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 outlying 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

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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).
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 Francaise, 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 Sinémurien Stage, named after Semur-en-Auxois in Burgundy, eastern France. Above was the Liassic Stage, its name derived from the old geological term ‘Liás’, 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 ‘Liás’ and erected his own sequence of stages, called ‘zonengruppen’ or ‘étages’. These were based, in part, on d’Orbigny’s subdivisions but instead were termed ‘Semur-Gruppe’ (equivalent to d’Orbigny’s Sinémurian Stage), ‘Pliensbach-Gruppe’ (equivalent to the Liassic 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 Liassicus 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.
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

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**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.
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 Styte 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 ‘Lotharian’, 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.
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.
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–Lillstock 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 *Verniceras 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).
Establishment of Lower Jurassic chronostratigraphy

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.
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 Batt-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 (Paltecbioceras 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 Apoderocephas are also found at this level; this is a genus more characteristic of the Taylori Subzone than the index fossil, Phricodoceras taylori, itself. Indeed Apoderocephas 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*, *Ovati- ceras* 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
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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.
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 ranges). After Page (2002) and unpublished observations.
British Lower Jurassic stratigraphy: an introduction

\textit{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.

\section*{RADIOMETRIC DATING AND THE BASE OF THE JURASSIC SYSTEM}

\textbf{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 \textbf{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. \textit{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 \textit{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 \textit{Choristoceras} and the first \textit{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. \textit{Psiloceras tilmanni} and \textit{P. spelae} have been recorded in low numbers up to c. 5 m below the highest occurrence of \textit{Choristoceras minutum} in the Muller Canyon of Nevada (Taylor et al., 1999), while \textit{Psiloceras} and \textit{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 \textit{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

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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 tsunamiite 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 radiolarians (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 *bemera*, 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 chronzone, 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 breakup 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 1.10 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 interconnected sedimentary basins and shelf areas, producing local differences in the sedimentary successions. Nonetheless these local successions can be correlated with some precision. At some stratigraphical levels the same lithostratigraphical 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 lithostratigraphical 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 subdivisions 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 geographical 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 lithostratigraphical 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 lithostratigraphical 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–Rudstock Shelf area; the East Midlands Shelf; and the Cleveland Basin. They also recognized that other significant, though poorly exposed, outcrops in the Cheshire and Carlisle basins were not fully covered in their report, whereas offshore successions and those in Scotland were specifically excluded. In this volume the lithostratigraphical 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 uppermost 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
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 lithostratigraphical units. 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. Several 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).