but eustatic events may be superimposed upon the genetic stratigraphy.

GCR SITE SELECTION

M.J. Simms

The rationale, methodology and history behind the selection of sites for inclusion within the Geological Conservation Review programme was discussed in detail by Wimbledon *et al.* (1995) and much of this has been re-iterated in the introductory GCR volume (Ellis *et al.*, 1996). The main factors considered during the selection process for the stratigraphy GCR sites are: (a) is the site of importance to the international Earth scientist community on account of the site being the type locality for a particular time interval, boundary or fossil species? (b) does the site encompass exceptional geological features? (c) is the site nationally important because features there are representative of geological events or processes that are fundamental to understanding the geological history of Britain? and

(d) is the site of historical significance in the development of the science? There is also a stated philosophy in site selection that within the list for a particular stratigraphical interval (such as the Lower Jurassic Series), the site should be the best-available example and should encompass a minimum of duplication with features seen at other GCR sites. Ideally it should also be accessible and not obviously vulnerable to any threat that might compromise its scientific importance.

Following these basic guidelines an initial selection of Lower Jurassic GCR sites was undertaken in the early 1980s through consultation with appropriate Earth scientists with relevant experience, and preliminary reports were prepared. Inevitably the list that was compiled reflected, to some extent, the personal preferences and knowledge of those consulted so that a number of important or poorly documented sites were excluded. In the intervening two decades some of the selected sites have become degraded through weathering and growth of vegetation, although this does not necessarily detract from their ultimate scientific importance if they still remain recoverable with only a little excavation. Other important new sites have become available but, with the increasing reluctance of many journal editors to publish descriptive accounts of such sites, they often remain poorly known. However, with only one or two additions and deletions from the original list the selection of Lower Jurassic GCR sites has remained largely unchanged, although undoubtedly there are sites that others will feel should have been included.

Although the title of this volume is 'British Lower Jurassic Stratigraphy', the site accounts are not confined only to the description and interpretation of that particular aspect of their geology. Many sites are justly important for their fossil biotas or have been the subject of palaeoenvironmental, diagenetic or other investigations. The scientific value of any site is increased by the breadth of research undertaken there and hence the site accounts have attempted to be as comprehensive as possible in their coverage. For some there has been little modern research and hence description and interpretation is correspondingly brief but for others a great deal more has been published and so much fuller accounts have been compiled. Hopefully one outcome of this review is that long-neglected sites may be looked at afresh and

act as a spur to further research on the British Lower Jurassic Series as a whole.

Within this GCR volume the sites are arranged broadly in terms of the depositional basin in which they are located, moving northwards through the Wessex Basin, Mendip High, Severn Basin, East Midlands Shelf, Cleveland Basin and the Scottish localities, with all but one of the latter located in the Hebrides Basin. Within this framework the sites are then arranged in approximate stratigraphical order, where applicable, following a brief overview of each depocentre.

Although some of the GCR sites have been the subject of intensive research for many decades, and hence are well documented, many other sites have long been neglected. Some are represented by little more than a general account of the stratigraphy, often published in a local journal a century or more ago and with little interpretation relevant to the present account. The situation now is little better and indeed quite possibly worse than in the past. Although basic stratigraphical investigations of sites must form the basis for larger-scale geological and palaeoenvironmental inter- pretations, such research is seldom supported by academic institutions today and many journals are reluctant to publish the results. As a result new exposures, which may have significant implications for palaeogeography, facies analysis or basin history, often remain unknown to geologists active in those fields of research. Journal editors, PhD supervisors and research students, must strive to ensure that this basic stratigraphical data enters the public realm before published interpretations become too distant from the actual field exposures on which, ultimately, they are based. With the ever increasing pressure on journal space, these GCR stratigraphy volumes therefore serve an invaluable function. Unconstrained by the research 'fashions' of the day, they provide a vehicle for the publication of reviews, newly measured sections and new interpretations of old sites that otherwise would never receive the attention they deserve. Furthermore it attempts to take a holistic view, with even the smallest, seemingly insignificant, site contributing to an understanding of the whole picture of Lower Jurassic events in Great Britain.

Invertebrate fossils and GCR site selection

Although the relatively common invertebrate fossils do not have a separate selection category in the GCR in their own right, the scientific importance of many stratigraphy sites lies in their fossil content. Invertebrate fossils are important in stratigraphy because they help to characterize stratal units. In practice, strati- graphy is at its most secure where adequate fossils are found. One of the main tasks of stratigraphers is to determine the relative ages of strata and to compare or correlate them with strata of the same age elsewhere. Fossils have long provided one of the most reliable and accurate means of approaching these problems.

Therefore, some 'stratigraphy' GCR sites are selected specifically for their faunal content, which facilitates stratal correlation and enables the interpretation of the environments in which the animals lived. Other 'stratigraphy' GCR sites are of crucial importance palaeontologically and palaeobiologically, because they yield significant assemblages of invertebrates that provide evidence for past ecosystems and the evolution of life. Moreover, some sites have international significance because they have yielded fossils that are the 'type' material for a species.

In contrast to the manner in which most invertebrate fossils are represented in the GCR, fossils of vertebrates, arthropods (except trilobites) and terrestrial plants do have their own dedicated selection categories, owing to the relative rarity of the fossil material.