British Lower Jurassic Stratigraphy

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Chapter 2

The Wessex Basin (Dorset and central Somerset)

M.J. Simms

INTRODUCTION

The Wessex Basin has seen more intensive research than any other single Lower Jurassic depocentre in Britain. This is largely on account of the exceptional exposure along the Dorset coast of virtually the entire Jurassic succession, but it perhaps also owes something to the fact that the exhumed periclines of the Mendip Hills, at the north-western edge of the basin, allow direct observation of the Palaeozoic basement structures that are believed to have controlled subsidence and uplift throughout the basin's history. Numerous papers have been published on various aspects of the basin, or parts of it (e.g. Stoneley, 1982; Chadwick *et al.*, 1983; Whittaker, 1985; Chadwick, 1986; Lake and Karner, 1987; Jenkyns and Senior, 1991; Evans and Chadwick, 1994, to name but a few). There is also a substantial body of sub-surface data obtained from a large number of boreholes that have been drilled in the search for hydrocarbons (e.g. Sellwood *et al.*, 1986; Ainsworth *et al.*, 1998b) and from geophysical surveys that have been conducted across the area.

The Wessex Basin comprises a series of linked, but nonetheless distinct, roughly E–W-trending, fault-bounded basins separated by relative highs (Chadwick, 1986; 1993; Lake and Karner, 1987; Ainsworth *et al.*, 1998b) (Figure 2.1). In all it covers more than 20 000 km^2 onshore, encompassing the Dorset and Central Somerset basins in the west, and the Pewsey, Weald and part of the Portland–Wight basins farther to the east. At least a comparable area to the south lies beneath the English Channel (Chadwick, 1986), with a further north-westward offshore extension represented by the Bristol Channel Basin (Lloyd *et al.*, 1973; Evans and Thompson, 1979; Tappin *et al.*, 1994). The northern margin of the basin lies roughly along the Variscan Front, defined by the southern flanks of the Welsh Massif and the Mendip High in the west and the London Platform to the east. To the west Palaeozoic basement crops out in Devon, and to the east beneath Kent Lower Jurassic strata onlap the basement of the London–Brabant High (Donovan *et al.*, 1979). Within the basin the sedimentary fill, of Permian to Tertiary age, lies unconformably upon Lower Palaeozoic to Carboniferous rocks. Typically the fill is about 2 km thick though locally it may exceed 3 km.

The only areas of the Wessex Basin that expose Lower Jurassic strata are in the south-west, extending from the Dorset coast northwards through Somerset to the Bristol Channel. Only the Dorset and Bristol Channel coasts expose extensive sections through the Lower Jurassic Series and elsewhere in the basin exposure is poor. Documentation of small and temporary inland exposures has been made by, among others, Lang (1932), Kellaway and Wilson (1941a), Hallam (1956), Wilson *et al.* (1958), Green and Welch (1965), Hollingworth *et al.* (1990) and Prudden (pers. comm.); much of this information is summarized in Cope *et al.* (1980a).

Lithostratigraphy and facies

Details of facies and lithostratigraphy in Dorset largely are covered in the site account for the Dorset coast, and are also summarized in Ainsworth *et al.* (1998b). In general the succession in the Dorset Basin is attenuated by comparison with that farther north, in the Central Somerset Basin. The exceptional exposure along the Dorset coast has allowed detailed lithostratigraphical subdivision of the succession. Many of the named units are well established with a long history of use. Recent rationalization of the Lower Jurassic lithostratigraphy for England and Wales (Cox *et al.*, 1999) has largely retained these original names. Within this revised lithostratigraphical framework five formations are recognized on the Dorset coast (Figure 2.2) and can, for the most part, be mapped at outcrop inland. Ten members were formally named for the Dorset coast succession, with an eleventh, the Stonebarrow Pyritic Member, proposed for the upper part of the Upper Sinemurian Substage (K.N. Page, pers. comm.). Other finer subdivisions have yet to be accorded formal status. The lithostratigraphical framework recognized farther north, and summarized in Figure 2.3 mostly lacks the high resolution of that on the Dorset coast, reflecting generally poorer exposure and less extensive documentation.

The Blue Lias Formation encompasses the highest part of the Triassic Rhaetian Stage, the Hettangian Stage and the lowest part of the Sinemurian Stage. Throughout the Wessex Basin it is developed in typical facies of alternating limestones and mudstones, superbly

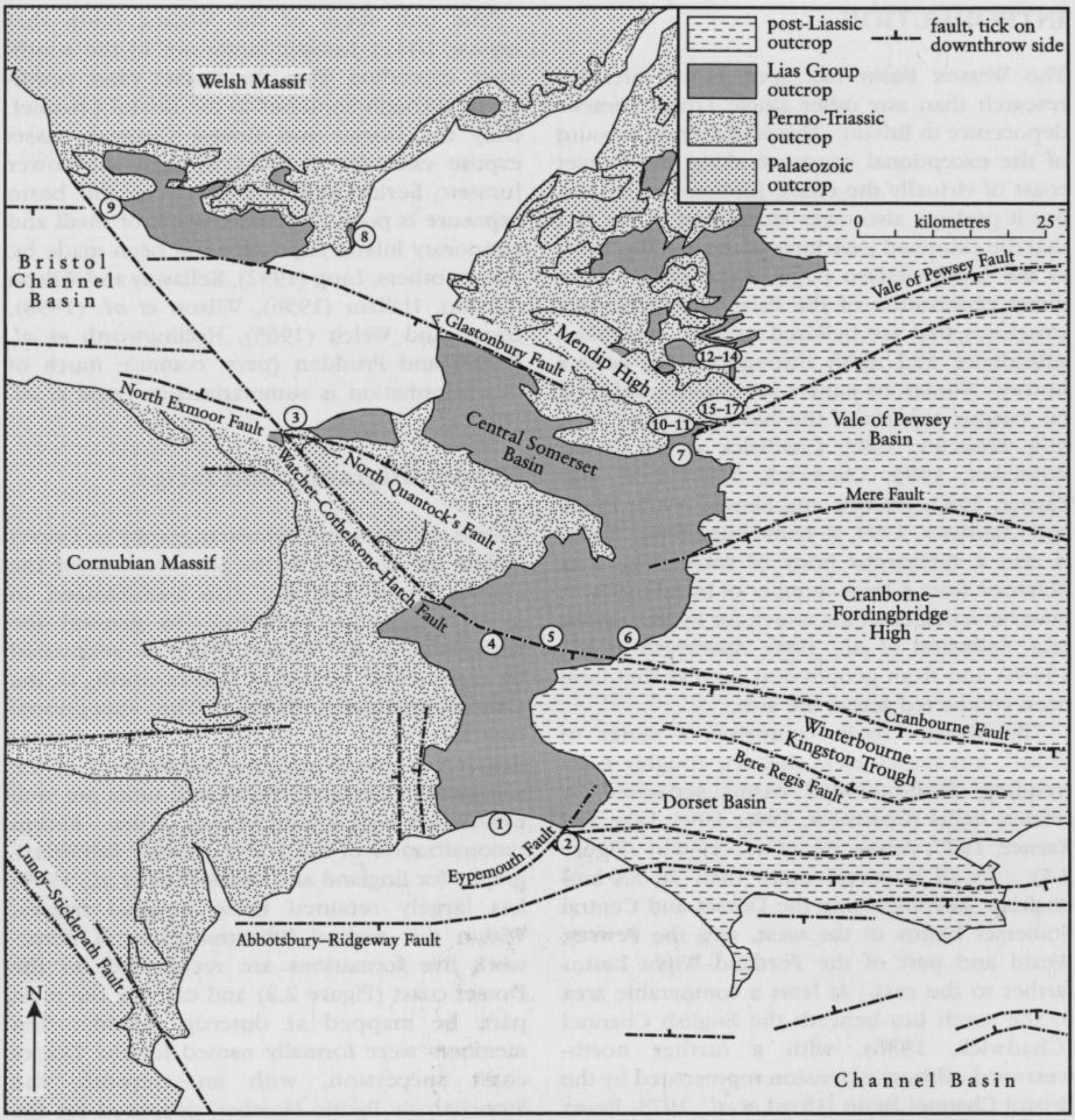

Figure 2.1 The major structural elements and sub-basins of the Wessex Basin and its margins. Numbers correspond to the locations of the GCR sites: 1 – Pinhay Bay to Fault Corner and East Cliff; 2 – Cliff Hill Road Section; 3 – Blue Anchor–Lilstock Coast; 4 – Hurcott Lane Cutting; 5 – Babylon Hill; 6 – Ham Hill; 7 – Maes Down; 8 – Lavernock to St Mary's Well Bay; 9 – Pant y Slade to Witches Point; 10 – Viaduct Quarry; 11 – Hobbs Quarry; 12 – Bowldish Quarry; 13 – Kilmersdon Road Quarry; 14 – Huish Colliery Quarry; 15 – Cloford Quarry; 16 – Holwell Quarry; 17 – Leighton Road Cutting. After Lake and Karner (1987).

exposed at the **Pinhay Bay to Fault Corner** and **Blue Anchor–Lilstock Coast** GCR sites in the Dorset and Central Somerset basins respectively. At the basin margins it passes laterally into a more massive limestone, as seen at the **Hobbs Quarry** and **Viaduct Quarry** GCR sites on the Mendip High and the **Pant y Slade to Witches Point** GCR site in south Wales (Chapter 3). The succeeding Charmouth Mudstone Formation, which encompasses much of the Sinemurian Stage and the lower part of the Pliensbachian Stage, is divided into five members (Figure 2.2). These members have been mapped out only close to the coastal exposures, but they have

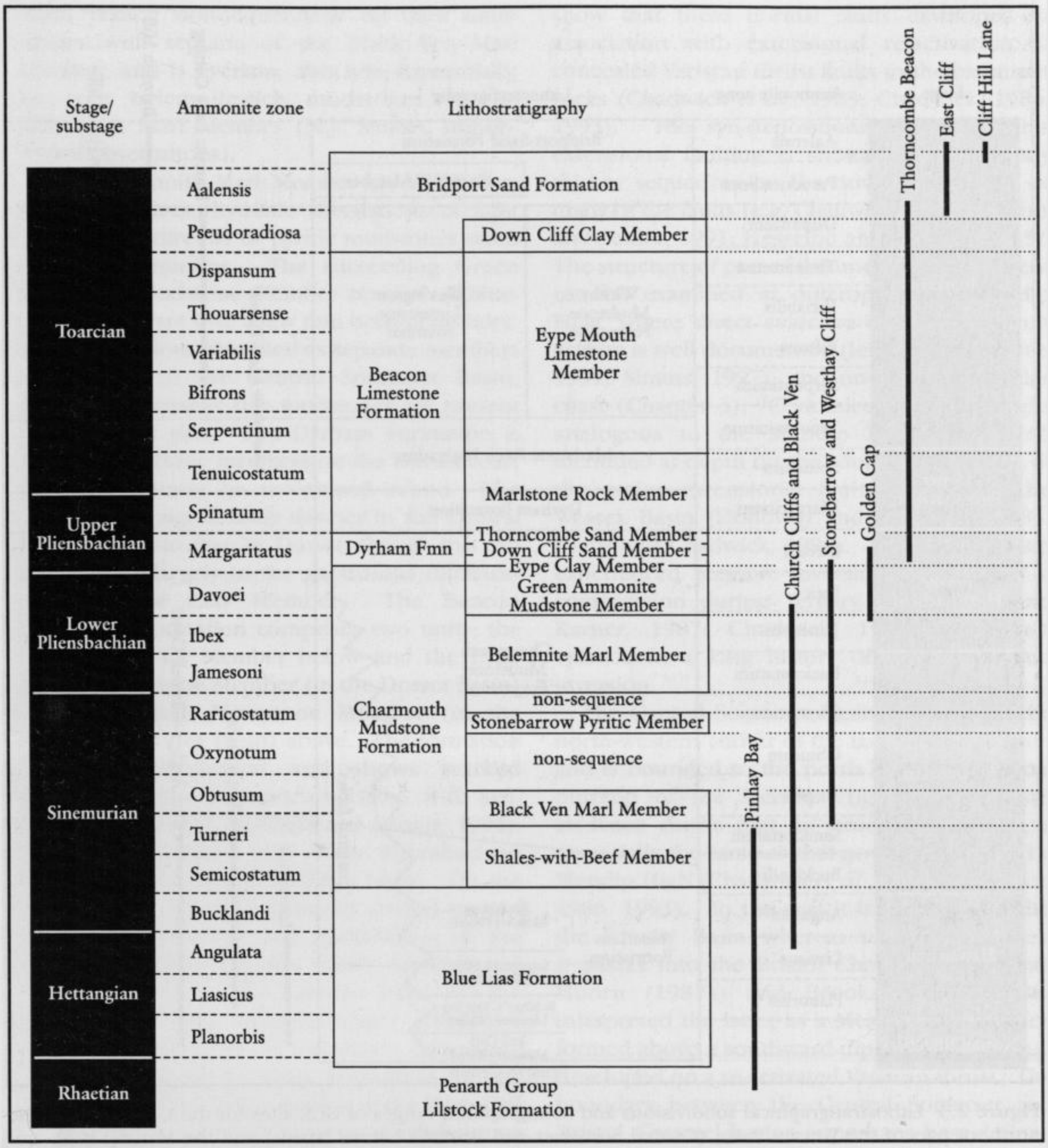

Figure 2.2 Lithostratigraphical subdivisions and stratigraphical ranges of GCR sites for the Lias Group of the Dorset coast, in the southern part of the Wessex Basin.

been identified inland in Dorset (e.g. Lang, 1932). On the Dorset coast the Shales-with-Beef Member consists of finely laminated and bituminous dark-grey mudstones with a few bands of limestone nodules or septaria and thin beds of fibrous calcite, or 'beef', which give the member its name. The succeeding Black Ven Marl Member is very similar lithologically, although 'beef' lenses are less well-developed. The boundary between the two is essentially arbitrary but was drawn below a conspicuous limestone band, the Birchi Tabular (Bed 76a of Lang *et al.*, 1923). In the Central Somerset Basin correlative strata are developed in similar facies to that seen on the Dorset coast, although there is little development of 'beef'. Separate members can be recognized only where distinctive marker beds are present, such as at Chard

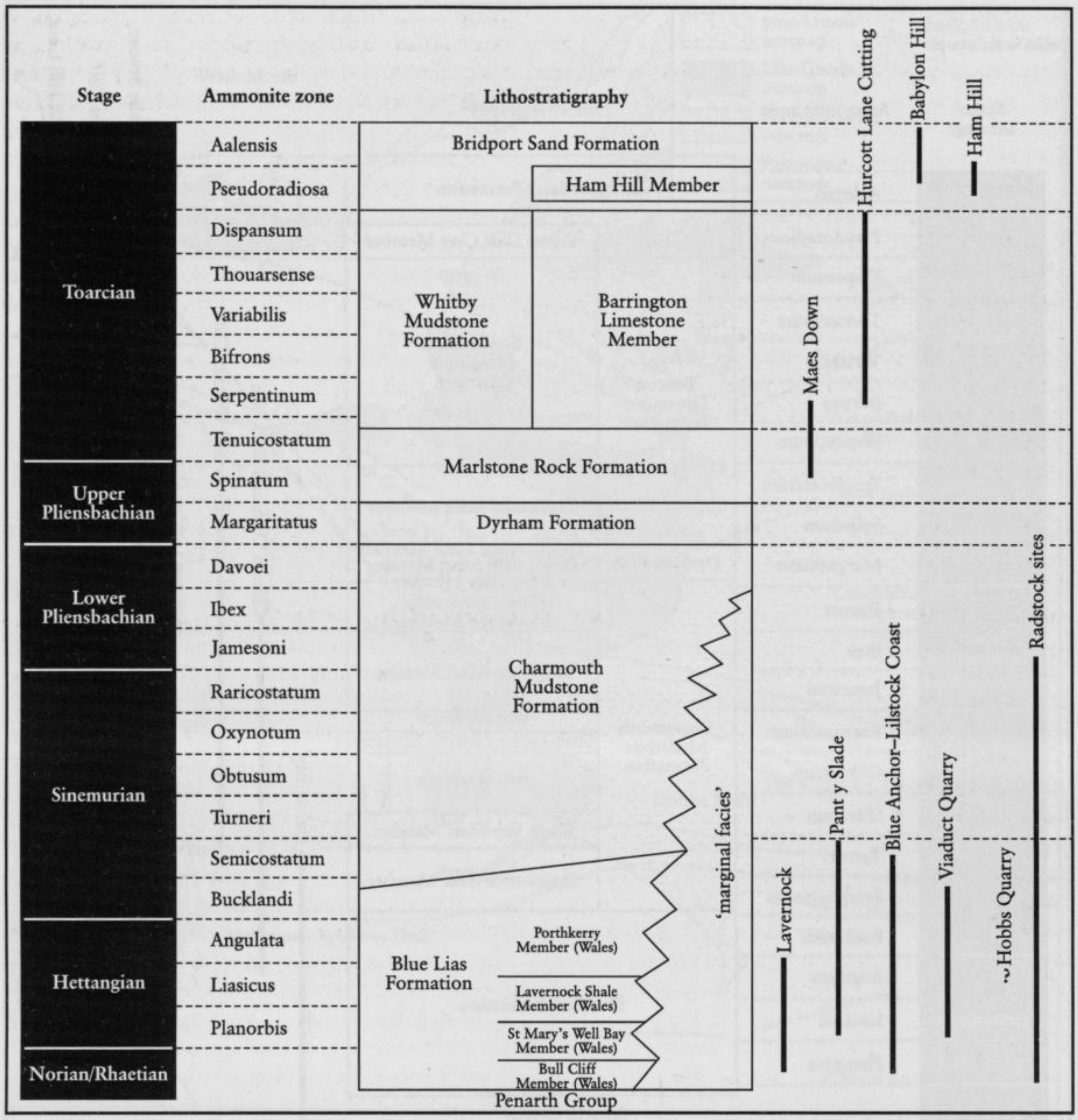

Figure 2.3 Lithostratigraphical subdivisions and stratigraphical ranges of GCR sites for the Lias Group in the northern part of the Wessex Basin (Central Somerset and Bristol Channel basins) and the Mendip High and Welsh Massif.

Junction where the Stellare Nodules near the top of the Black Ven Marl Member have been identified (M.J. Simms, unpublished observations). The succeeding Stonebarrow Pyritic Member, proposed by Page (pers. comm.) for the upper part of the Sinemurian Stage, comprises blue-grey shaly to blocky mudstones with often abundant pyritic ammonites. On the Dorset coast it is represented by some 14 m of sediment in the lower part of the Raricostatum Zone, bounded above and below by significant non-sequences. In the Central Somerset Basin it is more fully developed; at Castle Cary the member is more than 24 m thick and encompasses both the Oxynotum and Raricostatum zones (Hollingworth *et al.*, 1990). Between the Dorset and Central Somerset basins the Stonebarrow Pyritic Member is greatly reduced in thickness. At Chard Junction it comprises only about 2 m of mudstone of the Raricostatum

Zone resting non-sequentially on dark mudstones with septaria of the Black Ven Marl Member, and is overlain, also non-sequentially, by pale belemnite-rich mudstones of the Belemnite Marl Member (M.J. Simms, unpublished observations).

The Belemnite Marl Member on the Dorset coast comprises rhythmic alternations of light and dark calcareous or pyritic mudstones often rich in belemnites. The succeeding Green Ammonite Mudstone Member consists of blue-grey mudstones with a few thin beds of nodules. They are seldom identified as separate members at outcrop in the Central Somerset Basin, although belemnite-rich mudstones are present in the lower part. The Dyrham Formation is divided into three members on the Dorset coast but these cannot be recognized inland. The formation is significantly thinner in the Central Somerset Basin than in Dorset, though this can be ascribed largely to the anomalous thickness of the Eype Clay Member. The Beacon Limestone Formation comprises two units; the Marlstone Rock Member below and the Eype Mouth Limestone Member (in the Dorset Basin) and Barrington Limestone Member (in the Central Somerset Basin) above. The formation is highly condensed and shows marked lateral thickness changes associated with syn-sedimentary faults (Jenkyns and Senior, 1991). It spans the highest part of the Pliensbachian Stage and most of the Toarcian Stage. On the Dorset coast it is succeeded by several tens of metres of siltstones and sandstones of the Bridport Sand Formation, which encompasses the highest part of the Toarcian Stage and the lowest part of the Aalenian Stage. There are local developments of bioclastic limestone within the Bridport Sand Formation of the Central Somerset Basin, notably at the **Ham Hill** GCR site. The lithostratigraphical subdivisions of the Lias Group for the Dorset coast are summarized in Figure 2.2. The lithostratigraphy of GCR sites farther north in the Wessex Basin, and on the Mendip High and South Wales Massif, is summarized in Figure 2.3.

Basin development

The 'Wessex Basin' is an inclusive term for a series of inter-connected E–W-orientated asymmetric grabens or half-grabens bounded by major faults or fault zones downthrowing mainly to the south (Figure 2.1). Geophysical investigations show that these normal faults developed in association with extensional re-activation of concealed Variscan thrust faults in the basement rocks (Chadwick *et al.*, 1983; Chadwick, 1986, 1993). The syn-depositional nature of this extensional faulting is shown by significantly thicker sequences on the downthrown side of many of the faults (e.g. Chadwick, 1986; Jenkyns and Senior, 1991; Hesselbo and Jenkyns, 1995). The structure of part of the underlying basement can be examined at outcrop in the Mendip Hills, where direct evidence of Mesozoic fault activity is well documented (Jenkyns and Senior, 1991; Simms, 1997), and on the south Wales coast (Chapter 3). Concealed basement highs analogous to the Mendip High have been identified at depth on the south side of some of the major extensional faults that cross the Wessex Basin (Holloway and Chadwick, 1984; Evans and Chadwick, 1994). The Wessex Basin experienced tectonic inversion as a result of compression during Tertiary times (Lake and Karner, 1987; Chadwick, 1993), the latest episode in a long history of subsidence and inversion.

The Central Somerset Basin lies towards the north-western corner of the larger Wessex Basin and is bounded to the north by the Palaeozoic outcrop of the Mendip High. Geophysical evidence shows that its structure at depth is essentially the same as that now exposed on the Mendip High (Chadwick *et al.*, 1983; Chadwick, 1986, 1993). To the east it is continuous with the Pewsey Basin whereas to the north-west it passes into the Bristol Channel Basin. Van Hoorn (1987a) and Brooks *et al.* (1988) interpreted the latter as a Mesozoic half-graben formed above a southward-dipping normal fault developed on a re-activated Variscan thrust. The boundary between the Central Somerset and Bristol Channel basins is perhaps best defined by a major strike-slip structure, the Watchet–Cothelstone–Hatch Fault System. The Central Somerset and Dorset basins are separated by the westward extension of the Cranborne–Fordingbridge High (Figure 2.1).

The Dorset, Central Somerset and Bristol Channel basins probably formed during the Permian Period, with the Watchet–Cothelstone–Hatch Fault System acting as a zone of transfer between southern and northern, possibly syn-orogenic, extension. The east–west strike of the basement thrusts is reflected in the east–west orientation of the Bristol Channel Basin and the

Mendip and Cranbourne–Fordingbridge highs, while the NW-trending faults, which together comprise the Watchet–Cothelstone–Hatch Fault System, represent lateral ramps to these thrusts.

Comparison with other areas

Because of the long history of investigation of the Lower Jurassic succession on the Dorset coast, the sequence there is often taken as the 'standard' against which correlative successions elsewhere are compared. The lithostratigraphy of the Wessex Basin shows greater contrasts with the more distant basins, such as those of Cleveland and the Hebrides, than with those of the nearby Severn Basin and East Midlands Shelf. In a comparison of the Wessex and Cleveland basins, Hesselbo and Jenkyns (1995) concluded that the large-scale facies differences between the two reflected the more proximal (to land) setting of the Cleveland Basin. The same interpretation can probably be applied to the Hebrides Basin. The most obvious significant difference between the Wessex Basin succession and those elsewhere occurs in the Toarcian Stage, where dark laminated mudstones, which are present across most of Britain and mainland Europe, are represented by the highly condensed Beacon Limestone Formation. This difference undoubtedly reflects local structural controls. Structural influences on the Wessex Basin succession are also evident from the reduced thickness of the overall succession and greater frequency of hiatuses on the Dorset coast compared with that in the Central Somerset Basin, or with those in the Severn or Cleveland basins.

The distribution of faunal elements through the Lower Jurassic succession of the Wessex Basin typically reflects either their biostratigraphical range (vertical distribution) or facies control (lateral distribution). Provincialism has been documented among two invertebrate groups in particular. In the Upper Pliensbachian Stage Ager's (1956a) work on brachiopods distinguished a South-western Province (the Wessex and Severn basins) from three others farther north. Within this province he recognized distinct Bridport and Ilminster subprovinces, which effectively correspond to the Dorset and Central Somerset basins, and a Gloucester Subprovince corresponding to the Severn Basin, that was transitional to the Midland Province farther north. Howarth (1958) noted a close correlation between the brachiopod provinces recognized by Ager (1956a) and the distribution of species of the ammonite genus *Pleuroceras*. Both authors noted a profound difference in faunal composition between the South-western and Yorkshire provinces that they attributed to physical barriers to migration of the various taxa.

PINHAY BAY TO FAULT CORNER, and EAST CLIFF, DORSET (SY 317 907–SY 453 907 and SY 463 902–SY 475 896)

Introduction

The importance of the Lower Jurassic succession exposed at the Pinhay Bay to Fault Corner GCR site, which incorporates the Seatown to Watton Cliff GCR site, and farther east at the East Cliff GCR site, cannot be overstated. This locality provides the most continuous section of this stratigraphical interval exposed anywhere in Britain, exposing a diverse range of facies, and is among the most intensively studied Jurassic areas in Britain. The succession at Pinhay Bay to Fault Corner is more frequently cited as a comparative succession for Lower Jurassic sequences elsewhere than any other site in Britain and, probably, the world. The diverse fossil fauna from this locality is uniquely well-documented and includes a greater number of type specimens than any other Lower Jurassic site in Britain. The sites form part of the Dorset and east Devon Coast, England's only natural World Heritage Site. They are of immense importance for understanding early Jurassic stratigraphy, palaeontology and sedimentology.

The earliest reference to the Lias of Dorset was by Woodward (1728) who commented on 'incredible numbers of these shells thus flattened and extremely tender in shivery stone about Pyrton Passage, Lime and Watchet'. Maton (1797) gave a general description of the Dorset Lias, referring to the presence of septarian nodules and also to the abundance of pyrite and organic matter in the shales. Other early accounts included those of De Luc (1805) and Townsend (1813); more detailed descriptions were published by De la Beche (1822, 1826) and Conybeare and Phillips (1822). De la Beche (1826) noted the main lithological and palaeontological features and was the first to illustrate the cliffs and their contained successions in the schematic form that has become characteristic of publications dealing with this stretch of coast. Many subsequent publications have referred to the Dorset Lias in some context. Notable among these are the works of Day (1863), Wright (1878–1886), Woodward (1893), Woodward *et al.* (1911), Wilson *et al.* (1958) and the seminal series of papers by Lang (1914 to 1936). The application of new technology has seen the publication of useful alternative stratigraphies based on, for instance, spectral gamma-ray analysis (Parkinson, 1996; Bessa and Hesselbo, 1997) which has proven a useful aid to correlation with successions elsewhere as well as a tool for palaeoecological interpretations.

There have been many useful summary accounts of the succession, notable among which are those by Wilson *et al.* (1958), Macfadyen (1970), House (1989), Callomon and Cope (1995), and Hesselbo and Jenkyns (1995), although Arkell's (1933) description seems somewhat confused in parts.

The succession in this locality is of immense palaeontological significance on account of its extensive exposures, the often fossiliferous nature of the succession, and the exceptional preservation at some horizons. Material from here has formed the basis of many monographic studies and continues to do so. It is the type locality for at least 14 species of fossil reptile (Benton and Spencer, 1995), many species of fish (Dineley and Metcalf, 1999), and an even greater diversity of invertebrates of all types. It also played an important part in the early development of the science of palaeontology and the theory of evolution, particularly through the collecting of Mary Anning.

Description

The western boundary of this locality lies just west of a fault that downthrows the lower part of the Blue Lias Formation to the west against the Triassic Langport Member (formerly White Lias) of the Lilstock Formation (Figure 2.4). The Langport Member, described by Hallam (1957), consists largely of matrix-supported intraclastic conglomerates, with individual beds showing internal deformation due to slumping. It is succeeded by the lowest, late Triassic part of the Blue Lias Formation, which is exposed only at the western end of the GCR site and has been described recently by Wignall (2001). The Blue Lias Formation, as recognized here, is about 26 m thick at Lyme Regis. The formation is wholly exposed in the cliffs and foreshore between Pinhay Bay and Monmouth Beach, Lyme Regis, in an easterly dipping section that brings successively higher beds to beach level (Figure 2.4). The upper half of the formation is exposed in Church Cliffs (Figure 2.5), to the east of the town, before descending eastwards below beach level under the western flank of Black Ven. It was divided by Lang (1924) into 143 beds; beds 1 to 53 for the succession exposed in the Church Cliffs and Chippel Bay anticlines (Lang, 1914), and H1 to H91 for lower parts of the succession exposed only farther west. Although Lang (1924) took Table Ledge (Bed 53) as the top of the formation, on lithofacies grounds it is more appropriately placed above Bed 49 (Hesselbo and Jenkyns, 1995) (Figure 2.6).

The Blue Lias Formation comprises frequent alternations, mostly on a scale of a few decimetres or less, of tabular or nodular micritic limestones interbedded with darker, organic-rich, laminated shales, and light and dark marls (Figure 2.5). Symmetrical cycles, displaying a sequence of limestone–marl–mudstone–marl–limestone, are well developed at some levels. The limestones are of two types; most are tabular to highly nodular with numerous fossils and burrow mottling but no trace of lamination. Much rarer are tabular limestones with planar surfaces, lamination and a virtual absence of benthos. These laminated limestones are restricted, within the Blue Lias Formation, to two groups within the Johnstoni Subzone (Lang beds H30, H32, H34 and H36, and H46, H48, H50 and H52). The marls show various degrees of burrowing and evidence of benthos while the laminated shales contain neither benthos nor burrows (Moghadam and Paul, 2000). The limestones and marls typically are sharply demarcated from each other. Any laminations within the marls envelope, rather than are cut by, irregularities in the surface of the limestones. Thin (< 2 cm) fibrous calcite, or 'beef', seams may be present at marl–shale junctions. Some of the limestones form distinctive marker bands and many of these were named by quarrymen who worked the limestones for building stone and cement manufacture. Intruder (Bed H30) is a homogeneous, fine-grained limestone with a strikingly sharp base, and is the most distinctive of the lower beds exposed to the west of Lyme Regis. It is unusual in having centimetre-wide

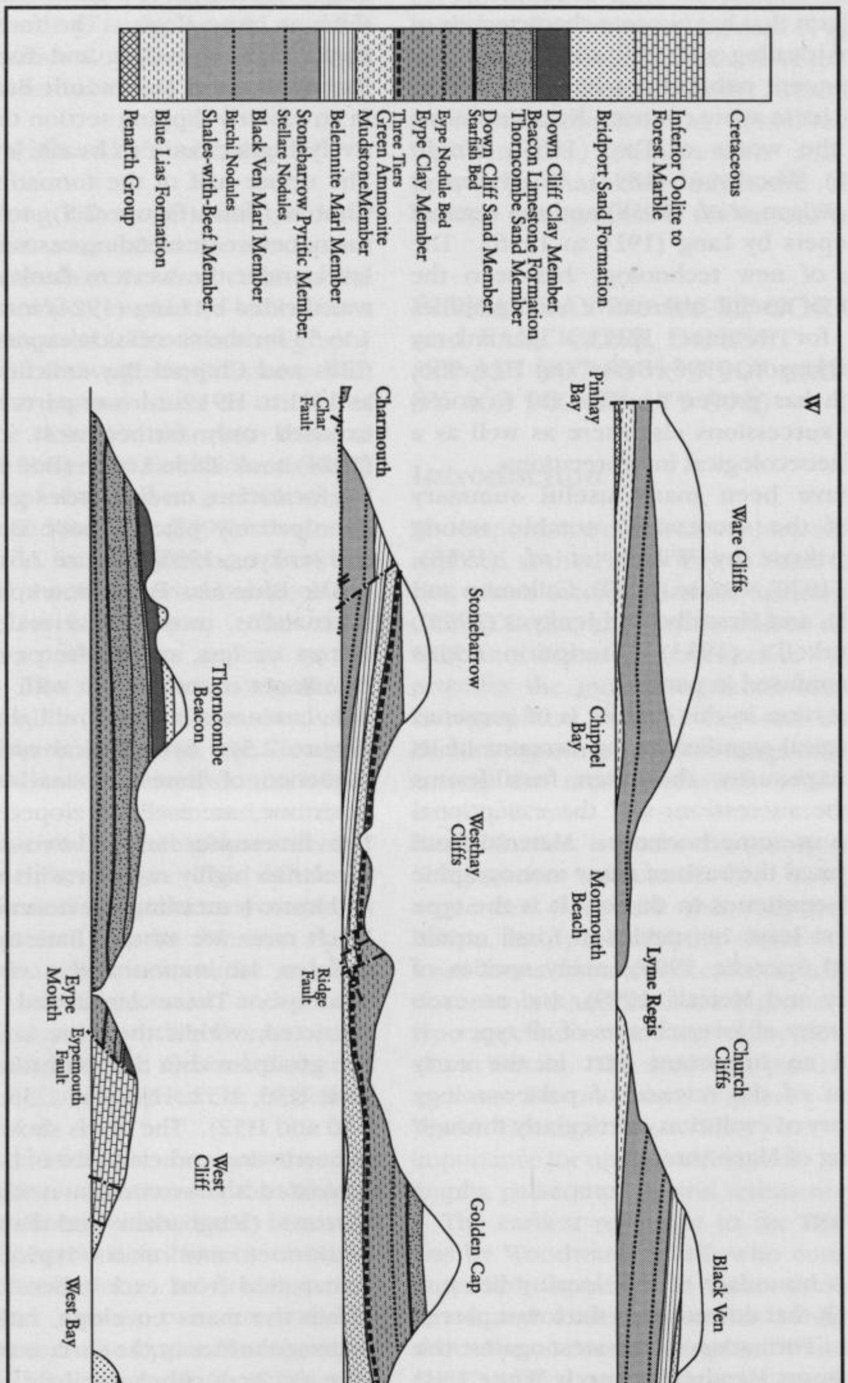

Figure 2.4 Coastal sections of the Lower Jurassic Series between Pinhay Bay and East Cliff. Based on House (1989) and Hesselbo and Jenkyns (1995).

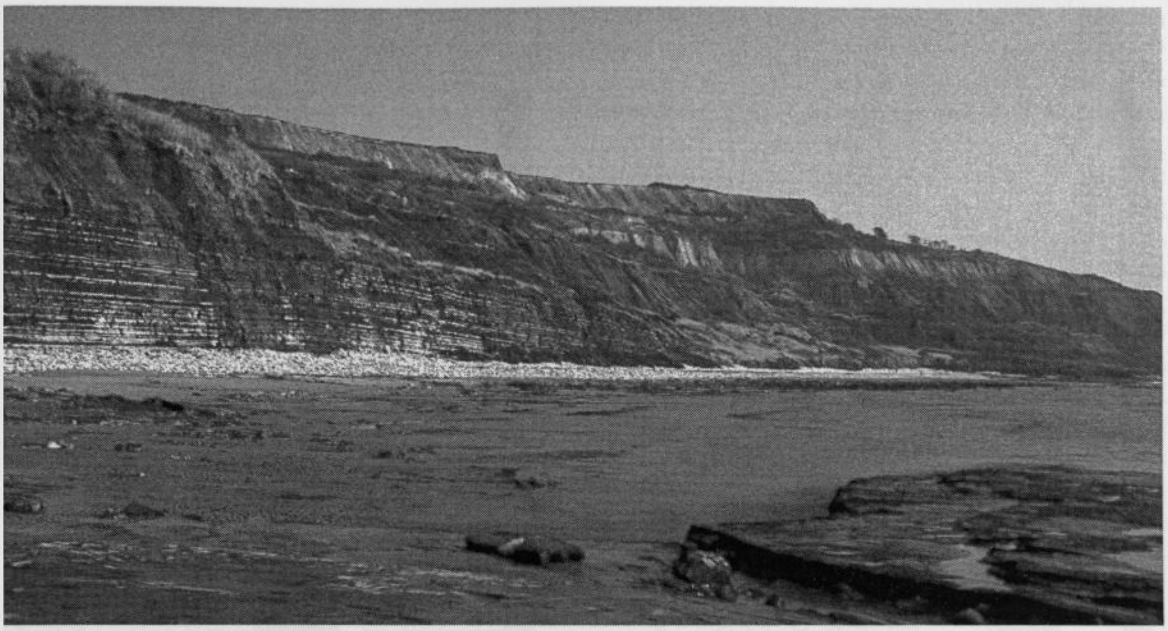

Figure 2.5 Looking eastwards along Church Cliffs to Black Ven. The classic limestone–mudstone alternations of the Blue Lias Formation are exposed in Church Cliffs, with the various members of the Charmouth Mudstone Formation exposed in the extensively slipped cliffs of Black Ven behind. The pale mudstones of the Belemnite Marl Member are clearly visible across the middle of Black Ven. (Photo: M.J. Simms.)

vertical fissures part-filled with bioclastic limestone, a feature otherwise seen only in Under Copper (Bed 11), and in containing limestone intraclasts. Mongrel (Bed 23) is conspicuous by its highly undulose upper surface, while Top Tape (Bed 29) has its upper surface crowded with large specimens of the ammonite *Metophioceras conybeari*. Grey Ledge (Bed 49) is also distinctive. Its upper surface is characterized by an erosion surface with truncated ammonites, shell and belemnite accumulations, together with glauconite, phosphate and limestone intraclasts.

On a larger scale, division into limestone-dominated and shale-dominated intervals is less strongly developed than at some other sites, such as the **Blue Anchor–Lilstock Coast** or the **Lavernock to St Mary's Well Bay** GCR sites, although mudstone-dominated intervals are evident in the Liasicus and mid-Bucklandi zones. This can be seen clearly in Church Cliffs, where the lower 5 m is characterized by crowded limestones with Top Tape (Bed 29) at the top, and is overlain by some 9 m of more widely spaced limestones.

The Blue Lias Formation contains a rich and diverse fauna. Benthic taxa are well represented, particularly in some of the limestones and the paler mudstones but not in the organic-rich paper shales. Benthos includes various species of bivalve, including *Plagiostoma* and *Gryphaea arcuata*, the crinoid *Isocrinus psilonoti*, echinoids including *Miocidaris lobatum* and *Diademopsis*, the brachiopods *Calcirhynchia calcaria* and *Spiriferina* and, at some horizons, gastropods, bryozoa and, rarely, isastraeid corals. The microfauna includes foraminifera and ostracods (Lord and Boomer, 1990), ophiuroid and holothurian debris (Gilliland, 1992), and both marine and non-marine palynomorphs (Cole and Harding, 1998; Waterhouse, 1999). Copestake (pers. comm. in Parkinson, 1996) noted a significant incursion of benthic foraminifera near the top of the Blue Lias Formation. Among the non-benthic fauna ammonites are the most conspicuous element, and many, particularly the schlotheimiids and coroniceratids, attain a large size. They are sufficiently common and well preserved to have allowed a detailed biostratigraphical subdivision to be developed with the identification of several ammonite-correlated horizons in the Hettangian and Sinemurian stages (Page, 1992, 1994a, 2002). Other non-benthic invertebrate macrofossils are much rarer. They include the belemnite *Nannobelus* and the pseudoplanktonic

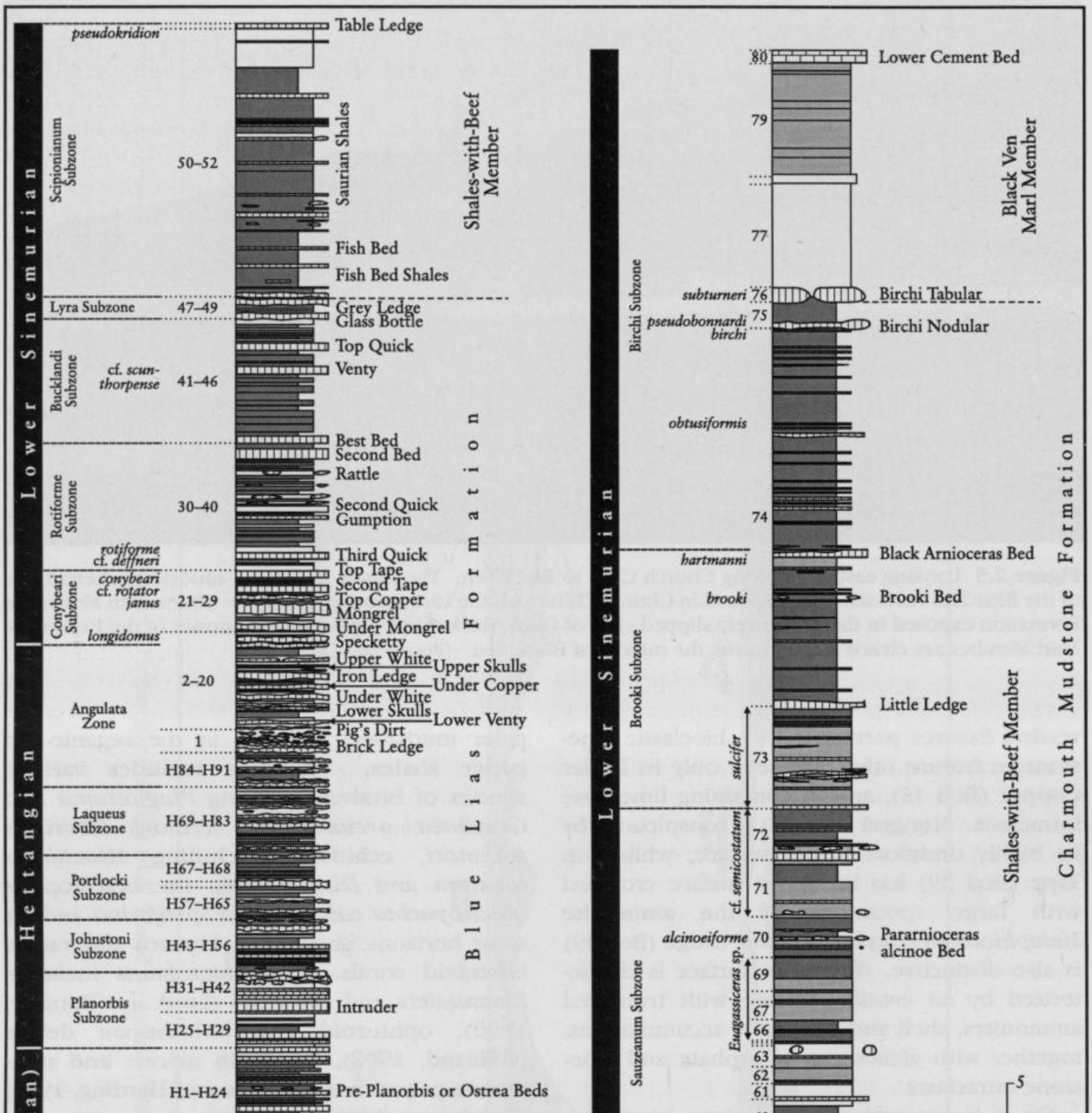

Figure 2.6a Section through the Penarth Group, Blue Lias Formation, Shales-with-Beef Member and basal Black Ven Marl Member west of Charmouth. After Hesselbo and Jenkyns (1995); with ammonite zones, subzones and biohorizons after Page (1992); and bed numbers after Lang (1924), Lang *et al.* (1923) and Lang and Spath (1926) . See Figure 2.6b for a key to the lithologies.

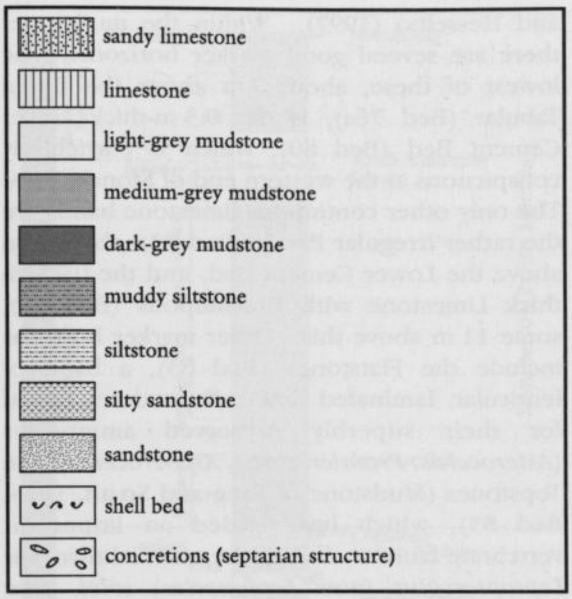

Figure 2.6b Key to lithologies.

crinoid *Pentacrinites doreckae*, which has been found in an exquisite state of preservation comparable with examples of the better-known *P. fossilis* from higher in the succession. Vertebrate remains, other than occasional disarticulated teeth and bones, are rare but the Blue Lias Formation and overlying Shales-with-Beef Member along this stretch of coast has furnished many type specimens of fish and marine reptile (Benton and Spencer, 1995; Dineley and Metcalf, 1999). Many specimens were obtained by early collectors such as Mary Anning, but articulated skeletons are still being found.

The Blue Lias Formation is succeeded by a substantial thickness of mudstone-dominated strata, the Charmouth Mudstone Formation, which has as its type section the cliffs and foreshore of Black Ven and Stonebarrow (Figure 2.4). It has been subdivided into several members following the work of Lang (1936; Lang *et al.*, 1923, 1928; Lang and Spath, 1926). The lowest of these is the Shales-with-Beef Member (Lang *et al.*, 1923), incorporating about 30 m of strata from the top of Grey Ledge (Bed 49) to the base of the Birchi Tabular (Bed 76a) spanning the Scipionianum Subzone to about the middle of the Birchi Subzone (Figure 2.6). Above Grey Ledge (Bed 49) there is a marked increase in the proportion of mudstone. The Birchi Tabular (Bed 76a) is a lenticular, and usually beef-enveloped, limestone that forms a conspicuous marker band across The Spittles and Black Ven, before finally descending below beach level at the mouth of the River Char. The Shales-with-Beef Member is well exposed in the cliffs and terraces of The Spittles and Black Ven, and also as a series of ledges on the foreshore below, where they were mapped out by Lang (Lang *et al.*, 1923, fig. 1). The succession is dominated by dark mudstones, many of them organic-rich and finely laminated. Such paper shales are prominent in the lower part of the member, which includes the Fish Bed Shales (Bed 50), Fish Bed (Bed 51) and Saurian Beds (Bed 52), and particularly in the middle part of the member (beds 74 and 75). The mudstones contain numerous thin beds (mostly < 10 cm) of fibrous calcite, or 'beef', which were discussed in detail by Richardson (in Lang *et al.*, 1923). Typically they form double or multiple seams, separated by clay partings, which often show cone-in-cone structure. They are always developed along bedding planes except where they envelope nodules and fossils; seams often thin or even pinch out altogether beneath large nodules. Most of the reefs on the foreshore outcrop are formed by thick 'beef' seams. Richardson (in Lang *et al.*, 1923) recorded small biconvex discs of barite in the paper shales of Bed 71e.

The Shales-with-Beef Member contains a few limestone beds, most of which are nodular and/or laterally impersistent. Several contain well-preserved ammonites from which they take their names, as in the Brooki Bed (Bed 74d), the Black Arnioceras (or Hartmanni) Bed (Bed 74f) and the Birchi Nodular (Bed 75a) (Figure 2.7). The last has been the subject of research into the growth of carbonate nodules and fibrous calcite veins within mudstones (Raiswell, 1971; Marshall, 1982). Preservation of ammonites and other invertebrate fossils in the mudstones is almost invariably poor. The lower part of the Shales-with-Beef Member contains a moderately diverse benthic fauna similar to that in the mudstones of the Blue Lias Formation. Lang *et al.* (1923) recorded a number of bivalve taxa, including *Plagiostoma*, *Gryphaea*, *Liostrea*, *Chlamys*, *Avicula* and *Gervillia*, from numerous levels between Table Ledge (Bed 52) and Little Ledge (Bed 74). Brachiopods are present at several horizons and include clusters of *Piarorhynchia juvensis* in Table Ledge (Bed 53) and *Spiriferina* in the Pararnioceras alcinoe Bed (Bed 70c). Fragmentary remains of the crinoid

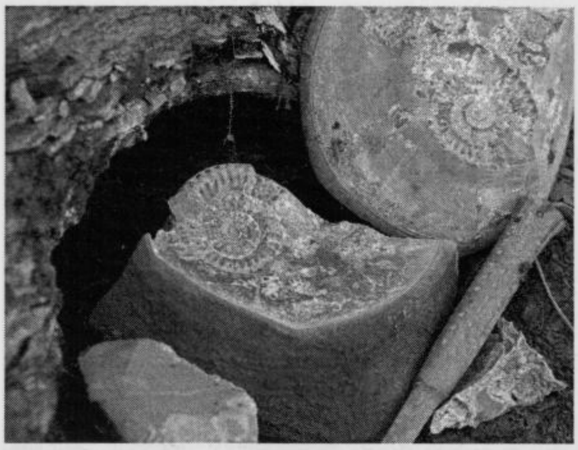

Figure 2.7 Diagenetic concretion in the Shales-with-Beef Member containing a topotype specimen of the ammonite subzonal index fossil *Microderoceras birchi* (M.J. Simms collection, 1981). (Photo: M.J. Simms.)

Isocrinus tuberculatus are not uncommon at some horizons. In the lower part of the Shales-with-Beef Member the organic-rich mudstones of beds 50 to 52 are reputed to have been the source of many of the superbly preserved fossil fish and marine reptiles obtained from the Dorset Lias over the past two centuries, though precise horizons for most of these are lacking (Benton and Spencer, 1995; Dineley and Metcalf, 1999). Little Ledge (Bed 74) marks an abrupt change to the organic-rich paper shales that dominate the upper part of the Shales-with-Beef Member. These have yielded virtually no benthic fauna, containing only nektonic, planktonic or pseudoplanktonic taxa, including ammonites, the bivalve *Avicula* and, rarely, the crinoid *Pentacrinites fossilis*.

The base of the Black Ven Marl Member (Lang and Spath, 1926) is taken at the base of the Birchi Tabular (Bed 76a) and the top is defined by the hiatus above the Coinstone (Bed 89) on Stonebarrow, although a comparable development of hiatus concretions has not been observed on Black Ven (Hesselbo and Palmer, 1992). The full thickness of the member is exposed on Black Ven and all except the lowest part on Stonebarrow. It comprises about 27 m of mostly dark-grey mudstones, with subordinate beds of nodular and tabular limestone (Figure 2.8). A 6.5 m-thick development of organic-rich paper shales in the upper part of the member corresponds to a peak in authigenic uranium concentration documented by Bessa and Hesselbo (1997). Within the mudstones there are several good marker horizons. The lowest of these, about 7 m above the Birchi Tabular (Bed 76a), is the 0.3 m-thick Lower Cement Bed (Bed 80), which is particularly conspicuous at the western end of Stonebarrow. The only other continuous limestone bands are the rather irregular Pavior (Bed 82), about 5 m above the Lower Cement Bed, and the 0.25 m-thick Limestone with Brachiopods (Bed 87), some 11 m above this. Other marker horizons include the Flatstones (Bed 83), a band of lenticular, laminated limestone nodules famed for their superbly preserved ammonites (*Asteroceras*, *Promicroceras*, *Xipheroceras*); the Topstones (Mudstone of Lang and Spath, 1926; Bed 85), which has yielded an important vertebrate fauna including the giant ichthyosaur *Leptopterygius* (now *Leptonectes*) *solei*, now held in Bristol City Museum (McGowan, 1993), and several specimens of the dinosaur *Scelidosaurus harrisoni*; and the Stellare Nodules (Bed 88f), spheroidal septaria famed for the large *Asteroceras stellare* they sometimes contain. The so-called 'Pentacrinite Bed' (Bed 84b) is not a single horizon but actually encompasses more than 2 m of organic-rich mudstones through which groups of the crinoid *Pentacrinites fossilis*, often associated with driftwood and exquisitely preserved (Figure 2.9), are scattered (Simms, 1986, 1999). Lang and Spath (1926) commented on the difficulties of correlating several of the nodular limestone beds between Black Ven and Stonebarrow. Several distinct bands of laminated limestone nodules, known locally as the 'Yellowstones', 'Woodstones', 'Lower Flatstones', 'Goldstones' and 'Flatstones', are present on Black Ven but not all have been recognized on Stonebarrow. Hesselbo and Jenkyns (1995) noted that the succession was slightly expanded on Black Ven in comparison with that on Stonebarrow, with the first *Asteroceras* appearing at a slightly higher level above the Pavior (Bed 82) on Black Ven. On Stonebarrow they noted a distinctive burrowed surface with a concentration of belemnites a short distance above the Pavior (Bed 82).

The highest part of the Black Ven Marl Member is perhaps the most intensely collected part of the entire Lower Jurassic succession, mostly for commercially valuable fossils such as ammonites (Figure 2.7), vertebrates and *Pentacrinites* (Figure 2.9). The organic-rich

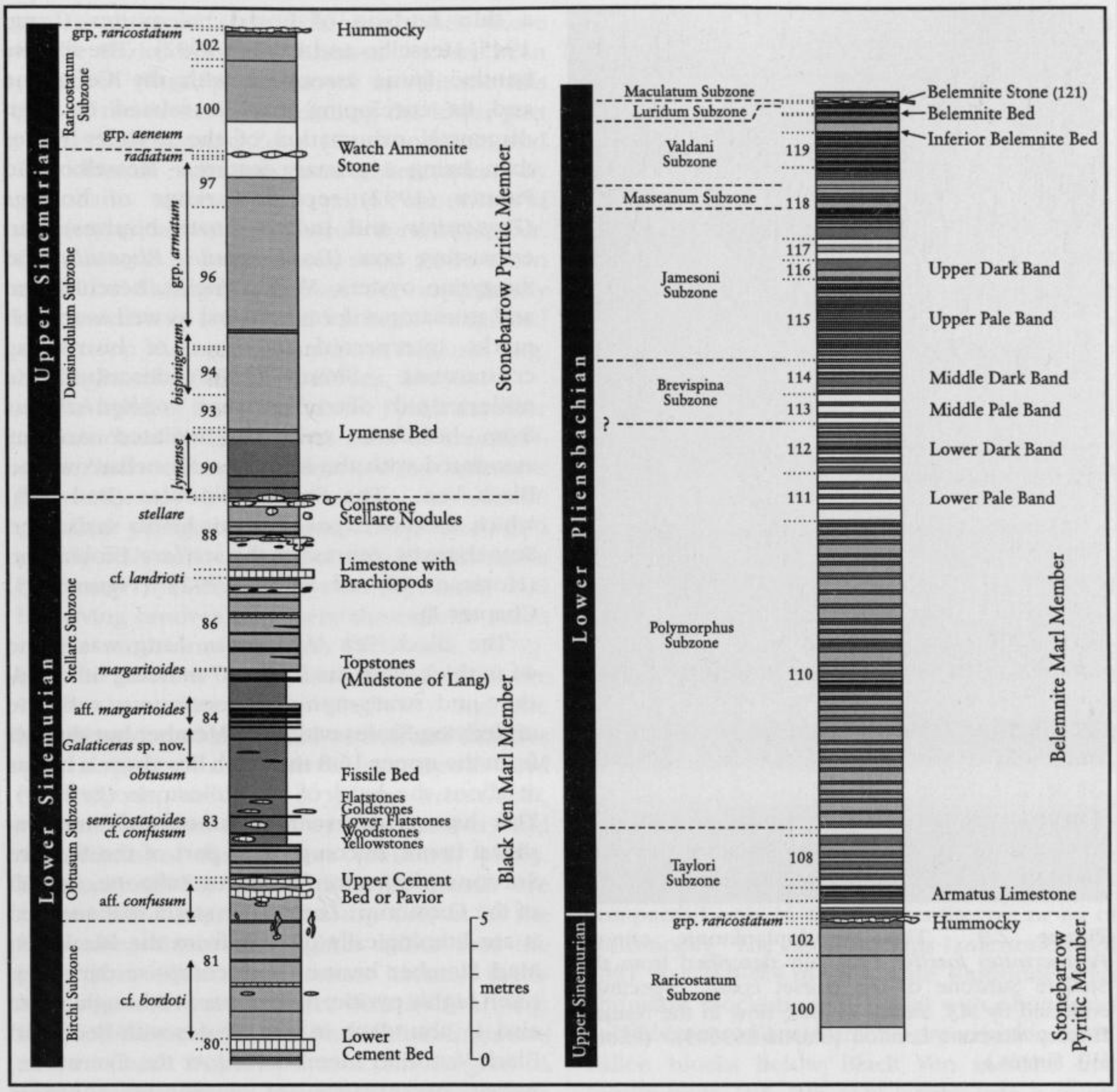

Figure 2.8 Section through the Black Ven Marl, Stonebarrow Pyritic and Belemnite Marl members of the Charmouth Mudstone Formation on Black Ven and Stonebarrow. After Hesselbo and Jenkyns (1995); with ammonite zones, subzones and biohorizons after Page (1992); and bed numbers after Lang and Spath (1926) and Lang *et al.* (1928).

mudstone parts of the succession, and particularly the laminated, early diagenetic concretions, have yielded much scientifically important material. A rich insect fauna (Zeuner, 1962; Whalley, 1985) has been obtained, particularly from the Flatstones nodules, and includes the oldest known representative of the Lepidoptera. Soft-part preservation of both vertebrates (Martill, 1991, 1995) and invertebrates (Kear *et al.*, 1995) has also been described. Other elements of the fauna have received little attention other than by Lang and Spath (1926). In general the fauna in the organic-rich mudstones is dominated by nektonic, planktonic and pseudoplanktonic organisms, mainly ammonites, belemnites and pseudoplanktonic bivalve taxa such as *Cuneigervillia* and *Oxytoma*. Nonetheless, even here there are occasional thin discrete horizons in which benthic bivalves, notably *Plagiostoma*, occur and benthic bivalve spat (less than 2 mm) across are common throughout (Simms, 1986). The limestone bands of the

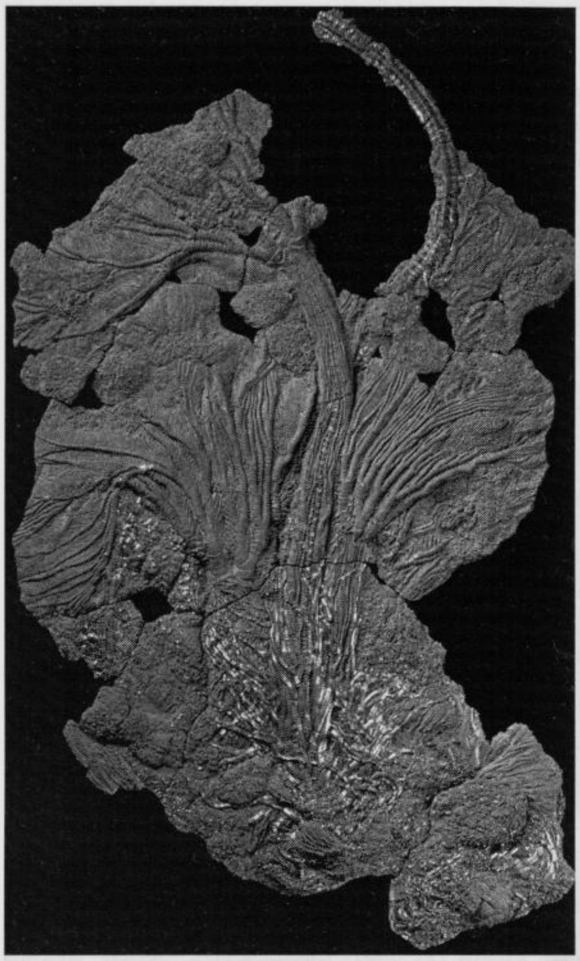

Figure 2.9 The pseudoplanktonic crinoid *Pentacrinites fossilis*, originally described from the Stellare Subzone of the Dorset coast. Specimen collected by M.J. Simms (1982); now in the Natural History Museum, London (BMNH E69605). (Photo: M.J. Simms.)

Pavior (Bed 82) and the Limestone with Brachiopods (Bed 87) contain a noticeably richer benthic fauna than is typical of the mudstones, with the Pavior yielding the bivalve *Chlamys* and the brachiopod *Spiriferina*, while the Limestone with Brachiopods contains *Plagiostoma* and abundant *Cuneirhynchia oxynoti*. The Coinstone (Bed 89) on Stonebarrow is an irregular bed of bored, encrusted and partly pyritized septarian hiatus nodules that preserve evidence for a complex history of burial, exhumation and re-burial (Lang, 1945; Hallam, 1969, 1999; Hesselbo and Palmer, 1992; Coe and Hesselbo, 2000). Nodules are present at this level on Black Ven, to the west, but the hiatus itself lies more than 1 m above, at a thin horizon of bored belemnites (Lang, 1945; Hesselbo and Palmer, 1992). The diverse benthic fauna associated with the Coinstone and its enveloping marl is related to post-diagenetic exhumation of the nodules rather than being a primary feature. Hesselbo and Palmer (1992) record a range of borings (*Trypanites* and indeterminate bivalves) and encrusting taxa (*Dorsoserpula*, *Plicatula* and exogyrine oysters, *Nubeculinella*, bereniciform and stomatoporiform bryozoa) as well as scratch marks interpreted as those of burrowing crustaceans. Simms (1989) described the millericrinid *Shroshaecrinus obliquistratus* from holdfasts and disarticulated ossicles associated with the hiatus on Stonebarrow and Black Ven. The Stellare Nodules (Bed 88f), which also are exposed at this hiatus surface on Stonebarrow, represent the *stellare* Biohorizon (Horizon 40) of Page (1992) (Figure 1.5, Chapter 1).

The Black Ven Marl *sensu* Lang was some 44 m thick, with the lower 27 m being lithologically and stratigraphically continuous with the underlying Shales-with-Beef Member but distinct from the upper 16.8 m, which lies above a hiatus at about the level of the Coinstone (Bed 89). This hiatus represents a substantial stratigraphical break, encompassing part of the Stellare Subzone, the entire Denotatus Subzone, and all of the Oxynotum Zone. The strata that succeed it are lithologically distinct from the Black Ven Marl Member beneath and comprise dark-grey, often highly pyritic, mudstones. Although pyrite also is abundant in the Shales-with-Beef and Black Ven Marl members below the Coinstone, pyritic preservation of ammonites there is relatively uncommon and, where it does occur, the pyrite usually occurs as a surface encrustation of a previously crushed ammonite. However, in the dark mudstones above the Coinstone, pyrite commonly occurs as well-preserved and uncrushed internal moulds of ammonites, bivalves and gastropods. The 16.8 m of dark mudstone above the Coinstone also lacks the large diagenetic nodules characteristic of the Black Ven Marl Member. The only prominent development of limestone is the Watch Ammonite Stone (Bed 99), a lenticular unit up to 0.3 m thick and often packed with abundant *Echioceras* grp. *aeneum* lying at various angles to the bedding. Occasional small limestone nodules may be present at other levels. Thin seams of 'beef' are present but they too are on a greatly reduced scale compared with those in the Shales-with-Beef Member. It has been proposed (Page, pers. comm.) to re-name this part of the succession, spanning the lower part of the Raricostatum Zone (Densinodulum and Raricostatum subzones) and characterized by abundant uncrushed pyritic moulds of ammonites, as the Stonebarrow Pyritic Member. On this style of fossil preservation alone it can easily be distinguished from the superficially dark mudstones below and has been recognized at outcrop throughout southern England (e.g. Hollingworth *et al*., 1990; Simms, 2003b).

The fauna of the Stonebarrow Pyritic Member is dominated by ammonites such as *Crucilobiceras*, *Eoderoceras*, *Echioceras* and the distinctive *Oxynoticeras lymense*, whose uncrushed pyritized phragmocones are conspicuous and readily collected. A low-diversity benthic fauna of mostly thin-shelled, byssate epifaunal and free-living bivalves is present throughout much of the mudstone sequence (Sellwood, 1972). Benthic diversity is significantly higher in the Watch Ammonite Stone (Bed 99) and the bioturbated marl associated with it, and includes several genera of bivalves, gastropods and brachiopods, including *Gryphaea mccullochi*, which otherwise is rare in the member, and 14 species of foraminifera (Barnard, 1950). Sellwood (1972) noted that the fossils are concentrated mainly in the top 0.09 m of the limestone, which has a lighter colour than the lower part, while the limestone lenticles themselves have a sharp contact with an overlying, intensely bioturbated, shell-hash rich in fragments of the crinoid *Hispidocrinus schlumbergeri*. A second small increase in benthic diversity occurs about 1.6 m below the base of Hummocky (Bed 103), where an abrupt change from laminated to more homogeneous mudstones is associated with the appearance of protobranch bivalves and an increased abundance of other species already present lower in the succession.

The abundant ammonites (Figure 2.7) found throughout the Sinemurian part of the Charmouth Mudstone Formation have allowed for a detailed biostratigraphical subdivision of this part of the succession. Page (1992) established a sequence of ammonite-correlated biohorizons for the Sinemurian Stage (Figures 1.4 and 1.5, Chapter 1), with the Dorset coast as type locality for several of these. Although most of the species in Page's scheme are common and widespread elsewhere, *Oxynoticeras lymense* is known only from the basal Densinodulum Subzone (beds 90–92) of this site.

The Stonebarrow Pyritic Member is overlain by the Belemnite Marl Member, a 23 m-thick succession of blue-grey, occasionally organic-rich, mudstones alternating with pale-grey, richly calcareous mudstones. These form the uppermost Lias precipice on Black Ven and on the western flank of Stonebarrow (Figures 2.5 and 2.10), descending to form the lower part of the Westhay Cliffs before being faulted below beach level at the Ridge Fault. The upper beds are also exposed in some of the foreshore reefs below Golden Cap. The base of the Belemnite Marl Member is taken at the base of Hummocky (Bed 103), an irregular limestone band up to 0.15 m thick. Abundant echioceratid ammonites are present on its lower surface while serpulid-encrusted examples also occur sparsely throughout Bed 103 and the overlying 0.1 m-thick clay of Bed 104, the latter also yielding *Eoderoceras miles*. Hummocky contains abundant bioclastic material, including bivalves, belemnites, crinoid and echinoid debris, serpulids and fragments of reptile bone. The upper part of Hummocky and the basal few centimetres of Bed 104 contain numerous intra-formational limestone clasts; these are sometimes bored, contain phosphatic specks and have a pyritic skin. Both units are intensely burrowed but these burrows are compacted only in the top centimetre or so of Hummocky. The Apoderoceras Limestone (Bed 105) is a 0.3–0.4 m-thick pale limestone with abundant bioclastic debris and with *Chondrites* and *Rhizocorallium* burrows preserved in relief. Fallen blocks below Black Ven indicate that locally beds 103–105 may merge into a single complex limestone unit up to 1 m thick.

Much of the remainder of the Belemnite Marl Member, more than three quarters of which lies within the Jamesoni Zone, comprises alternating pale and dark mudstone bands, which are clearly visible in the near-vertical cliffs on Black Ven and Stonebarrow (Figure 2.10). Weakly laminated organic-rich shales form a minor component, particularly near the top. In addition to the basic stratigraphical description of Lang *et al*. (1928), detailed analyses of this part of the Charmouth Mudstone Formation have been made by Sellwood (1970, 1972) and by Weedon and Jenkyns (1990, 1999). The latter demonstrated an inverse relationship between carbonate content (higher in the pale bands) and total organic carbon content (higher in the

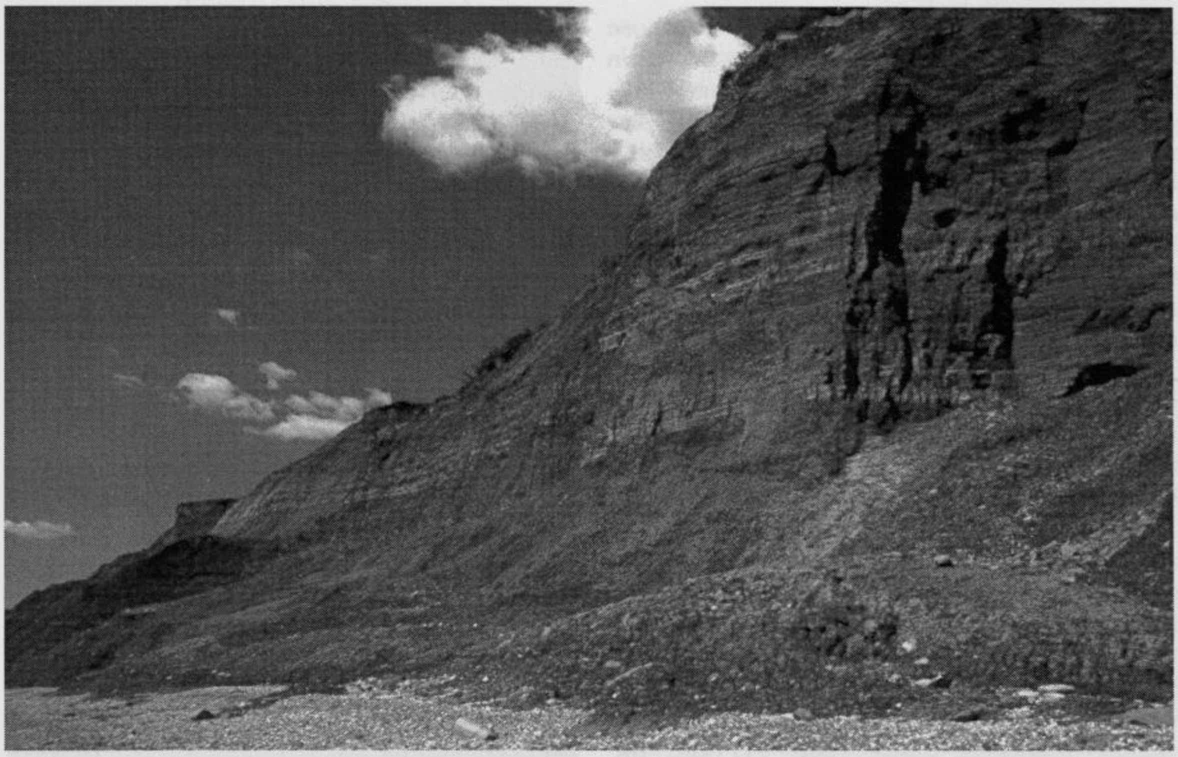

Figure 2.10 Conspicuously striped mudstones and marls of the Belemnite Marl Member, overlying dark mudstones of the Stonebarrow Pyritic Member (largely obscured by talus) at the eastern end of Stonebarrow, Charmouth. (Photo: M.J. Simms.)

darker bands). This correlation is also reflected in the concentrations of radioactive uranium, thorium and potassium as documented by Bessa and Hesselbo (1997). Sellwood (1970, 1972) showed that both the body-fossil and trace-fossil assemblages changed in parallel with the light–dark couplets. The pale, carbonate-rich bands proved to contain abundant fine bioclastic debris such as crinoid and echinoid fragments, foraminifera, ostracods and faecal pellets, while the more organic-rich darker units yielded a more depauperate fauna. Both the light and dark units show intense burrow mottling. Sellwood (1970) described from here his 'Type II' cycles and the trace fossils associated with them. He noted that *Diplocraterion* were present only in the tops of the pale units, piping darker sediment downwards, while *Rhizocorallium* and *Thalassinoides* were conspicuous at the lower junctions, piping paler sediment down into the darker mudstones beneath. Only very small *Chondrites* are present within the pale units. Larger *Chondrites*, where they extend down from the dark units into the paler horizons below, were found by Simpson (1957) usually to follow the dark clay fill of pre-existing *Rhizocorallium* or *Diplocraterion* burrows.

The rhythmicity conspicuous throughout much of the Belemnite Marl Member is less well-developed in the highest 4 m at the top of the member (Lang, 1917). The upper 2 m is dominated by dark, weakly laminated, organic-rich shales. At some levels, notably the thin Belemnite Bed (Bed 120c), belemnites are profuse, while pyritized ammonites are abundant in beds 120a–b. Storm scours up to 1 m wide and 0.1 m deep, and filled with debris of *Isocrinus basaltiformis*, belemnites, brachiopods and wood, are a conspicuous feature in this part of the succession. Jones *et al.* (1994) noted a sudden increase in the strontium isotope values at the level of the Belemnite Bed. The Belemnite Marl Member is capped by the Belemnite Stone (Bed 121), an irregular, pale grey-brown, richly bioclastic limestone seldom more than 0.15 m thick, which has yielded a Luridum Subzone fauna. Despite the condensed nature of the Ibex Zone here, the sequence of ammonite zonules is largely complete (Phelps, 1985).

Much of the Belemnite Marl Member contains a limited benthic assemblage. Some elements of the fauna, namely ammonites, belemnites, bivalves, gastropods and brachiopods, were described in Lang *et al.* (1928). Throughout the sequence only belemnites are common and well preserved. They are especially abundant in the Belemnite Bed (Bed 120c) and in the Belemnite Stone (Bed 121), and in the Inferior Belemnite Bed of Hesselbo and Jenkyns (1995) about 0.6 m lower in the succession. Belemnites in general are the most conspicuous fossils elsewhere in the member, which led Lang *et al.* (1928) to describe the stratigraphical succession of morphotypes (see Chapter 1). Ammonites usually are poorly preserved, either as pyritized phragmocones or mudstone impressions. There are no infaunal, semi-infaunal or protobranch bivalves, and *Gryphaea* also is absent. Only *Plagiostoma*, *Parainoceramus ventricosus* and thin-shelled pectinids are at all common. Barnard (1950) noted an extreme paucity of forminifera in this part of the succession. Disarticulated remains of *Isocrinus basaltiformis* are locally abundant in storm scours near the top of the Belemnite Marl Member. Brachiopods generally are rare except at two levels; in beds 111–114 and 118–119. In common with other organic-rich mudstones elsewhere in the Lias Group of Dorset, those that occur immediately below the Belemnite Stone (beds 119–120) have yielded well-preserved vertebrate remains including a new species of ichthyosaur (McGowan and Milner, 1999) and remains of *Scelidosaurus* (Ensom, 1987, 1989).

The Belemnite Stone is overlain by the Green Ammonite Mudstone Member, which comprises blue-grey mudstones (Figure 2.11). The member is well exposed beneath Golden Cap, though often badly slumped in cliff sections to the west where they form a low-angle slope above the steep cliffs of the Belemnite Marl Member. There is a marked eastward thickening of the member from about 15 m on Stonebarrow to 34 m beneath Golden Cap (Lang, 1936). Only about 5 m remains on the eastern flank of Black Ven beneath the Cretaceous overstep. Originally described by Lang (1936), the stratigraphy was significantly revised by Phelps (1985). Most of the succession falls within the Davoei Zone though the top 3 m contains *Amaltheus* and hence lies within the Stokesi Subzone at the base of the Upper Pliensbachian Substage. Limestone nodules occur scattered through the mudstone and, particularly in the lowest 6 m, may contain the so-called 'green ammonites' with their camerae filled with green calcite. More persistent irregular limestone bands occur at three levels. These are the Lower Limestone (Bed 123a of Lang, 1936; Bed 14 of Phelps, 1985), a persistent horizon of flattened blue-grey nodules; the Red Band (Lang's Bed 126; Phelps' beds 21–23), a series of three, red-weathering limestones separated by shales; and the Upper Limestone (Lang's Bed 129; Phelps' beds 32 and 34). The mudstones that dominate the member become increasingly sandy towards the top, which is taken at the base of the lowest of the Three Tiers, a 2 m-thick sandstone. The upper 2 m of the Green Ammonite Mudstone Member (Lang's beds 132b–c; Phelps' beds 40–41) is a dark, highly pyritic mudstone lithologically unlike any other mudstone in the Green Ammonite Mudstone Member or the Pliensbachian Stage of Dorset.

Ammonites are abundant in the Green Ammonite Mudstone Member and include species of *Aegoceras*, *Oistoceras*, *Liparoceras* and *Tragophylloceras*. Several species of *Prodactylioceras*, a relatively rare genus in the British Lias, occur in the middle part of the member. *Lytoceras* is very rare in the Green Ammonite Mudstone Member although it occurs commonly in the Belemnite Stone below and in the Three Tiers above. Phelps (1985) defined a series of fine-resolution ammonite zonules within the Ibex and Davoei zones based largely on the Dorset coast succession. He showed that all three subzones and the full sequence of zonules of the Davoei Zone are present in the GCR sections. The Maculatum Subzone at the base is much thinner than the Capricornus and Figulinum subzones. He also identified here a local *Cymbites* horizon between his Figulinum and Bifurcus zonules, the latter equivalent to the Occidentale and Monestieri zonules of Figure 1.6 (Chapter 1) indicating that the Davoei Zone and basal Margaritatus Zone succession is unusually complete on the Dorset coast. Belemnites also are common; stout species of *Pseudohastites* are particularly conspicuous, and slender hastitids are present throughout.

A diverse benthic fauna was recorded from the Green Ammonite Mudstone Member by Lang (1936), with several new species of bivalve, gastropod and brachiopod described by Cox (1936) and Muir-Wood (1936). Small gastropods are particularly abundant in the lowest few

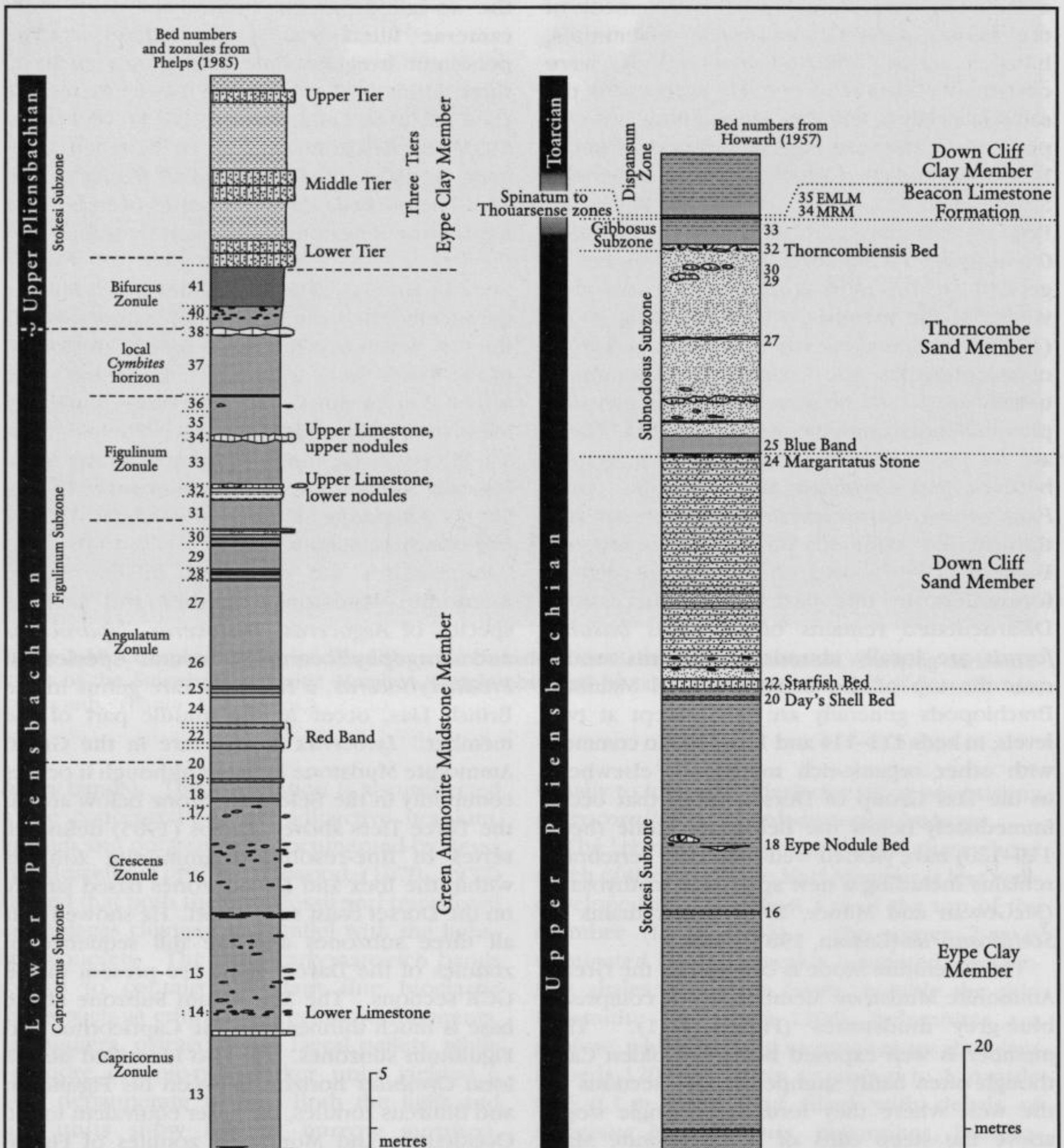

Figure 2.11 Section from the (Lower Pliensbachian) Green Ammonite Mudstone Member to the (Toarcian) Down Cliff Clay Member of the Dorset coast. After Hesselbo and Jenkyns (1995); with ammonite zonules after Phelps (1985); and bed numbers after Lang (1936) and Howarth (1957).

metres, together with the epibenthic bivalve *Parainoceramus ventricosus*, the echinoid *Eodiadema minuta* and the crinoids *Isocrinus basaltiformis* and *Balanocrinus subteroides*. Higher in the succession shallow-burrowing nuculid bivalves are the only common macrobenthos. Macfadyen (1941) recorded a total of 55 species of foraminifera, together with sparse ostracods, in the Green Ammonite Mudstone Member.

The Charmouth Mudstone Formation is succeeded by the Dyrham Formation, which equates approximately with the lower part of the Upper Pliensbachian Substage (Figure 2.2). Its outcrop on the coast extends from the western flank of Stonebarrow, where only a few metres are preserved beneath the Cretaceous overstep, eastwards for about 5 km, beneath Golden Cap and Thorncombe Beacon (Figure 2.12), to where it is faulted out against the Bathonian strata of West Cliff. The base of the Dyrham Formation is marked by an abrupt lithological change from the mudstones of the Green Ammonite Mudstone Member to the sandstones that comprise the Three Tiers at the base of the Eype Clay Member. The Dyrham Formation of Dorset attains a thickness of about 123 m of which all but about 0.5 m can be assigned to the Margaritatus Zone. This is the maximum thickness of the zone anywhere in Britain. The succession was described in detail by Howarth (1957) and by Hesselbo and Jenkyns (1995).

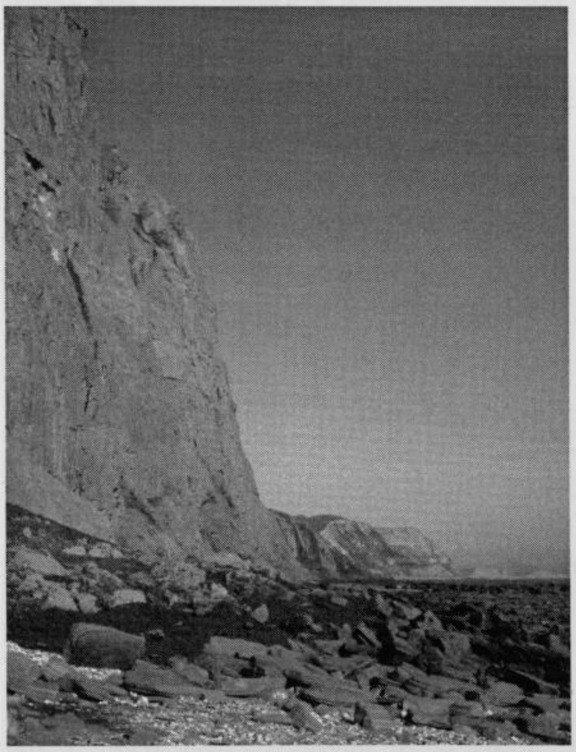

Figure 2.12 The sheer cliff face of the Eype Clay Member below Golden Cap, part of the spectacularly thick development of the Stokesi Subzone in Dorset. Thorncombe Beacon and East Cliff are visible in the distance. (Photo: M.J. Simms.)

Three well-cemented, fine-grained, muddy sandstones, each 0.5–1 m thick, form conspicuous marker bands in the lowest part of the Dyrham Formation. They form prominent ledges in the cliffs and have long been known as the 'Three Tiers'. Each has a gradational boundary with the intervening, less cemented, silty and sandy mudstones and, although often well-bioturbated with conspicuous *Thalassinoides* (Sellwood *et al.*, 1970), show planar and ripple bedding. Above the Upper Tier lies about 60 m of grey, micaceous, silty mudstone, the Eype Clay Member, in which there are a few thin sandstone beds (Figure 2.12). Body fossils, other than crushed *Amaltheus* and *Tragophylloceras loscombi*, are scarce except at two levels. The lower of these is the Eype Nodule Bed, some 38 m above the Upper Tier, which contains bivalves, brachiopods, crinoids and crustacea along with a diverse ammonite fauna (Howarth, 1957), some of which show evidence of predation (Ensom, 1985a). Beneath Golden Cap the Eype Nodule Bed is overlain by a bed of blue-grey calcareous sandstone up to almost 1 m thick which, in places, incorporates some of the nodules into its base. The fauna of this sandstone includes bivalves, brachiopods, gastropods, ammonites and a montlivaltiid coral. Eastwards from there the sandstone pinches out and the nodules show the development of pyritic rims and clear evidence of reworking by burrowing organisms. Near Eype Mouth the nodules were exhumed and colonized by a diverse range of encrusting organisms before being re-buried (Ensom, 1985b; Hesselbo and Jenkyns, 1995).

Near the top of the Eype Clay Member is Day's Shell Bed, an indurated shelly and crinoidal mudstone less than 0.3 m thick with occasional small calcareous nodules. It has yielded an abundant and diverse benthic fauna together with ammonites and belemnites, described by Palmer (1966), many of which are immature individuals.

About 1 m above Day's Shell Bed a conspicuous fine-grained sandstone, the Starfish Bed, marks the base of the Down Cliff Sand Member. The Starfish Bed is a composite unit about 1 m thick that comprises several distinct beds, each of which has a sharp base succeeded by planar-laminated sands. The sands are locally rippled or show hummocky cross-stratification, and become increasingly bioturbated upwards. The ophiuroids, from which the Starfish Bed gets its name, are confined to the sole of the lowermost of these units (Goldring and Stephenson, 1972). Most are immature individuals of *Palaeocoma milleri*, with a second species referred to by Hess (1960) as *Ophioderma tenuibrachiata*. Scattered remains of the crinoid *Balanocrinus gracilis* also occur together with rare examples of the asteroid *Tropidaster pectinatus*. Ensom (1988) recorded siltstone dykes in fallen blocks of the Starfish Bed near Eype Mouth, though not on Thorncombe Beacon farther to the west. The Down Cliff Sand Member consists mainly of grey-brown sandy mudstones, becoming more sandy towards the top. It contains many indurated lenticles (Howarth, 1957), some of which contain abundant superbly preserved examples of *Balanocrinus gracilis* and *Palaeocoma milleri* (Simms, 1989), together with rarer examples of the ophiuroid *Hemieuryale lunaris* and the asteroids *Tropidaster pectinatus*, *Archastropecten* and *Solaster* (C. Moore, pers. comm.). Sellwood *et al.* (1970) noted abundant trace fossils and the presence, locally, of load structures on the sole of some beds. Wilson *et al* (1958) cited a thickness of about 30 m for the Down Cliff Sand Member below Thorncombe Beacon, thinning eastwards to about 22 m near Eype Mouth. The Margaritatus Stone, a 0.3 m-thick bluish fossiliferous sandy limestone, is the only conspicuous marker band within the member and defines its top, although Wilson *et al.* (1958) noted several other minor marker horizons within the member. The ammonite fauna shows this bed to correspond to the base of the Subnodosus Subzone. Sellwood *et al.* (1970) described the Margaritatus Stone as a complex conglomeratic bed with angular sandstone blocks up to 0.6 m long as well as rolled and bored bioclasts and lithoclasts.

The Margaritatus Stone is succeeded by the Thorncombe Sand Member. This is mostly more yellow-weathering and homogeneous than the Down Cliff Sand Member, and contains conspicuous cemented 'doggers', up to 2 m thick and 3 m across at several levels, together with a 0.3 m-thick sandy limestone about mid-way up the succession. The sands frequently exhibit bioturbated units interbedded with hummocky cross-stratification (Sellwood *et al.*, 1970). The basal 2 m of the member is a blue-grey mudstone, termed the 'Blue Band' or 'Margaritatus Clay'. The top 2.3 m of the member also is of grey mudstone. This is overlain by the Thorncombiensis Bed, a 0.36 m-thick bipartite unit of highly bioclastic limestone and calcareous mudstone that yields an ammonite assemblage indicative of the Gibbosus Subzone. Fossils, notably amaltheid ammonites (Howarth, 1957), rhynchonellid brachiopods (Ager, 1956–1967) and crinoids (Simms, 1989), are locally abundant. Lord (1974) recorded some 40 species of ostracod from from the clays and silts of the Margaritatus Zone, with species of *Ogmoconcha* particularly abundant.

The base of the Beacon Limestone Formation (= Junction Bed *sensu lato* of earlier authors) rests on an erosion surface at the top of the Thorncombe Sand Member. At West Cliff the Thorncombiensis Bed and overlying clays are absent and the Beacon Limestone Formation contains large blocks of Thorncombiensis Bed at its base (Howarth, 1957). The Beacon Limestone Formation is exposed only in the cliffs between Seatown and West Cliff and is rarely accessible *in situ*; its type locality is on Thorncombe Beacon (SY 4354 9148). Detailed accounts of the Beacon Limestone Formation were published by Jackson (1922, 1926), Jenkyns and Senior (1991) and Howarth (1992), with descriptions of some inland sections by Walker (1892). The formation reaches a maximum thickness of 3.65 m adjacent to the Eypemouth Fault but thins rapidly westwards and typically is less than 1 m thick. It contains a diverse ammonite fauna, mainly of amaltheids and hildoceratids, which establishes the presence of the full sequence of seven successive ammonite zones, and many of the subzones, from the Spinatum Zone to the Dispansum Zone; on the Yorkshire coast this interval is represented by almost 130 m of strata. At the base of the Beacon Limestone Formation is the Marlstone Rock Member, a brown or pink, conglomeratic limestone with abundant berthierine and goethite ooliths, and containing a diverse fauna including ammonites (Howarth, 1957, 1980), brachiopods (Ager, 1956–1967, 1990), bivalves and other invertebrates (Jackson, 1926). There is a conspicuous planar hard-ground surface between the Marlstone Rock Member and the overlying Eype Mouth Limestone Member (= Junction Bed *sensu stricto* of earlier authors). The basal bed of the Eype Mouth Limestone Member comprises pink to buff stromatolitic calcilutites, containing ammonites indicative of the Serpentinum Zone, overlain by pale conglomeratic limestones containing ammonites indicative of the Bifrons to Dispansum zones. Planar erosional hiatuses occur at several levels and are often conspicuously marked by planed-off ammonites and other fossils. Pebble beds and worn and broken ammonites also occur at some levels. The Eype Mouth Limestone Member is traversed by numerous fissures, mostly sub-parallel to bedding but with some at an angle to it (Jenkyns and Senior, 1991). These are filled with pale calcilutites, sometimes cross-bedded, which contain ammonites younger than the enclosing sediments. Both the matrix sediments and fissure fills have yielded a moderately diverse benthic fauna alongside the rich ammonite assemblages. Certain elements of the fauna within this member here are unique to the British Lias. These include several species of ammonite (Howarth, 1992) and brachiopod (Ager, 1956–1967) of Tethyan affinities, and the crinoid *Plicatocrinus inornatus*, which occurs as profuse disarticulated ossicles in vertical fissures close to the Eypemouth Fault (Simms, 1989).

The Eype Mouth Limestone Member is overlain by the Down Cliff Clay Member of the Bridport Sand Formation (Figure 2.11). The latter member comprises silty clays that pass up into sandy siltstones with cemented horizons. The Down Cliff Clay Member reaches a maximum thickness of 21 m in the Bridport area, but thins rapidly away from there and is less than 11 m thick at East Cliff. It is succeeded by the main part of the Bridport Sand Formation, magnificently exposed in the sheer cliffs between West Bay and Burton Bradstock, the type section of the formation being at East Cliff (Figure 2.13) and Burton Cliff (the latter is a Middle Jurassic GCR site, see Cox and Sumbler, 2002). Its thickness is fairly constant, at a little over 40 m, between West Bay and Burton Bradstock. Farther west, on Thorncombe Beacon, less than half of the formation, extending up to about Bed 10 of Hesselbo and Jenkyns (1995), is preserved beneath the Cretaceous overstep yet there is a 140% expansion in thickness relative to the same succession to the east.

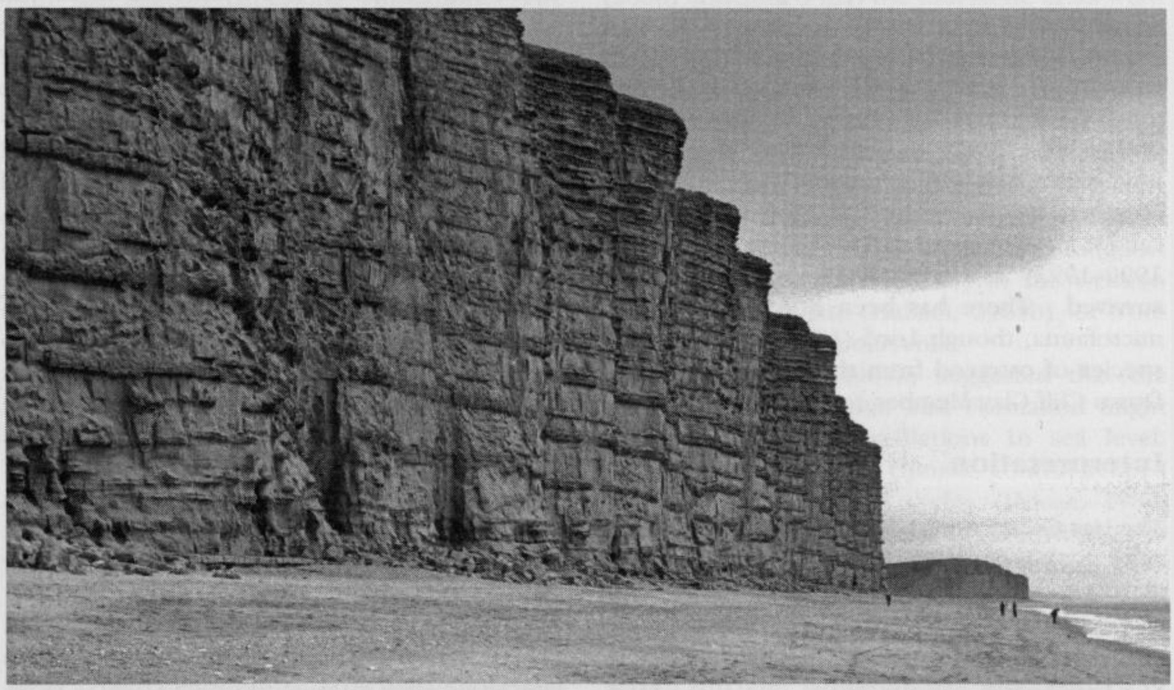

Figure 2.13 The Bridport Sand Formation at East Cliff, west of Burton Bradstock. (Photo: M.J. Simms.)

There is a progressive increase in grain size from the silty clays of the Down Cliff Clay Member, through siltstones to fine sand about the middle of the Bridport Sand Formation and then a decrease again towards the top (Hesselbo and Jenkyns, 1995). This grain-size pattern is roughly coincident with an increase, and then decrease, in bed spacing upwards through the succession. Calcite-cemented bands and 'doggers' are a conspicuous feature of weathered exposures of the Bridport Sand Formation (Figure 2.13). Sellwood *et al.* (1970) noted that detrital mica grains are crumpled in the softer bands but remain undistorted in the cemented units, indicating pre-compactional cementation. Intense bioturbation has destroyed most non-biogenic sedimentary structures, although small-scale scours occur sporadically in the lower part of the formation (Davies, 1967, 1969; Hounslow, 1987). Near the base of the Bridport Sand Formation both on East Cliff and on Thorncombe Beacon there is a series of conspicuous undulating cemented bands, with a wavelength of about 20 m and amplitude of about 3 m, that have been described by Hesselbo and Jenkyns (1995) and Pickering (1995). The top of the Bridport Sand Formation is marked by a hardground that is locally overlain by a thin iron-stained clay seam, immediately beneath the Scissum Bed at the base of the Inferior Oolite Group.

Identifiable fossil material is generally sparse in the Bridport Sand Formation except in the uppermost beds, which are packed with ammonites and other fossils. Buckman (1910) and Jackson (1926) recorded impressions of the ammonite *Dumortieria* in the Down Cliff Clay Member, but generally only the more robust calcitic fossil material such as belemnites (Doyle, 1990–1992) and crinoids (Simms, 1989) have survived. There has been little work on the microfauna, though Lord (1974) recovered ten species of ostracod from the lower part of the Down Cliff Clay Member.

Interpretation

The Lias Group on the Dorset coast has been the subject of intense collecting and research for at least two centuries. An outline of the ammonite sequence was already well-established by the time Lang and his co-authors (1914 to 1936) described the stratigraphy in this area. Subsequent stratigraphical work has served to refine the earlier stratigraphical schemes and define the position of the biostratigraphical and lithostratigraphical boundaries.

The base of the Lias Group and of the Blue Lias Formation was placed by Lang (1924) at the base of a conspicuous paper shale (Bed H1), which rests on an erosion surface at the top of the limestones of the Langport Member (formerly White Lias) of the Penarth Group (Wignall, 2001). This boundary was formerly taken to mark the base of the Jurassic System, but this is now defined by the first appearance of the ammonite *Psiloceras*, which at Pinhay Bay occurs in Lang's Bed H25 (Cope *et al.*, 1980a).

The junction of the Blue Lias Formation and the overlying Charmouth Mudstone Formation was originally placed by Lang (1924; Lang *et al.*, 1923) at Table Ledge (Bed 53). However, this boundary is well above the onset of mudstone-dominated deposition and accordingly it is now placed at an erosion surface at the top of Grey Ledge (Bed 49), which marks the upper limit of closely spaced limestones in the type section. The junction between the Shales-with-Beef and the Black Ven Marl members is taken at the base of the Birchi Tabular (Bed 76a) at an upward change from predominantly organic-rich to carbonate-rich mudstones. A significant boundary, and hiatus representing at least three ammonite subzones, lies within the Black Ven Marls of Lang and Spath (1926) at about the level of the Coinstone (Bed 89). Although the dark-grey mudstones above the hiatus resemble those below, they lack the large diagenetic limestone nodules and are much richer in pyritized ammonites. This same facies can be recognized elsewhere in the Wessex Basin and in the Severn Basin, and at its maximum development spans the Oxynotum and Raricostatum zones. Accordingly Page (pers. comm.) has proposed that the Black Ven Marl Member be emended to include only the lower part of the succession beneath the Coinstone, with the pyritic ammonite-rich mudstones above being re-named as the 'Stonebarrow Pyritic Member'.

The position of the Sinemurian–Pliensbachian boundary has been the subject of some debate. Lang *et al.* (1928) placed the boundary below the upper part of Hummocky (Bed 103b) but, based on later discoveries, Cope *et al.* (1980a) placed it at the base of the Apoderoceras Limestone (Bed 105), as did Page (1992). However, Hesselbo and Jenkyns (1995) maintained that Hummocky and the clays above Hummocky (beds 103 and 104) accumulated during extensive reworking of Raricostatum Zone sediments in earliest Pliensbachian times and hence the boundary should be drawn at the base of Hummocky (below Bed 103a). The boundary between the Belemnite Marl and Green Ammonite Mudstone members is clearly defined, both lithostratigraphically and biostratigraphically, by the top of the Belemnite Stone, which is coincident with the Ibex–Davoei zonal boundary.

The junction between the Charmouth Mudstone Formation, and hence also the Green Ammonite Mudstone Member, and the succeeding Dyrham Formation is placed immediately below the lowest of the Three Tiers at the base of the Eype Clay Member, one of three members within the formation. This is not quite coincident with the base of the Upper Pliensbachian Substage, which is marked by the first appearance of amaltheid ammonites about 3 m below the top of the Charmouth Mudstone Formation. The base of the Down Cliff Sand Member is drawn at the base of the Starfish Bed, with the base of the Thorncombe Sand Member placed at the top of the Margaritatus Stone. An erosion-surface contact with the highly condensed Marlstone Rock Member marks the junction of the Dyrham Formation with the Beacon Limestone Formation. The Marlstone Rock Member has yielded ammonites indicating both subzones of the Spinatum Zone and all but the Clevelandicum Subzone of the Tenuicostatum Zone (Howarth, 1980). The vertical extent of pale, fine-grained limestones of the overlying Eype Mouth Limestone Member clearly define its boundaries. The member is highly condensed and incorporates representatives of nearly all of the Toarcian zones and subzones. Howarth (1980) noted that there was no evidence for the presence of the lower part of the Exaratum Subzone. However, the presence of ammonites in the neptunian fissures caused considerable difficulties of interpretation for some of the earlier accounts (Buckman, 1922; Jackson, 1922, 1926) and was not satisfactorily resolved until the work of Jenkyns and Senior (1977, 1991). The base of the overlying Bridport Sand Formation is clearly drawn above the topmost limestone bed of the Beacon Limestone Formation and, although more than ten times as thick as the latter formation, it represents only the uppermost two ammonite zones of the Toarcian Stage. A distinct hiatus marks the boundary with the succeeding Middle Jurassic succession.

There has been considerable discussion concerning the primary or secondary (diagenetic) nature of some of the conspicuously rhythmic sequences developed in the Lias Group of Dorset. Richardson (in Lang *et al.*, 1923) proposed a secondary origin for both the Blue Lias Formation limestones and the limestone nodules higher in the succession. Hallam (1957) and Simpson (1957) described evidence, particularly from trace fossils, for an essentially primary origin for the limestones although subsequently Hallam (1960a, 1964a) conceded that many of the limestones in the Blue Lias Formation were accentuated to some degree by diagenetic segregation. More recently Hallam (1986) proposed that many may have formed solely through rhythmic unmixing of calcium carbonate during diagenesis. Bottrell and Raiswell (1989) concluded from a study of pyrite abundance and sulphur-isotope composition that the limestone–mudstone rhythms reflected primary differences in the carbonate content of the sediment, which subsequently exerted a direct effect on the diagenetic accentuation of the carbonate-rich units. They noted that diagenetic cementation would be enhanced by a hiatus in sedimentation. Moghadam and Paul (2000) concluded that the limestone units were entirely diagenetic, but that the rhythmicity evident in the Blue Lias Formation reflected primary differences in the sediment rather than the effects of diagenetic unmixing. Hesselbo and Jenkyns (1995) have suggested that a few of the limestones, notably beds H4 and H30, may have been deposited from submarine mudflows, analogous to those seen in the Langport Member (formerly White Lias) at the western end of the GCR site (Hallam, 1960b), or from low-density turbidity currents.

Hallam (1960a, 1964a) suggested that the rhythmicity in the Blue Lias Formation might reflect epeirogenic oscillations in sea level. Others have suggested climatic control related to Milankovitch orbital cycles (House, 1985; Weedon, 1986, 1987; Smith, 1989; Weedon *et al.*, 1999). Waterhouse (1999) described palynofacies cycles in the Blue Lias Formation that appear independent of lithology and which may also be linked to Milankovitch cycles. Cole and Harding (1998) found a close correspondence between palynofacies cycles and transgressive–

regressive sequence boundaries in the Charmouth Mudstone Formation. Bessa and Hesselbo (1997) noted cyclicity in their gamma-ray log for the Belemnite Marl Member reflecting variable calcium carbonate contents through the succession. Supposed Milankovitch cyclicity has also been described from beds 110 to 117 (Polymorphus to Jamesoni subzones) in the Belemnite Marl Member (Weedon and Jenkyns, 1990, 1999). Bioturbation and changes in the body-fossil and trace-fossil assemblages in parallel with the light–dark couplets indicate a primary origin for these cycles, which they considered had experienced less diagenetic modification than the Blue Lias Formation. Weedon and Jenkyns (1990, 1999) identified at least two scales of cycle that they they interpreted as a 20 ka precession cycle and more irregular, larger amplitude, climatic variations. Van Buchem and McCave (1989) documented a strikingly similar succession of light–dark sediment couplets in the Banded Shales, also spanning the Polymorphus to Jamesoni subzones, of the Redcar Mudstone Formation at Robin Hood's Bay. They too suggested a periodicity of 20 ka for each couplet. House (1986) has identified analogous rhythms elsewhere in the Lias succession, specifically in the Shales-with-Beef Member and Bridport Sand Formation. In both cases there is evidence for at least some diagenetic accentuation of the cyclicity. Hesselbo and Jenkyns (1995) also identified small-scale, coarsening-upward cycles in the Bridport Sand Formation. Diagenetically cemented bands within this formation also display a conspicuous rhythmicity but Davies (1967) suggested that the cementation reflected primary differences in the detrital carbonate content of the sediments.

Evidence for a diagenetic origin is clearer for many of the limestones in the Shales-with-Beef and Black Ven Marl members, most of which are discontinuous and nodular. Many are laminated or have a septarian structure, and the frequent presence of beautifully preserved uncrushed ammonites indicates nodule formation at shallow burial depth before compaction. Raiswell (1971) considered that the Birchi Nodules (Bed 75) (Figure 2.7) may have developed during a pause in deposition, with porosity estimates, strontium isotopes and mineralogy indicating growth in a geochemical system partially open to the sea. Hesselbo and Palmer (1992) have described the sequence of events in diagenetic nodule formation. In the Lias within the GCR section this reached its acme in the Coinstone (Bed 89) and associated nodule horizons that experienced burial, exhumation and re-burial over the duration of at least three ammonite subzones. Their observations indicate that initial fracturing during septaria formation occurred not in a hard, brittle material, such as the nodules present today, but in a more plastic medium perhaps analogous to cheese.

The development of early diagenetic limestone nodules in the Shales-with-Beef and Black Ven Marl members contrasts with their scarcity in the Stonebarrow Pyritic Member. Conversely, although pyrite is common in all three members it is only in the Stonebarrow Pyritic Member that it commonly occurs as uncrushed pyritic moulds of ammonites and other fossils, indicating early diagenetic formation. In the Shales-with-Beef and Black Ven Marl members it more typically occurs as nodules and encrustations of already crushed ammonites, indicating formation later in diagenesis. Both pyrite and early diagenetic carbonate nodules form in the sulphate reduction zone but differences in the development of these in the mudstones above and below the Coinstone hiatus may reflect differences in sedimentation rates and probably in benthic oxygen levels. Precipitation of pyrite is inhibited by rapid burial of organic-rich sediment, since this allows insufficient time for the necessary downward diffusion of sulphate (Curtis, 1995). Downward diffusion rates of sulphate will also be slowed significantly by the exclusion of burrowing benthos, which is a consequence of benthic anoxia, since burrows provide potential diffusion routes for sulphate ions. Consequently, pyritization of fossil material in the Shales-with-Beef and Black Ven Marl members tends to occur at a relatively late stage, after the fossils have been crushed by sediment compaction. However, benthic anoxia does seem to favour the precipitation of very early diagenetic calcite concretions in which the ammonites are uncrushed; these are a conspicuous feature of many organic-rich mudstone units at this site, particularly in the Shales-with-Beef and Black Ven Marl members, but are also a significant component of organic-rich successions at other GCR sites, notably those in the Toarcian succession on the Yorkshire coast. There are at least two horizons in the Dorset Lias, the Coinstone (Bed 89) of the

Black Ven Marl Member and the Eype Nodule Bed of the Eype Clay Member, where early diagenetic calcite concretions locally have a pyrite skin. In both instances this is associated with a history of burial, exhumation and re-burial, thereby allowing two distinct periods of sulphate reduction to occur at these horizons. Observations made by Hesselbo and Palmer (1992) indicate that this pyritization did not occur during the exhumation phase but was associated with, or shortly preceded, re-burial by the mudstones of the Stonebarrow Pyritic Member. These examples may be analogous to some of the pyrite-skinned carbonate nodules noted in the Jet Rock of the Mulgrave Shale Member on the Yorkshire coast (Hallam, 1962a; Coleman and Raiswell, 1981), such as at the **Staithes to Port Mulgrave** GCR site.

The development of discontinous layers and lenses, or seams, of fibrous calcite, or 'beef', within parts of the Dorset Lias, notably in the Shales-with-Beef Member, has long elicited debate. Richardson (in Lang *et al.*, 1923) recognized that the 'beef' seams post-dated the carbonate nodules and concluded that the 'beef' was deposited by downwardly percolating carbonate solutions into cracks that had opened as a result of the desiccation and contraction of the shales. It is now thought that 'beef' seams form as a result of rapid over-pressuring of organic-rich shales at burial depths of several tens to hundreds of metres, within the methanogenic zone (Marshall, 1982; Stoneley, 1983). On the Dorset coast, about 100 m above the Shales-with-Beef Member lies the base of the Dyrham Formation, of which the lowest 93 m (the Eype Clay and Down Cliff Sand members) was deposited during just one ammonite subzone (Stokesi Subzone) (Figure 2.11). This rapid influx of sediment may have caused the hydrostatic over-pressuring of the organic-rich shales of the Shales-with-Beef and Black Ven Marl members while their high organic content ensured that sufficient carbon survived oxidation in the sulphate-reducing zone to generate carbonate for 'beef' formation during methanogenesis. The absence or poor development of 'beef' in organic-rich successions elsewhere in the British Lias may reflect the unusually high sedimentation rate during the Stokesi Subzone in Dorset, while its poor development in the Blue Lias Formation and other parts of the Charmouth Mudstone Formation reflects generally lower organic-carbon contents.

The Dorset Lias has been important for understanding the varied nature of stratigraphical hiatuses, the processes by which they are formed, and the various techniques by which they can be detected. That associated with the Coinstone (Bed 89) is among the best documented of these. Hesselbo and Palmer (1992) attribute the exhumation of the carbonate nodules in large part to bio-erosion but could not decide whether this event reflected lower sea level or reduced sediment supply. Hallam (1969, 1999) favoured the former and cited the absence of any associated condensed facies as evidence against sediment starvation. Further examples include the hiatus at the top of the Watch Ammonite Stone (Bed 99), the top of Hummocky (Bed 103) (Sellwood, 1972) and, in the Upper Pliensbachian, the Eype Nodule Bed (Ensom, 1985b), the Margaritatus Stone (Sellwood *et al.*, 1970) and others noted by Wilson *et al.* (1958). The Beacon Limestone Formation, encompassing the top of the Pliensbachian Stage and much of the Toarcian Stage, is highly condensed and contains spectacular hiatuses with ammonites and other fossils abruptly truncated along some surfaces (Jackson, 1922, 1926; Jenkyns and Senior, 1977, 1991). Many hiatuses elsewhere in the Lias are less obvious, with no evidence of a major biostratigraphical break or lithological change. They may be indicated by concentrations of obdurate fossils, such as belemnites, or by reworked lithoclasts, or an intensely burrowed horizon. Examples include the erosion hiatus surfaces at Grey Ledge (Bed 49), in the mudstones of Bed 83 (Hesselbo and Jenkyns, 1995), and at the top of the Belemnite Bed (Bed 120c). Jones *et al.* (1994) also found evidence in the strontium isotope record for a hiatus at this last horizon. More tenuously, Smith (1989) suggested, on the basis of correlation of presumed Milankovitch cycles, that there was a hiatus within the Angulata Zone of the Blue Lias Formation on the Dorset coast that is not present in equivalent strata in the Somerset coast section.

The Dorset Lias has contributed a great deal to our understanding of the effects of syn-sedimentary fault movement and its manifestation in the geological record. One example is the westward thinning of the Belemnite Marl Member and the Green Ammonite Mudstone Member away from the Eypemouth Fault. The Bridport Sand Formation has been cited as an exception to this westward thinning, showing a distinct thickening westwards from East Cliff to Thorncombe Beacon (Hesselbo and Jenkyns, 1995). However, this supposed exception does not take into account the fact that different stretches of the coastline are being compared. The sections through the Belemnite Marl and Green Ammonite Mudstone members referred to all lie to the west of the Eypemouth Fault, known to have been active during Early Jurassic times (Jenkyns and Senior, 1977, 1991), whereas the Bridport Sand Formation exposures are located both to east and west of the fault. Hence the apparent westward thickening of the latter formation may reflect thickness differences across the fault rather than being analogous with the eastward thickening of the Belemnite Marl and Green Ammonite Mudstone members. More direct evidence of syn-sedimentary movement comes from the correlation of individual marker bands across specific faults. Various authors (Lang, 1945; Hallam, 1969; Hesselbo and Palmer, 1992) noted that whereas there was a hiatus directly above the Coinstone (Bed 89) on Stonebarrow, the same hiatus occurred more than 1 m above the level of the Coinstone on Black Ven. Similarly, the difficulties of tracing several of the nodule bands in the Obtusum Zone from Black Ven to Stonebarrow, a problem noted by Lang and Spath (1926), may be attributable to erosive removal of the Woodstone (Bed 83f) and Lower Flatstones (Bed 83d) horizons on Stonebarrow. This is suggested by a hiatus surface above the Pavior (Bed 82) at the latter site (Hesselbo and Jenkyns, 1995). Both the Coinstone and Pavior hiatuses may indicate syn-sedimentary movement on the nearby Char Fault.

The Eypemouth Fault at the eastern end of the GCR site has provided some of the most convincing evidence for syn-sedimentary faulting (Jenkyns and Senior, 1977, 1991). As the fault is approached from the west the Eype Mouth Limestone Member thickens dramatically, from less than 0.5 m to as much as 3.5 m over a distance of less than 0.5 km, and is cut by many sediment-filled 'neptunian' sills and dykes. These formed as a result of tectonic stresses associated with fault movements and allowed ammonites and other fossils to become intercalated, out of sequence, into older parts of the succession. Ensom's (1988) observations of siltstone dykes cutting the Starfish Bed near Eype Mouth, and their absence from this same unit farther west, provides further evidence of syn-sedimentary movement on this fault and the extent of its influence on surrounding sediments.

The relationship between syn-sedimentary movement on faults and the development of erosional hiatuses is exemplified by the diachronous nature of the hiatus surface associated with the Eype Nodule Bed. As the Eypemouth Fault is approached from the west the sequence shows an initial incorporation of nodules into the base of the overlying sandstone, then the pinching out of the sandstone and development of pyritic rims on the nodules, and finally evidence of exhumation and encrustation of nodules adjacent to the fault.

There have been few broad-based palaeoenvironmental interpretations of the Lias of Dorset, largely because the mudstone-dominated nature of much of the succession has deterred investigations of this type. Hesselbo and Jenkyns (1998) provide the only general account, describing the succession in terms of sequence stratigraphy and relative sea level. They have interpreted the organic-rich mudstones, such as those of the Shales-with-Beef and Black Ven Marl members, as deposited during periods of sea-level rise or highstand, and the erosional hiatuses associated with the Coinstone and the Hummocky horizons to represent sediment starvation during deepening events. In the Belemnite Marl Member, they attributed the condensed nature of the Belemnite Bed to shallowing, and condensation in the Belemnite Stone to deepening. They concluded that the facies developed at any particular level reflect the interplay of a variety of factors.

Some of the sandier units in the Lias have been specifically discussed and some general observations and interpretations can be made for other parts of the succession or extrapolated from contiguous strata. Goldring and Stephenson (1972) concluded that the exceptional preservation of the ophiuroids in the Starfish Bed at the base of the Down Cliff Sand Member was due to burial by a sudden influx of sand that was thick enough to prevent subsequent disruption of the remains by bioturbation. The load structures reported by Sellwood *et al.* (1970) from other levels in the Down Cliff Sand Member also suggest rapid sedimentation. A similar mechanism can be invoked for the occurrence of most intact echinoderms throughout the Lias Group of

Dorset, including other occurrences of intact crinoids, ophiuroids and asteroids from the Eype Clay Member and intact examples of the echinoid *Miocidaris lobatum* and the ophiuroid *Palaeocoma escheri* from the Blue Lias Formation. In other parts of the sucession the presence of intact multi-element skeletons, such as echinoderms and vertebrates, is due largely to preservation in anoxic or dysaerobic benthic environments. The organic-rich parts of the Shales-with-Beef and Black Ven Marl members are developed in such facies and have proven an important source of well-preserved marine reptiles and fish. Simms (1986) demonstrated that the extraordinary preservation of the crinoid *Pentacrinites fossilis* in the Black Ven Marl Member was also due to benthic anoxia, though current winnowing of the upper surfaces of these specimens demonstrated that conditions were not entirely stagnant and that sedimentation rates were low. Although very low levels of bioturbation sometimes are present in these organic-rich mudstones, benthic bivalve larvae did not generally survive spatfall except during brief periods of more oxygenated conditions that allowed the development of thin shell pavements. In contrast, the pseudoplanktonic *Pentacrinites* was brought in on floating driftwood, which then sank to the anoxic sea floor. Simms (1999) has suggested that a current gyre may have developed across this area for a relatively brief period during the Obtusum Zone, trapping many crinoid-laden floating logs that eventually sank to form a relatively high concentration of specimens through some 2 m of the Black Ven Marl Member.

Dysaerobic benthic conditions appear to have been fairly prevalent in the basal part of the Blue Lias Formation on the Dorset coast, and in other areas such as the north Somerset coast. The fauna has a relatively low diversity dominated by the bivalve *Liostrea hisingeri* and the slender-spined echinoids *Diademopsis* and *Eodiadema*, presumably tolerant of low oxygen levels. The echinoids typically are disarticulated but intact material occurs in some laminated shales, suggesting that benthic oxygen levels periodically dropped still further.

Despite the overwhelming dominance of marine organisms in the Lias at this GCR site, fossil evidence for a nearby landmass is also present. Fossil driftwood occurs sporadically thoughout the Lias Group, but it is particularly abundant in the upper part of the Shales-with-Beef and Black Ven Marl members, where trunks up to nearly 4 m long have been recorded (Macfadyen, 1970). This part of the succession has also yielded a rich fauna of insects, which are otherwise virtually unrepresented in the Dorset Lias, and several specimens of the ornithischian dinosaur *Scelidosaurus*. Whalley (1985) postulated that the preservation of the insects indicated a landmass less than 80 km away, perhaps an extension of the Cornubian Massif to the west (Figure 1.10; Chapter 1), which may have persisted for a few hundred thousand years.

The Bridport Sand Formation has been the subject of several palaeoenvironmental analyses. More than a century ago (Buckman, 1889) showed that the Toarcian sands of south-west England were diachronous and younged to the south. Davies (1969) proposed that the sands represented a large migrating sand-bar while others have suggested deposition in a lower or middle shoreface environment above storm wave-base (Colter and Harvard, 1981; Hounslow, 1987; Bryant *et al.*, 1988). More recently, Pickering (1995) proposed that broadly undulating cemented bands near the base of the Bridport Sand Formation formed as near-symmetrical scours beneath standing waves in shallow water, while Hesselbo and Jenkyns (1995) suggested that they are predominantly aggradational and formed as ridges at the toe of an advancing sand slope. The well-cemented layers have been interpreted as tempestites and have a significantly lower clay content than the uncemented layers. This suggests that their higher permeability allowed earlier cementation of these horizons (Bryant *et al.*, 1988).

The Lias succession in Dorset has long served as a standard against which other Lower Jurassic successions in Britain and farther afield have been compared. The most recent lithostratigraphical comparison was by Hesselbo and Jenkyns (1995), between the Dorset succession and that exposed on the Yorkshire coast. Although some eustatic signals are evident in both basins, they noted a relationship between several of the facies units in the two areas in which a coarser-grained unit in one basin would be represented by a finer-grained one in the other basin and vice versa. Assuming the same sea-level histories for both areas they explained these differences in terms of proximal and distal settings and the role of local tectonics in creating accommodation space for sediment.

Faunal differences between the Dorset Lias and correlative strata in other basins have formed the basis of several palaeobiogeographical studies and established the existence of distinct provinces for several groups of fossils, notably ammonites (Howarth, 1958) and brachiopods (Ager, 1956a).

Conclusions

The Dorset coastline between Pinhay Bay and Fault Corner, and the separate GCR site of East Cliff provides unparalleled and readily accessible exposures through the entire Lower Jurassic succession. The site has been investigated and collected from for more than 200 years and has played an important role in the development of geology as a science and in the sub-disciplines of palaeontology and stratigraphy. As such it has been of fundamental importance in establishing a biostratigraphy for the marine Lower Jurassic Series and has also furnished an impressive diversity of type specimens of both vertebrate and invertebrate fossils. It continues to be of outstanding importance as a source of fossil material. It incorporates lithostratigraphical type sections and has contributed significantly to an understanding of the relative roles of climate, sea-level change, syn-sedimentary faulting and diagenesis on preserved sedimentary sequences. The organic-rich horizons within the succession are oil-source rocks for the richest onshore oil-field in Britain, at Wytch Farm, and hence have been much studied.

CLIFF HILL ROAD SECTION, DORSET (SY 486 892)

Introduction

The cliffs at Burton Bradstock have always afforded magnificant exposures of the Bridport Sand Formation (Figure 2.13) but the upper beds are largely inaccessible there. In the early 1880s a lane cutting was excavated just to the north of Burton Cliff (Figure 2.14) giving easy access to this part of the succession for the first time (Woodward, 1885). This section, the Cliff Hill Road Section GCR site provides an excellent, accessible section through the boundary between the Lower and Middle Jurassic series, with the mainly Toarcian Bridport Sand Formation passing up into the Aalenian and Bajocian Inferior Oolite Group. It provides possibly the best exposure of the late Toarcian Aalensis Zone in Britain.

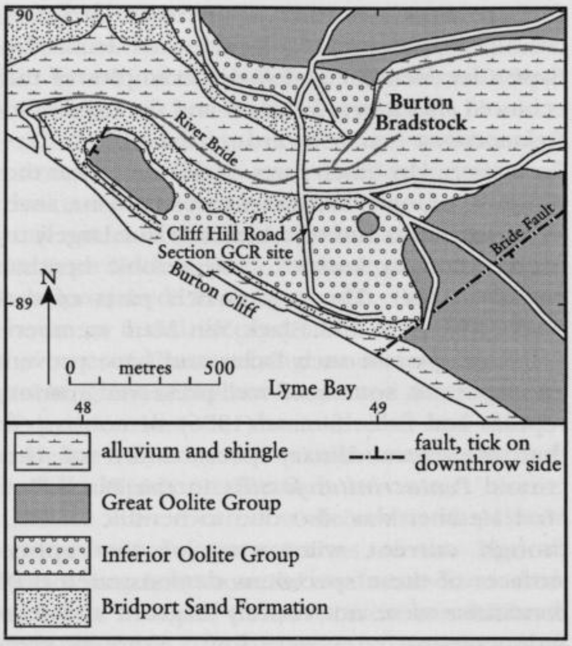

Figure 2.14 Geological map of the Burton Bradstock area showing the location of the Cliff Hill Road Section. After House (1989).

The richly fossiliferous Inferior Oolite Group in this section has always attracted attention, but the underlying Bridport Sand Formation has never been adequately recorded. An unannotated photograph of the section was published by Richardson and Butt (1912, pl. vi), and Richardson (1915) provided a brief account and annotated log of the section. Buckman (1910) published a composite log and annotated sketch section constructed from this site, the cliffs, two quarries and 'even from the walls'. Richardson (1928) mentioned the site again briefly and included an annotated version of the photograph first published by Richardson and Butt (1912), and Arkell (1933) published a simplified version of Richardson's (1915) section. Subsequent brief descriptions include those by Wilson *et al.* (1958), Hemingway *et al.* (1969), and House (1989). Hesselbo and Jenkyns (1995) incorporated data from here into their composite log and description of the Bridport Sand Formation and the section was also described by Callomon and Cope (1995).

Description

More than 3 m of the Bridport Sand Formation is visible beneath about 2 m of the Inferior Oolite Group at the top of the section (Figures 2.15 and 2.16). The lowest part of the succession exposed here (beds 32–36 of Hesselbo and Jenkyns, 1995, fig. 15) comprises yellow, slightly micaceous sands with several layers of burrowed, concretionary, calcite-cemented sandstone. Richardson (1915, fig. 4) described these sandstone concretions as 'crowded with ammonites' that Buckman (1910) and Callomon and Cope (1995) identified as *Pleydellia aalensis*, indicative of the Aalensis Zone. This is overlain by a fairly continuous bed of cemented sandstone 0.2 m thick (Bed 37) with *P. aalensis*, which is overlain by 0.6 m of poorly cemented sand (Bed 38) from which no ammonites have been obtained. This latter unit is intensely burrowed, with the burrows infilled by more cemented sand from the overlying basal bed of the Inferior Oolite Group (Bed 4 of Callomon and Cope, 1995) (Richardson, 1915), with which it has an undulating contact (Callomon and Cope, 1995). Richardson (1915) noted that the overlying fine sandstone was in two distinct layers, although it was assigned a single bed number (Bed 39) by Hesselbo and Jenkyns (1995). Callomon and Cope (1995) divided it into a more weakly calcareous lower unit (Bed 4a) about 0.2 m thick, and a more strongly calcareous and burrowed upper unit (Bed 4b) 0.25 m thick with local accumulations of *Leioceras opalinum* near the top and rare *Tmetoceras scissum* and *Pachylytoceras torulosum*, together indicative of the Opalinum Zone at the base of the Aalenian Stage. Above this bipartite sandstone lies the most conspicuous unit, the Rusty (or Foxy) Bed (Bed 5 of

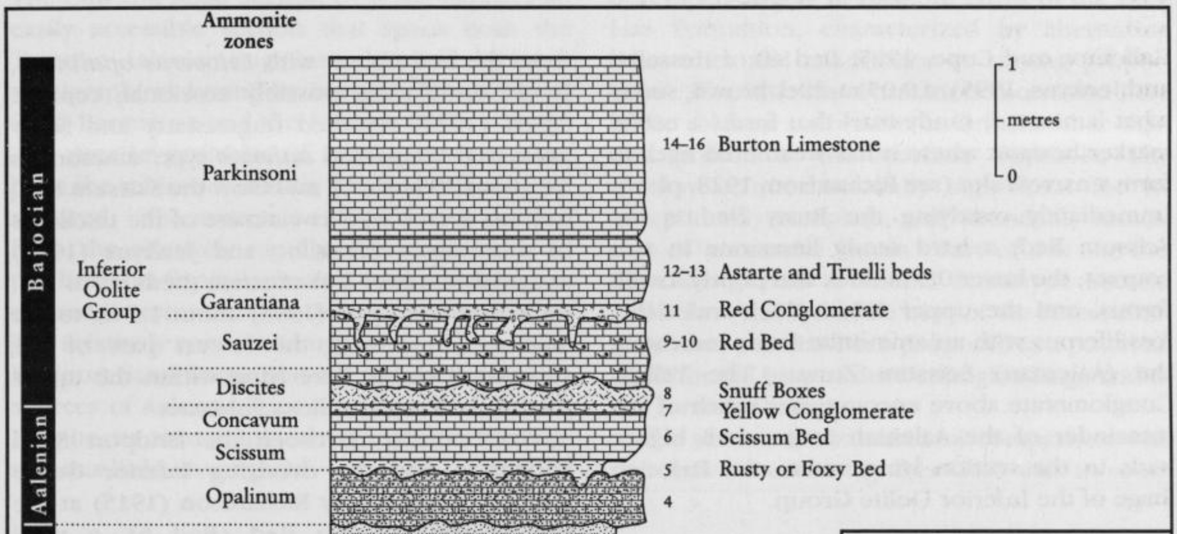

Figure 2.15 The section through the Lower–Middle Jurassic boundary exposed at the northern end of Cliff Hill Road Section, Burton Bradstock. After Hesselbo and Jenkyns (1995); with bed numbers for the Inferior Oolite Group from Callomon and Cope (1995).

Figure 2.16 The eastern side of Cliff Hill Road, looking north. The continous hard band just below the vegetation is Bed 37. (Photo: M.J. Simms.)

Callomon and Cope, 1995; Bed 40 of Hesselbo and Jenkyns, 1995), a 0.05 m-thick brown, somewhat laminated, sandy marl that forms a useful marker horizon where it has weathered back to form a narrow slot (see Richardson, 1928, pl. vi). Immediately overlying the Rusty Bed is the Scissum Bed, a hard sandy limestone in two courses; the lower 0.3 m thick and poorly fossiliferous, and the upper 0.2 m thick and richly fossiliferous with an ammonite fauna indicating the (Aalenian) Scissum Zone. The Yellow Conglomerate above encompasses much of the remainder of the Aalenian Stage, with higher beds in the section lying within the Bajocian Stage of the Inferior Oolite Group.

Interpretation

The accessibility of the highest part of the Bridport Sand Formation at this site has enabled the stratigraphy and facies of this critical part of the succession to be interpreted. The presence of the highest recorded *Pleydellia aalensis* at least 0.6 m below the lowest recorded *Leioceras opalinum* indicates the approximate position of the Toarcian–Aalenian boundary. Callomon and Cope (1995) and Hesselbo and Jenkyns (1995) included the highest unfossiliferous bed of the Bridport Sand Formation within the Aalensis Zone; this appears to represent a continuation of the facies beneath but is sharply demarcated from the bed above, with *Leioceras opalinum*, by an undulating, possibly erosional, contact. Arkell (1933) reported fragmentary and badly preserved '*Pleydellia aalensis* type' ammonites for about 25 feet (7.7 m) below the Scissum Bed, but this seems an over-estimate of the thickness of this zone. Hesselbo and Jenkyns (1995) assigned just over 2 m of strata (beds 35 to 38), Callomon and Cope (1995) about 1.5 m, to the Aalensis Zone with the lowest part of the succession visible here lying within the upper part of the Pseudoradiosa Subzone.

The boundary between the Bridport Sand Formation and the overlying Inferior Oolite Group was placed by Richardson (1915) at the top of the Scissum Bed (Bed 6), a view maintained by Arkell (1933). Parsons (in Cope *et al.*, 1980b) placed it at the base of the 'Scissum Beds' (?Bed 6), Hesselbo and Jenkyns (1995) placed it at the base of the Rusty Bed (Bed 5) while Callomon and Cope (1995) placed it at the base of Bed 4. The most recent revision of Lower Jurassic lithostratigraphy (Cox, *et al.*, 1999) followed Parsons (in Cope *et al.*, 1980b) and placed the top of the Bridport Sand Formation at the base of the Scissum Bed (Bed 6).

The highest part of the Bridport Sand Formation represents a transition between two contrasting depositional regimes. The bulk of the formation, which can be assigned to the

Pseudoradiosa Subzone alone, indicates rapid sedimentation. In contrast the Inferior Oolite Group consists of a condensed sequence of limestones separated by hiatuses and siliciclastic units. Indeed the entire Aalenian and Bajocian interval within this group is contained in less than 6 m of rock. The Aalensis Zone at the top of the Toarcian succession, and accessible at this site, is represented by only 2 m of intensely burrowed sand that is significantly more fossiliferous than the lower part of the formation. The greatly reduced thickness by comparison with the Pseudoradiosa Subzone below indicates that deposition rates slowed abruptly in this transition between the Bridport Sand Formation and the succeeding Inferior Oolite Group, perhaps reflecting sediment starvation as the sand supply was cut off.

Conclusions

The Cliff Hill Road Section GCR site exposes an easily accessible section that spans both the Toarcian–Aalenian stage boundary and the lithostratigraphical boundary between the Bridport Sand Formation and the Inferior Oolite Group. The precise positions of both boundaries has been the subject of debate, which is still not fully resolved. The succession displays a transition from the relatively rapidly deposited sands of the Bridport Sand Formation to the highly condensed limestones of the Inferior Oolite Group. The relatively condensed uppermost beds of the Bridport Sand Formation are one of the richest sources of Aalensis Zone ammonites in Britain. Despite its stratigraphical importance, the site remains little investigated.

BLUE ANCHOR–LILSTOCK COAST, SOMERSET (ST 033 436–ST 194 461)

Introduction

The Blue Anchor–Lilstock Coast GCR site stretches through almost continuous cliffs for 20 km along the coast between the eastern end of Blue Anchor Bay (ST 033 436) and Lilstock (ST 194 461) (Figure 2.17). The cliffs expose a section of between 160 m and 200 m of Lower Lias, which rests conformably on the Penarth Group (Upper Triassic). The succession is complicated by numerous faults, that repeat parts of the section, but the presence of distinctive marker bands allows correlation between fault blocks.

The series of sections provides an almost unbroken succession from the Penarth Group, through the Hettangian Stage and into the Lower Sinemurian Substage (Figure 2.18). It is developed largely in offshore facies of the Blue Lias Formation, characterized by alternating limestones and mudstones in varying proportions. The Blue Lias Formation succession here is the thickest succession in Britain other than that proven in the Mochras Borehole. The section is internationally significant for its exceptionally complete, and abundant, succession of ammonite faunas. Part of this site has been designated as Global Stratotype Section and Point (GSSP) for the base of the Sinemurian Stage, and part has been proposed as a potential GSSP for the base of the Hettangian Stage and of the Jurassic System.

The section is invaluable for comparison with correlative sections at other GCR sites in south

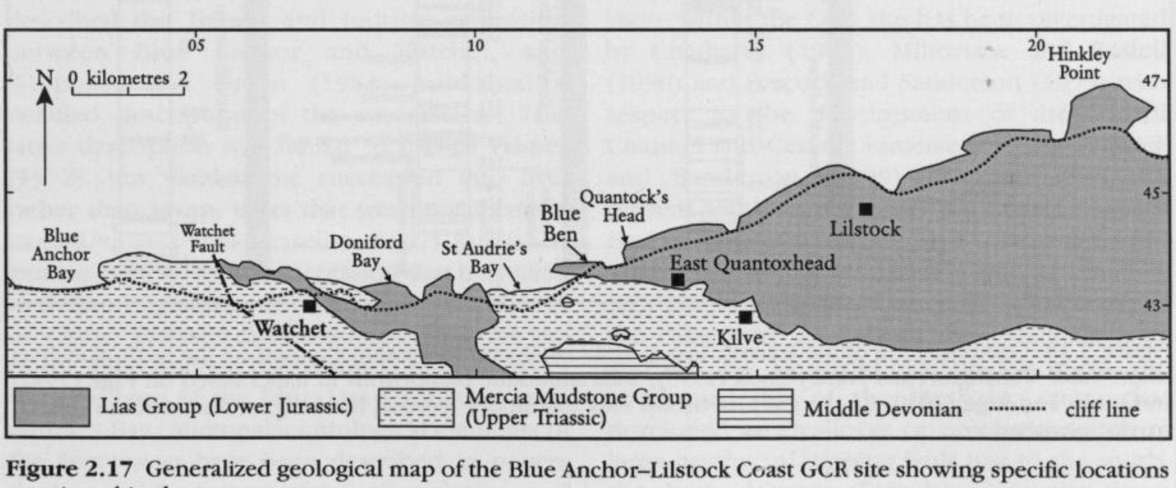

Figure 2.17 Generalized geological map of the Blue Anchor–Lilstock Coast GCR site showing specific locations mentioned in the text.

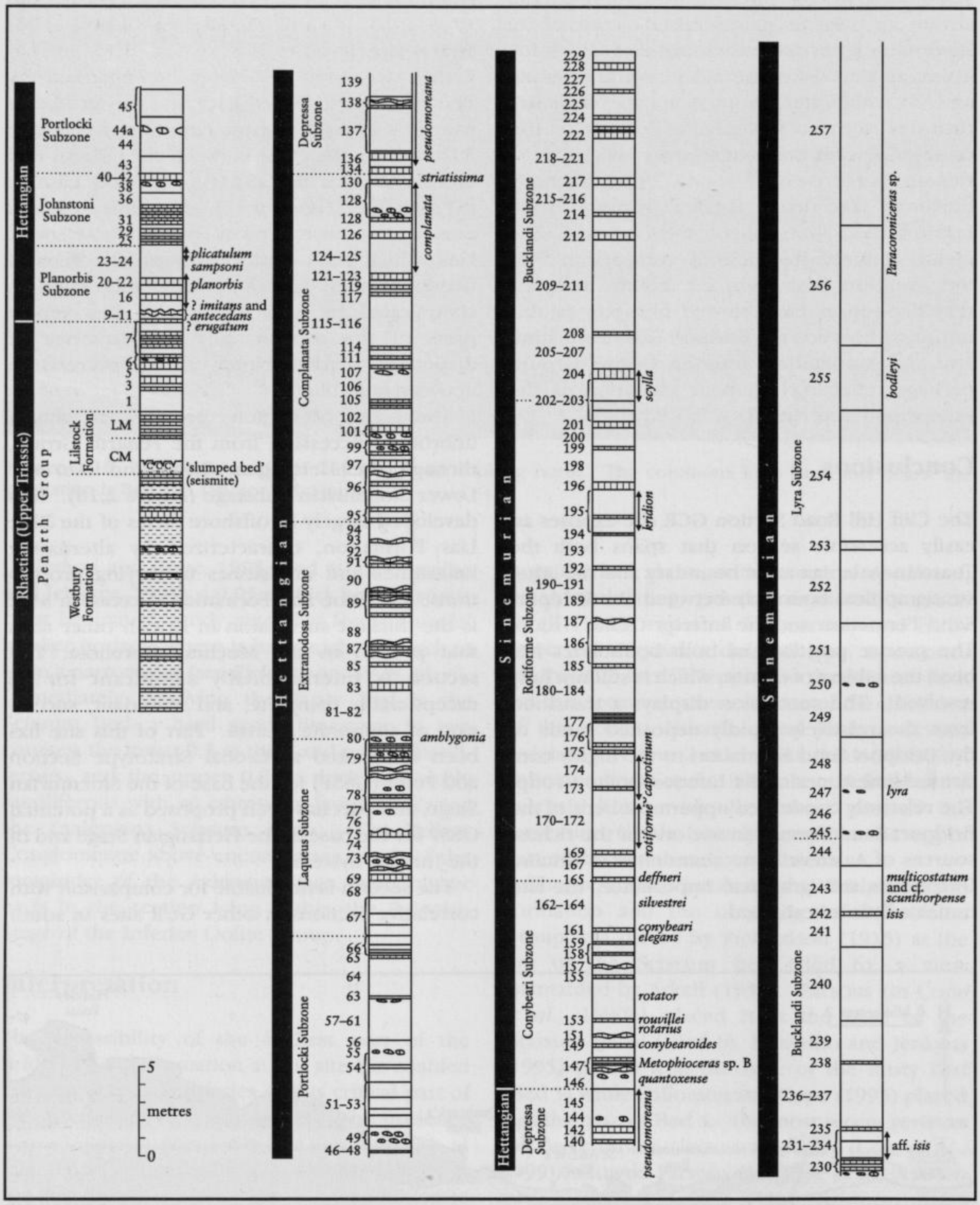

Figure 2.18 Composite log of the Penarth Group and Lias Group succession exposed on the north Somerset coast. After Warrington and Ivimey-Cook (1995); with ammonite biohorizons in italics based on Page (1992) and Bloos and Page (2000a,b). In the Lias Group only limestones (vertical hatching) and mudstones (blank) are distinguished.

Wales and those on the Dorset–Devon coast. The Blue Anchor–Lilstock Coast section has the advantage over these other sites in that the succession is substantially expanded, recording a virtually unbroken period of sedimentation, and fault-repetition of parts of the sequence provides access to greater volumes of any particular stratigraphical horizon than is possible at the other sites.

Horner (1816) was the first to refer to the Lias of the Somerset coast, but he considered that the numerous faults prevented accurate measurement of the succession. Furthermore, the faulting led him to believe that the red marls of the Mercia Mudstone Group (Upper Triassic) were interbedded with the Lias. A series of later papers (Dawkins, 1864; Etheridge, 1872; Bristow and Etheridge, 1873; Richardson, 1911) concentrated largely on the Penarth Group, with little more than passing mention of any parts of the succeeding Lias. Woodward (1893) was the first to provide a detailed account of the Lias, although he greatly under-estimated its thickness at about 50 m. He subdivided the Lias into five units and was the first to recognize that the Blue Lias Formation facies, of alternating limestones and mudstones, was interrupted by two thick mudstone developments. Later accounts by Arkell (1933) and Macfadyen (1970) were based largely on that of Woodward (1893) and it was to be almost 80 years before the first detailed stratigraphical description was published, by Palmer (1972). He established correlations between fault blocks and recognized seven major units. Each of these was assigned a formal name and accompanied by bed-by-bed descriptions of lithology and fauna.

Hamilton and Whittaker (1977) briefly described the Triassic and Jurassic succession between Blue Anchor and Watchet, and Whittaker and Green (1983) published a detailed description of the succession. This latter description was similar to that of Palmer (1972), but divided the succession into five, rather than seven, units that were not formally named. Bessa and Hesselbo (1997) published gamma-ray logs for the succession that they used to define 10 gamma-ray units, while Hesselbo *et al.* (2002) analysed carbon isotopes from the top of the Blue Anchor Formation (Upper Triassic) into the base of the Blue Lias Formation at St Audrie's Bay. Micropalaeontological elements of the succession have been described in papers dealing with foraminifera (Copestake and Johnson, 1989; Hylton, 1998), ostracods (Lord and Boomer, 1990), palynomorphs (Warrington, 1983, 1985; Warrington and Ivimey-Cook, 1990) and coccoliths (Hamilton, 1982). The reptilian vertebrate fauna has been summarized by Benton and Spencer (1995). Invertebrate macrofossils, other than ammonites, have been little investigated.

The ammonite faunas have formed the primary focus of attention on account of their biostratigraphical value (Ivimey-Cook and Donovan, 1983). Watchet is the type locality for the ammonite *Psiloceras planorbis*, the index species for the basal zone and subzone of the Jurassic System. Consequently Watchet and, more recently, St Audrie's Bay (Figure 2.19) have been proposed as stratotypes for the Triassic–Jurassic boundary, with the precise horizon being defined on the basis of lithostratigraphy (Whittaker, 1978; Hallam, 1990b,c), geochemistry (Hesselbo *et al.*, 2002) or biostratigraphy, in particular the first appearance of *Psiloceras*, including *P. planorbis* (Cope *et al.*, 1980a; Cope, 1990; Hodges, 1994; Page, 1994a; Page *et al.*, 1994; Warrington *et al.*, 1994; Bloos, 1997; Page and Bloos, 1998; Bloos and Page, 2000b). The Sinemurian part of the succession is of considerable importance for its ammonite faunas and has furnished data crucial to the establishment of a number of ammonite-correlated horizons within the Lower Sinemurian Substage (Page, 1992). A section at East Quantoxhead, some 4 km west of Lilstock, has been designated as the Global Stratotype Section and Point (GSSP) for the Hettangian–Sinemurian boundary (Figure 2.20) (Page, 1994b,c; Bloos and Page, 2000a, 2002; Page *et al.*, 2000).

The faulting exposed in the cliffs and foreshore within the GCR site has been investigated by Chadwick (1986), Miliorizos and Ruffell (1998) and Peacock and Sanderson (1999) with respect to the development of the Bristol Channel and Central Somerset basins. Peacock and Sanderson (1999) proposed that the present southern margin of the Bristol Channel Basin is bounded by the North Quantocks Fault, with a downthrow of at least 1 km. As evidence they cited the striking change in relief between the Palaeozoic uplands of the Quantock Hills and the low Mesozoic plain to the north, the southward dip of the Mesozoic strata that developed as a rollover or reverse drag into a large northward-dipping fault just to the south, the high density of faulting on the coast

Figure 2.19 The basal Lias Group and candidate Global Stratotype Section and Point (GSSP) for the base of the Hettangian Stage and Jurassic System at St Audrie's Bay, Somerset. The lowest level at which *Psiloceras* has been found is in Bed 8, visible immediately above the person's head. (Photo: M.J. Simms.)

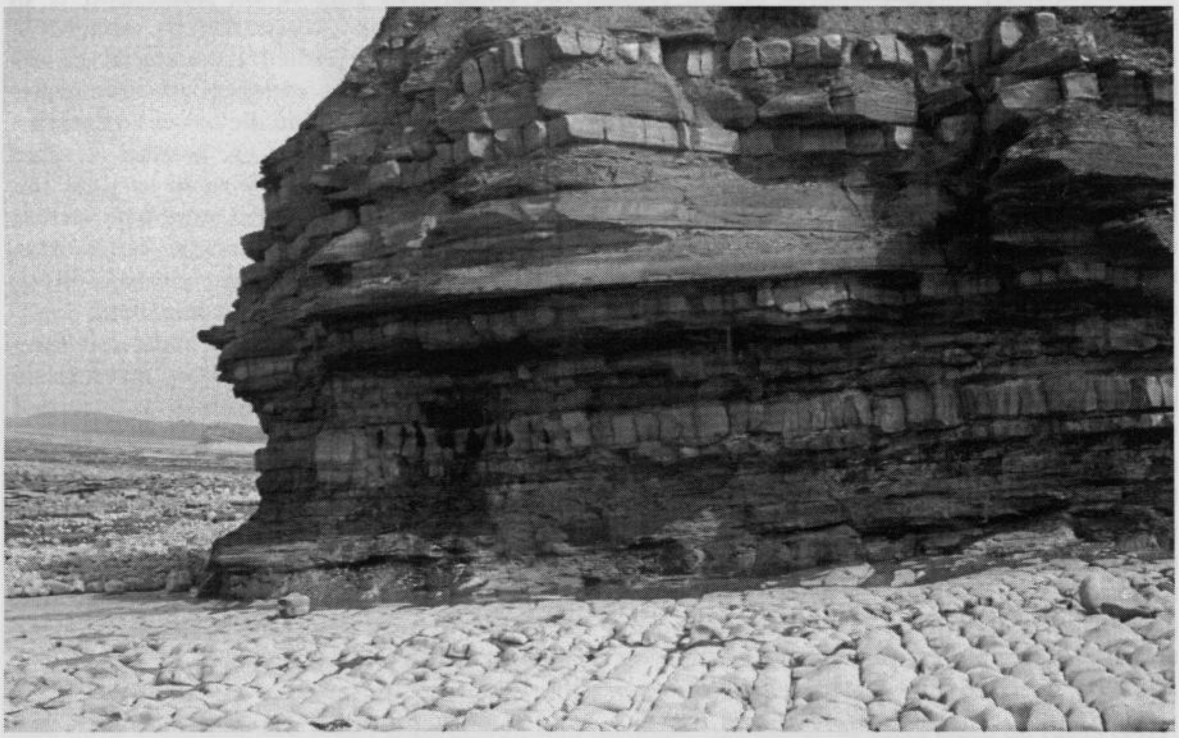

Figure 2.20 Limekiln Steps, East Quantoxhead, west of Kilve, the Global Stratotype Section and Point (GSSP) for the base of the Sinemurian Stage. The limestone platform at the foot of the cliff is the top of Bed 144 and the Hettangian–Sinemurian boundary lies in the thick shale unit at the base of the cliff (beds 145–146). (Photo: M.J. Simms.)

nearby, and the complete lack of marginal facies anywhere in the exposed Mesozoic succession. They also suggested the existence of a second fault to the west, the North Exmoor Fault, developed on a similar scale and offset by several kilometres to the north along the Watchet–Cothelstone–Hatch Fault System. The existence of the North Quantocks Fault implies that the Blue Anchor–Lilstock Coast GCR site lies entirely within the south-eastern part of the Bristol Channel Basin, whereas defining the boundary between this and the Central Somerset Basin places only the westernmost part of the site within the Bristol Channel Basin.

The most recent general account of the stratigraphy of the sections within the GCR site, summarizing much of the earlier work, is that by Warrington and Ivimey-Cook (1995).

Description

Palmer (1972) and Whittaker and Green (1983) have provided detailed descriptions of the Lower Jurassic succession exposed within the GCR site. Their accounts are broadly in agreement, although correlation of individual beds can be difficult. The bed numbers used here are those of Whittaker and Green (1983). Their logs also differ in minor respects from other published logs of the basal Lias (Hodges, 1994; Page and Bloos, 1998: Bloos and Page, 2000a) and of the Hettangian–Sinemurian boundary (Bloos and Page, 2000b, 2002; Page *et al.*, 2000; Page, 2002). In places the section is disrupted by faulting, both normal and reverse, and Peacock and Sanderson (1999) noted that the complexity of deformation is greater in the Lilstock area than in the Kilve–Watchet area. Among the largest of the faults are the Doniford Bay Fault (ST 0840 43630), which throws down Semicostatum Zone strata to the south against red and grey mudstones of the Mercia Mudstone Group, and the Blue Ben Fault (ST 202 4376), which brings Bucklandi Zone strata against red mudstones of the Mercia Mudstone Group. The Watchet Fault, a major transcurrent fault (Whittaker, 1972a) intercepts the coast about 1 km west of Watchet and is outside the GCR site.

The base of the Lias Group was taken by Whittaker (1978; Whittaker and Green, 1983) at the base of a fissile mudstone that rests on a hard, grey, calcareous mudstone, up to nearly 1 m thick, which separates it from the pale limestone of the Sun Bed beneath. The Sun Bed itself is a marker band that can be traced throughout southern England. Palmer (1972) placed the base of the Lias immediately above the Sun Bed.

The lowest part of the Lias succession is exposed at several points along the coast, including Doniford Bay and Lilstock Bay, but it can be examined most easily in the cliff at St Audrie's Bay (Figure 2.19). This section has been proposed as the Global Stratotype Section and Point GSSP) for the base of the Jurassic System (Warrington *et al.*, 1994) although, as noted by Bloos and Page (2000a), the ammonite sequence is actually better in Doniford Bay. Some 5 m of mudstones and rather nodular limestones at the base of the Lias are devoid of ammonites but contain a moderately diverse bivalve fauna. *Liostrea hisingeri*, a characteristic species of the basal Lias, occurs in some abundance at certain levels. The ammonite *Psiloceras*, taken as marking the base of the Jurassic System, has been found as low as Bed 8 (Figures 2.18 and 2.19) (Hodges, 1994), while Page and Bloos (1998) have identified a fauna of weakly ribbed *Psiloceras*, including *P. erugatum* (Bloos and Page, 2000a) and *Neophyllites*, below the typical smooth forms of *Psiloceras* in the lower part of the Planorbis Subzone. Unequivocal *Psiloceras planorbis* is abundant in beds 13 to 19. Bed 24 comprises 2 m or more of indurated laminated mudstone in which crushed iridescent specimens of *Psiloceras* ex. grp. *planorbis* are abundant; it is from Bed 24, or possibly beds 14 or 18, at either Doniford Bay or west of Watchet, that the lectotype of this species probably was obtained. The Planorbis Subzone is about 4.5 m thick at St Audrie's Bay and extends up to the base of Bed 25, a limestone band in which the appearance of *Caloceras* sp. marks the base of the Johnstoni Subzone. The latter comprises 3.4 m of limestones and mudstones. Hard laminated mudstones contain *Caloceras johnstoni* (in Bed 36) and *C. intermedium* (in Bed 37). Specimens of *Caloceras* from Doniford Bay, near Watchet, are iridescent, suggesting that this may be the source of the type of *C. johnstoni* described by J. de C. Sowerby (1824). The potential threat to these horizons from commercial exploitation has been discussed by Webber (2001). The base of the succeeding Liasicus Zone is indicated by the appearance of *Waehneroceras sensu lato* in Bed 43, with *Laqueoceras* appearing around Bed 67 to indicate the boundary between the

Portlocki Subzone and the succeeding Laqueus Subzone. The Liasicus Zone is about 28 m thick and, particularly in its lower part up to about Bed 69, is dominated by mudstones with only subordinate limestones. The base of the Angulata Zone is taken at the appearance of *Schlotheimia* cf. *amblygonia* in Bed 80 and extends up to Bed 145 through some 40 m of mudstones and nodular limestones. The bases of the Complanata Subzone and the Depressa Subzone have been placed at the bases of beds 95 and 134 respectively by Bloos and Page (2000b). The ammonite faunas across the Hettangian–Sinemurian boundary have been documented in considerable detail (Page, 1994b,c, 2001; Bloos and Page, 2000b, 2002; Page *et al*., 2000). Within a 27 m-thick sequence, from the upper Complanata to lower Rotiforme subzones, 15 distinct ammonite biohorizons have been recognized (Bloos and Page, 2002). From the Complanata into the Depressa subzones there is marked reduction in species diversity of *Schlotheimia*, the characteristic Angulata Zone genus. *Schlotheimia pseudomoreana* is present virtually throughout the Depressa Subzone but around the middle of the paper shale unit of Bed 145 the genus is abruptly replaced by an arietitid fauna dominated by species of *Vermiceras*, *V. quantoxense*, *V. palmeri* and *V. elegans*, from the basal Sinemurian Stage in the vicinity of the GSSP at Limekiln Steps, East Quantoxhead.

The first appearance of *Vermiceras quantoxense*, *V. palmeri* and *Metophioceras* occurs 0.9 m above the base of Bed 145, and this is taken as the base of the Bucklandi Zone and the Sinemurian Stage (Bloos and Page, 2002). Bessa and Hesselbo (1997) also placed one of their gamma-ray unit boundaries at the Hettangian–Sinemurian boundary on the basis of a marked increase in uranium concentration. Elsewhere in Britain and north-west Europe species of *Schlotheimia* are not found with *Vermiceras* and *Metophioceras* but, uniquely, they do occur together in the upper part of Bed 145 at this site. There is a rapid turnover of arietid faunas in the Conybeari Subzone enabling recognition of nine distinct ammonite biohorizons (Page, 2001; Bloos and Page, 2002). The lowest two of these have not been recognized elsewhere in north-west Europe and it is suspected that at most localities, including the **Pinhay Bay to Fault Corner** GCR site, they are represented by a hiatus. The Bucklandi Zone extends up to Bed 244, some 80 m higher in the succession and consists predominantly of mudstone, in part fissile and bituminous, with limestones, some of them laminated, at frequent intervals. Page (pers. comm.) has assigned beds 145 (upper) to 164 to the Conybeari Subzone (14.2 m thick) and beds 165 to 202 to the Rotiforme Subzone (32.6 m thick), though this differs by up to almost 9 m from the intervals cited by Whittaker and Green (1983) and reproduced in Figure 2.18. Page (pers. comm.) assigned beds 203–?244 to the Bucklandi Zone (about 41 m thick). The remainder of the succession, about 50 m thick up to Bed 257, is mudstone dominated with only a few, mostly nodular, beds of limestone. Page (1992) assigned this part of the succession to the Lyra Subzone, recognizing three distinct ammonite horizons within this part of the succession at Doniford Bay. There is no conclusive evidence for higher subzones despite the supposed record of *Agassiceras* from a fault-bounded block at East Quantoxhead (Ivimey-Cook and Donovan, 1983). This has been re-determined as a *Coroniceras* sp. cf. *kridion* (K.N. Page, pers. comm.). The completeness of the succession has led to the recognition of a series of ammonite-correlated biohorizons. Page (1992) cited locations within the GCR site as stratotypes for 13 of these, but more are added as the ammonite stratigraphy is refined.

Fossils other than ammonites have been relatively little investigated. Palmer (1972) recorded a few of the more conspicuous taxa, notably bivalves and the trace fossil *Diplocraterion*, while Warrington and Ivimey-Cook (1995) provided lists of some of the more characteristic taxa. The macrofauna of the Planorbis Zone is dominated by a few species of bivalve, notably *Liostrea*, *Camptonectes*, *Protocardia* and *Pteromya*. The echinoids *Diademopsis* and *Eodiadema bechei* are also present and, rather remarkably in such a facies, occasional small pyritized colonies of the coral *Heterastraea* in the laminated mudstones of Bed 24. Fragmentary, or more rarely articulated, skeletons of ichthyosaurs and fish have been found in the Planorbis Zone and include an embryo within a large well-preserved ichthyosaur skeleton (Deeming *et al*., 1993).

The macrofauna of the Liasicus Zone is more diverse than that of the Planorbis Zone, with a range of bivalve taxa (*Camptonectes*, *Gervillia*, *Lucina*, *Liostrea*, *Modiolus*, *Plagiostoma* and *Pseudolimea*) including the lowest *Gryphaea*

(*Gryphaea* cf. *obliquata*) in this area. The macrofauna of the Angulata Zone, although relatively sparse, includes an increasing abundance of *Gryphaea arcuata* and the brachiopod *Calcirhynchia calcaria*. The lower part of the Bucklandi Zone also has a sparse fauna, but the fauna of the upper part (Bucklandi Subzone) is locally abundant and diverse. It includes epifaunal and shallow infaunal bivalves together with rhynchonellid and terebratulid brachiopods, gastropods, serpulids and vertebrate remains.

Warrington and Ivimey-Cook (1995) summarized much of the micropalaeontological work that has been undertaken within the GCR site. Warrington (1983, 1985) found the Lower Jurassic spore, pollen and dinoflagellate cyst assemblages to be less diverse than those of the underlying Penarth Group, and to be dominated by conifer pollen such as *Classopolis*. The stratigraphical range of seven species of foraminifera at Watchet and St Audrie's Bay were listed by Copestake and Johnson (1989), but there are no published accounts of foraminifera from the GCR site except that of Hylton (1998), who examined foraminiferal assemblages across the Hettangian–Sinemurian boundary at East Quantoxhead. Of 35 sampled levels from the upper Angulata Zone to the Rotiforme Subzone (beds 135–170), Hylton (1998) found that most were barren and only 10, mostly in the Hettangian part of the succession, yielded foraminifera together with ostracods, echinoderm debris and microgastropods. These confirmed a microfaunal change across the Hettangian–Sinemurian boundary; *Lingulina tenera* plex. *substriata* are confined to the uppermost Angulata Zone while *Planularia inaequistriata* and the *Frondicularia terquemi* plexus group make their first appearance above the boundary. The ostracod fauna was investigated by Lord and Boomer (1990) for the latest Triassic and Hettangian successions at Watchet and St Audrie's Bay. The considerable stratigraphical overlap observed in some taxa prevented some of the ostracod subzonal boundaries being defined.

The mudstones within the succession vary in their colour, carbonate and organic content, and in the extent of bioturbation. Medium- to dark-grey, mostly non-fissile to only poorly fissile, blocky and calcareous mudstones are dominant but dark, brownish-grey, well-laminated bituminous mudstones are a major component of some parts of the succession with some individual shale units exceeding 1 m in thickness. The mudstones, other than the laminated bituminous units, usually contain evidence of benthic activity, either as body fossils or as bioturbation and burrow mottling. The limestones are mostly of two types. The more common are dark blue-grey, hard, compact and rather homogeneous, often grading downwards into calcareous mudstone. Most are laterally persistent but they may be lenticular or nodular, particularly in mudstone-dominated parts of the succession. Fossils are commonly associated with the boundaries of these limestones. The second type of limestone is fine grained or porcellanous, sometimes laminated; a few have a strikingly sharp junction with underlying mudstones.

Fossil preservation varies through the succession. Three-dimensional preservation is common in many of the limestone beds while all but the more robust fossils typically are flattened in the intervening mudstones. Original aragonitic shell material is common in the more organic-rich mudstones and is seen perhaps most spectacularly in the iridescent ammonites from the laminated mudstones of the Planorbis Zone. Pyrite is relatively uncommon as a preserving medium and silica is unknown.

Interpretation

The lithostratigraphy and ammonite biostratigraphy of the succession is now largely established, though some uncertainties still exist. Although the lithostratigraphies of Palmer (1972) and Whittaker and Green (1983) are broadly in agreement, direct correlation of individual beds can be difficult. There is a discrepancy between the measured thicknesses for part of the Bucklandi Zone, where Whittaker and Green (1983) recorded 45.9 m for beds 165–224 and Palmer (1972) recorded only 30.9 m for the equivalent beds (his beds D1–E15). This may partly account for the different total thicknesses that they record; 178.9 m for Palmer (1972) against 203 m for Whittaker and Green (1983). Uncertainty also surrounds the stratigraphical continuity between the succession up to Bed 224 and that above (beds 225–257; about 70 m in total) since no continuous section exposes this interval.

There have been various interpretations of the position of the Triassic–Jurassic boundary at St Audrie's Bay. Hallam (1990b,c) placed the boundary at the top of the Langport Member of the Penarth Group, while Hesselbo *et al.* (2002) suggested a position a little lower, within the Cotham Member. Others have taken the boundary within the Blue Lias Formation, at the first appearance of *Psiloceras* (Cope, 1990; Warrington *et al.*, 1994; Page and Bloos, 1998; Benton *et al.*, 2002). Intensive searching in the basal Lias by Hodges (1994) and others (Page and Bloos, 1998; Bloos and Page, 2000a) renders it unlikely that the range of *Psiloceras* will be extended significantly lower at this GCR site. Recent work has also resolved the positions of several zonal and subzonal boundaries higher in the succession, although biostratigraphical interpretation of the upper part of the succession has long proved problematic. Woodward (1893) implied that the Turneri Zone might be present, but this has been ascribed to a mis-identification of *Arnioceras bodleyi* (Whittaker and Green, 1983). Palmer (1972) assigned beds 229–253 to the Scipionianum Subzone and beds 254–257 tentatively to the Sauzeanum Subzone. Warrington and Ivimey-Cook (1995) followed Palmer (1972) in this respect, though conceding that the presence of these two subzones was largely unproven. Page (1992) has suggested that recognition at this GCR site of subzones higher than the Lyra Subzone is based on mis-identifications.

The microfaunal biostratigraphy of the succession is poorly documented. The foraminiferal succession conforms to the zonal scheme proposed by Copestake (1989), and Hylton (1998) has shown its importance for defining the Hettangian–Sinemurian boundary, which is particularly significant for the proposed designation of the East Quantoxhead section as the Global Stratotype Section and Point (GSSP) for this boundary. Dinoflagellate cysts, coccoliths and ostracods from this site provide only a crude biostratigraphy compared with ammonites. Stratigraphical overlap of the ostracod subzonal index fossils within the *Ogmoconchella aspinata* Biozone on the west Somerset coast prevented Lord and Boomer (1990) from identifying subzonal boundaries and cast doubt on the wider validity of Lower Jurassic ostracod subzones.

The thick, often mudstone-dominated, Hettangian and Lower Sinemurian sequence of this GCR site is comparable with the predominantly argillaceous succession beneath the Bristol Channel (Lloyd *et al.*, 1973). Whittaker and Green (1983, p. 98) noted similarities between Lower Lias successions in the Bristol Channel and Central Somerset basins, and Miliorizos and Ruffell (1998) considered the former to be an offshore continuation of the latter. A significant component of the more than five-fold increase in thickness of the Lias exposed at this GCR site, compared with the correlative succession at the Dorset GCR site, occurs in the mudstones suggesting that rapid subsidence in the Central Somerset Basin during early Jurassic times favoured the accumulation of fine clastic material. The offshore Blue Lias Formation facies of the south Wales succession, as seen at the **Lavernock to St Mary's Well Bay** and **Pant y Slade to Witches Point** GCR sites (see Chapter 3), shows a broad similarity to this GCR site in terms of large-scale lithostratigraphical units. Hence the major mudstone development in the Liasicus Zone, the 'St Audrie's Shales' of Palmer (1972), can be correlated with the Lavernock Shale Member of south Wales. This can be traced to successions farther afield, notably the Saltford Shale Member of the Bristol region (Donovan, 1956) and beds H55–H72 of the Dorset coast (Lang, 1924). This widely traceable mudstone development has been ascribed to a sea-level rise of at least regional extent (Hallam, 1981). Smith (1989) correlated presumed Milankovitch cycles between the Somerset coast, the nearby Burton Row Borehole (ST 3356 5208), and the Dorset coast, and found evidence for a hiatus in the Angulata Zone of Dorset that was absent in Somerset. Similarly, Bessa and Hesselbo (1997) inferred a stratigraphical gap at the Planorbis–Liasicus zone boundary in the Somerset coast succession on the basis of comparison between spectral gamma-ray data from St Audrie's Bay and the correlative section at St Mary's Well Bay in south Wales. However, the remarkably complete ammonite succession indicates virtually continuous sedimentation through the Hettangian and Sinemurian stages in this region and casts doubt on the existence of these inferred hiatuses (K.N. Page, pers. comm.). The nature of the much-studied Hettangian–Sinemurian boundary lends support to the view that sedimentation was not interrupted for any significant length of time. The actual boundary occurs within a paper shale unit rather than at a lithological boundary and there is a unique coexistence of the diagnostic ammonite groups for the upper Hettangian and lower Sinemurian stages. Whittaker (1978) attempted direct correlation of individual beds at the base of the Blue Lias Formation between Somerset and south Wales, demonstrating that Richardson's (1911) correlation of the Watchet Beds of Somerset with silty marls above the White Lias at Lavernock was incorrect. Whittaker and Green (1983) also noted the presence of laminated limestones in the Johnstoni Subzone at roughly the same level as similar limestones in Dorset and south Wales (Hallam, 1960a, 1964a), and Palmer (1972) correlated Bed 147 (his Bed C101) with the Calcaria Bed near the base of the Conybeari Subzone in the Keynsham area (Donovan, 1956). Page (1992) has made correlations of individual sedimentary units between Somerset, Bristol (the Keynsham area) and the Devon–Dorset coast on the basis of their characteristic ammonite faunas.

Many of the individual beds and groups of beds can be traced throughout this GCR site and can be correlated with the succession in the Burton Row Borehole (Ivimey-Cook and Donovan, 1983). This reveals an eastward thinning of the succession from the St Audrie's Bay and Watchet area to Blue Ben, particularly in the Angulata Zone and Conybeari Subzone, but also to some extent in the Planorbis Zone (Bloos and Page, 2000a). All of the principal limestone beds are present throughout the section, but some of those at Blue Ben have irregular junctions and the intervening shales have thinned markedly, perhaps indicating minor hiatuses. The Blue Ben section lies less than 1 km from outcrops of Devonian rock, and Whittaker and Green (1983) ascribed the eastward thinning of the Lias to differential subsidence near the basin margin. Whittaker (1973, 1975) also found evidence for a northwards thickening of the Lias away from the basin margin and toward an elongate ESE-trending basin. In this respect Bloos and Page (2002) noted that the succession exposed on the south Wales coast is approximately twice as thick as at this GCR site. Many of the faults that now cut the coastal sections probably relate to Tertiary basin inversion. However, two major faults that mark the northern edge of the Quantock and Exmoor hills have recently been identified as basin-bounding normal faults, with throws of perhaps more than 1000 m during the Mesozoic Era (Peacock and Sanderson, 1999). The Watchet–Cothelstone–Hatch Fault System, which intersects the coast near Watchet (Whittaker, 1972a) shows evidence of movement during early Jurassic times (Miliorizos and Ruffell, 1998). The greater structural complexity of the Lilstock area compared with the Kilve–Watchet section of coast has been attributed to the location of the latter within a stress shadow associated with a relay ramp represented by this fault system (Peacock and Sanderson, 1999).

Ivimey-Cook and Donovan (1983) noted an increase in the thicknesses of individual ammonite zones in passing up through the succession. In the Hettangian Stage the Planorbis Zone is about 8 m thick, the Liasicus Zone is about 27 m thick, and the Angulata Zone is about 40 m thick. This trend appears to continue into the Sinemurian Stage, where the combined Conybeari and Rotiforme subzones are about 50 m thick and the thickness of the combined Bucklandi and Lyra subzones may exceed 75 m. If the assumption of Torrens (in Cope *et al.*, 1980a) is correct, that ammonite zones are of similar duration (0.5–1 Ma), then the subsidence rates in this area, between the Mendip and Exmoor highs, increased from Hettangian into early Sinemurian times. Confirmation of this comes from comparison with correlative successions in other basins in southern England (Table 2.1). The Planorbis

Table 2.1 Table of approximate zone/subzone-pair thicknesses for the Hettangian and basal Sinemurian stages at six different locations. (* = figures estimated from total zone thickness.) Data from Cope *et al.* (1980a), Warrington and Ivimey-Cook (1995) and Page (1992, unpublished Geological Society Correlation Guide).

Ammonite zones/ subzone pairs	Somerset coast	South Wales (offshore facies)	Devon–Dorset coast	Stowell Park Borehole	Mochras Borehole	Radstock shelf
Bucklandi–Lyra	90	?	4	35	*c.* 90*	0
Conybeari–Rotiforme	47	*c.* 35*	6	18	*c.* 70*	0
Angulata	40	30	5	17	60	0
Liasicus	27	30	4	18	59	0.5
Planorbis	8	9	4	11	18	2.5

Zone is thin in most areas, but succeeding zones show a fairly consistent thickness within each succession (Dorset coast: 4–6 m; Severn Basin: *c*. 18 m; Mochras Borehole: 60–80 m; south Wales: *c*. 30 m). These variations in thickness reflect different rates of subsidence in each of the basins but the Central Somerset Basin appears to be unusual in that the subsidence rate increased progressively through Hettangian and early Sinemurian times rather than maintaining a fairly constant subsidence rate, at least for the Hettangian Age, as is seen in the other basins. The dominance of mudstones through much of the succession at this GCR site testifies to rapid subsidence and generally low-energy conditions with little erosion. The ammonite faunas documented by Page (1992, 1994b; Page and Bloos, 1998; Bloos and Page, 2000a,b, 2002) also indicate that the succession here is more complete than elsewhere in southern Britain. This pattern of deposition contrasts with that of the Radstock Shelf. There the Planorbis and Liasicus zones usually are present, but the Angulata and Bucklandi zones are absent or represented only by derived fossils in the basal bed of the overlying Sinemurian strata (Donovan and Kellaway, 1984).

Conclusions

The Blue Anchor–Lilstock Coast GCR site exposes a greater thickness of Hettangian and Lower Sinemurian strata than is seen in any other correlative section in an onshore basin in Britain. Its basinal setting provides a valuable contrast with the basin-margin succession exposed on the southern flanks of the Mendip High and along the south Wales coast. The succession contains an exceptionally full, and well-documented, sequence of ammonite faunas that have served as the basis not only for further subdivision of the established ammonite zonal scheme but also for designation of the Global Stratotype Section and Point (GSSP) for the base of the Sinemurian Stage, and a proposal for similar status for the base of the Hettangian Stage and the Jurassic System. This is a site of clear international significance for Lower Jurassic chronostratigraphy.

HURCOTT LANE CUTTING, SOMERSET (ST 3985 1635)

Introduction

The Hurcott Lane Cutting GCR site, on Hurcott Lane, also known as 'Hollow Road', lies approximately 1 km south of the village of Shepton Beauchamp and about 4 km north-east of Ilminster (Figure 2.21). It provides the finest exposure currently available of the Barrington Limestone Member of the Beacon Limestone Formation, found in the banks of a sunken lane, a common feature of this area. The Barrington Limestone Member is a highly condensed facies of the Toarcian Stage developed locally in the Ilminster area. In

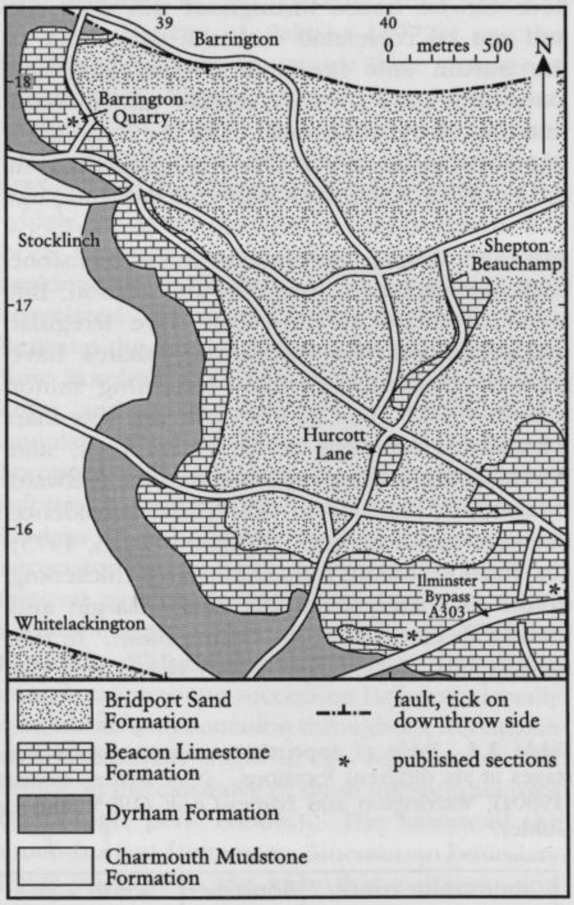

Figure 2.21 Geological map of the area around the Hurcott Lane Cutting GCR site showing the location of other published sections through the Beacon Limestone Formation.

little more than 2 m of strata it exposes a succession encompassing four ammonite zones and equivalent to more than 70 m of strata on the Yorkshire coast. The Barrington Limestone Member is spectacularly fossiliferous, yielding some of the most diverse Toarcian ammonite faunas anywhere in Britain as well as an unusual benthic fauna with a high prevalence of encrusting taxa.

This specific section was the subject of a MSc thesis by Constable (1992), on which the following account is partly based, and was mentioned briefly by Wilson *et al*. (1958, p. 56), but there have otherwise been no published descriptions. Previous accounts of correlative successions in the area were published by Moore (1867b), Hamlet (1922), Pringle and Templeman (1922), Spath (1922a), Wilson *et al*. (1958), Boomer (1992) and Howarth (1992).

Description

Hurcott Lane Cutting exposes just over 2 m of argillaceous limestones and calcareous mudstones of the Barrington Limestone Member, formerly known as the 'Junction Bed'. Much of the cutting is vegetated and exposure is commonly poor; two minor landslips on the east side of the lane have produced clearer sections, the larger of which is about 10 m long (Figure 2.22).

Constable (1992) identified 27 beds within the exposed part of the Barrington Limestone Member (Figure 2.23), with mudstone units greatly subordinate to limestones, which possibly are overlain by the basal part of the Bridport Sand Formation. The limestones typically have irregular surfaces and several are discontinuous or reduced to nodules within mudstone units. There is a general upward increase in the proportion of limestone to mudstone; mudstones

Figure 2.22 Landslip exposing the Barrington Limestone Member of the Beacon Limestone Formation on the east side of Hurcott Lane. The conspicuous notch is at about the level of beds 11–13. (Photo: M.J. Simms.)

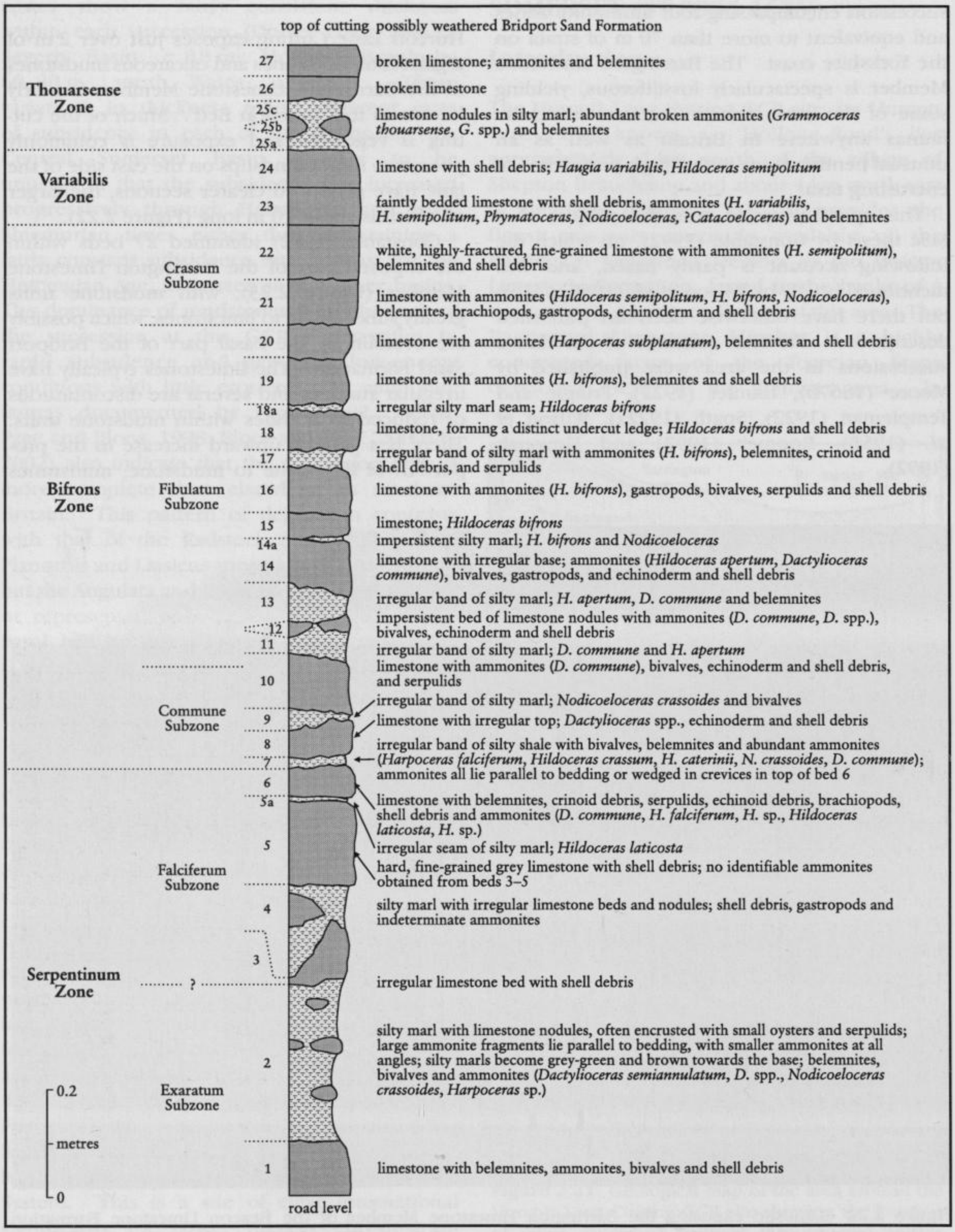

Figure 2.23 Section through the Barrington Limestone Member of the Beacon Limestone Formation exposed in Hurcott Lane Cutting. After B. Constable, 1992, MSc thesis, Birkbeck College, London.

predominate in beds 2–4 (middle Serpentinum Zone), and are common in beds 5–18 (upper Serpentinum and lower Bifrons zones), whereas beds 19–27 (upper Bifrons, Variabilis and Thouarsense zones) are developed very largely in limestone. The uppermost limestone bed is overlain by weathered and disturbed yellow-brown sands but the precise nature of the contact is difficult to ascertain. These may be the basal beds of the Bridport Sand Formation.

Fossils are abundant in the limestones and mudstones, with ammonites forming a conspicuous component of the fauna. The diverse fauna of hildoceratids and dactylioceratids has enabled biostratigraphical boundaries to be identified with precision and has demonstrated a virtually complete sequence from the middle part of the Serpentinum Zone through to the Thouarsense Zone at this site. On account of the quality of preservation and ease of extraction of the ammonites in the Barrington Limestone Member in this area, compared with the equivalent strata on the Dorset coast, many specimens have been figured in publications, notably those of Howarth (1992) who commented that the ammonites of the Falciferum Subzone in particular are more varied and abundant in this area than anywhere else in Britain.

The Barrington Limestone Member also yields common belemnites, occasional *Cenoceras*, and a rich and diverse benthic macrofauna of bivalves, gastropods, brachiopods, echinoderms and other groups, along with a similarly diverse microfauna and flora. Elements of the fauna were described and figured by Moore (1867b) and Boomer (1992). Aragonitic shell material is generally absent and many of the ammonites are preserved as steinkerns, or internal moulds, which subsequently have been incorporated into the sediment. Deformed ammonite steinkerns are common on the surfaces of many of the limestone beds. Preservation of original calcitic material is usually good, though often broken. Encrusting organisms are common on many of the macrofossils and on some of the limestone nodules. They include foraminifera, oysters, serpulids and rarer solitary corals and cyrtocrinid holdfasts. A horizon near the base of the Commune Subzone at the nearby Ilminster Bypass (ST 406 157) (Figure 2.21) yielded an exceptionally rich echinoderm fauna dominated by cyrtocrinids and *Isocrinus lusitanicus* (Simms, 1989), with common echinoid and ophiuroid debris. Closer examination of the Hurcott Lane Cutting may perhaps also reveal its presence there. Vertebrate remains occur in the Barrington Limestone Member, but are rare and typically disarticulated. Spectacularly well-preserved fish and marine reptiles described from this area by Moore (1867b) appear to be confined to the 'Saurian and Fish Bed', which occurs low in the Exaratum Subzone and is not exposed at Hurcott Lane Cutting.

Interpretation

The Toarcian succession at Hurcott Lane Cutting clearly is condensed. Four ammonite zones are present in little more than 2 m here compared with more than 70 m for correlative strata on the Yorkshire coast. The succession here is expanded by comparison with correlative sections in this area (Wilson *et al.*, 1958), and particularly with the Beacon Limestone Formation on the Dorset coast where equivalent strata locally are reduced to less than 1 m. No obvious hiatuses have been identified within the Barrington Limestone Member exposed at Hurcott Lane Cutting although they occur in the more condensed sections farther to the east, around Yeovil, and on the Dorset coast. The hildoceratid ammonites recorded from the Barrington Limestone Member indicate that the succession is also remarkably complete and includes some of the ammonite-correlated horizons proposed by Gabilly (1976) in his refined biostratigraphy of the Toarcian Stage. Despite the biostratigraphical detail with which the Hurcott Lane Cutting succession is known, lithostratigraphical correlation with other sections in the area (Boomer, 1992; Howarth, 1992) has proven difficult, suggesting that the Barrington Limestone Member shows rapid lateral variations. The succession at Hurcott Lane Cutting appears to be thinner, and with a lower proportion of mudstone units, than that recorded by Hamlet (1922; reproduced in Howarth, 1992) at Barrington (ST 385 178), less than 2 km to the north-west (Figure 2.21). It is also slightly thinner than that published in Boomer (1992) on the Ilminster Bypass (ST 406 157), less than 1 km to the south-east. Kellaway and Wilson (1941a) commented on the changes in thickness of the Beacon Limestone Formation between Ilminster and Yeovil and noted the disappearance of *Grammoceras* faunas in the upper part of the formation near Yeovil.

Hesselbo and Jenkyns (1998) attributed the condensed nature of the Beacon Limestone Formation of Dorset to sediment starvation; the same probably is true for the Barrington Limestone Member. Sections in the Ilminster and Yeovil area include firmgrounds and/or hardgrounds which, together with the abundance of ammonite and other shells, support the rich encrusting fauna that is such an unusual element of the British Lower Jurassic Series but well represented in the Tethyan Province. These include encrusting oysters, serpulids, foraminifera and cyrtocrinid crinoids. Broken, distorted and heavily encrusted ammonite steinkerns found at many sites indicate periods of exhumation and reworking of fossil material, while fossils encased in oncolitic algal overgrowths indicate prolonged periods of non-deposition in shallow water.

Some elements of the fauna indicate a palaeobiogeographical link between southern England and areas farther south, with Howarth (1992) noting the relatively frequent occurrence of Tethyan ammonite taxa in the Barrington Limestone Member. Boomer (1992) commented on the south European and north African affinites of the ostracod fauna and its distinctiveness from faunas recorded from basins farther north in England and Wales. A similar pattern is seen in the contrast between the hildoceratid-dominated faunas of southern England and the dactylioceratid-dominated faunas of Northamptonshire and Yorkshire. Boomer (1992) attributed this to the opening of new migration pathways associated with an early Toarcian sea-level rise.

Conclusions

The section exposed at Hurcott Lane Cutting is currently the best representative of the Barrington Limestone Member, a local development of the Beacon Limestone Formation, in the Ilminster area. It provides an important correlative section to the Beacon Limestone Formation exposed in the **Pinhay Bay to Fault Corner** GCR site, with which it shows significant contrasts. The Hurcott Lane Cutting section is highly condensed, with little more than 2 m of strata representing 4 ammonite zones and about 3 million years. It yields a more diverse and easily extractable fauna than that of the coastal exposures, including ammonites and many other fossils. The ammonite and ostracod faunas from the Barrington Limestone Member show evidence of Tethyan affinities and contrast markedly with faunas of the same age farther north in England. The encrusting benthos found in the Barrington Limestone Member provides valuable insights into aspects of the marine biota greatly under-represented in the British Lower Jurassic Series by comparison with many sites in the Tethyan Province.

BABYLON HILL, DORSET (ST 578 155–ST 584 161)

Introduction

The Babylon Hill GCR site comprises three roadside exposures, two of which, Underdown Hollow (ST 578 156) and Bradford Hollow (ST 577 155) (Figure 2.24) on the escarpment of Babylon Hill, are found in sunken lanes, a common feature of the Yeovil area caused by centuries of erosion on unmetalled roads. The third exposure is a more recently exposed section on the south side of the A30 Sherborne Road (ST 583 161), as it ascends the scarp. These roadside exposures represent the most extensive inland section in the Wessex Basin of the Bridport Sand Formation (= 'Yeovil Sands' of earlier authors). The Babylon Hill GCR site yields a sequence of stratigraphically important Upper Toarcian ammonite faunas in the type area of the Yeovilian Substage of the Toarcian Stage.

Little detailed information has been published on the Bridport Sand Formation succession at Babylon Hill. James Buckman (1874) provided a descriptive summary and a sketch through the formation, and his son, S.S. Buckman, reproduced this section and combined it with that of the Inferior Oolite Group exposed in a nearby quarry at Bradford Abbas (Buckman, 1887–1907). The stratigraphy at Babylon Hill was discussed briefly by Kellaway and Wilson (1941a), Wilson *et al*. (1958) and Hemingway *et al*. (1969). The most recent account, by Torrens (1969), was based on sections measured and ammonites collected by Mr Hugh Prudden.

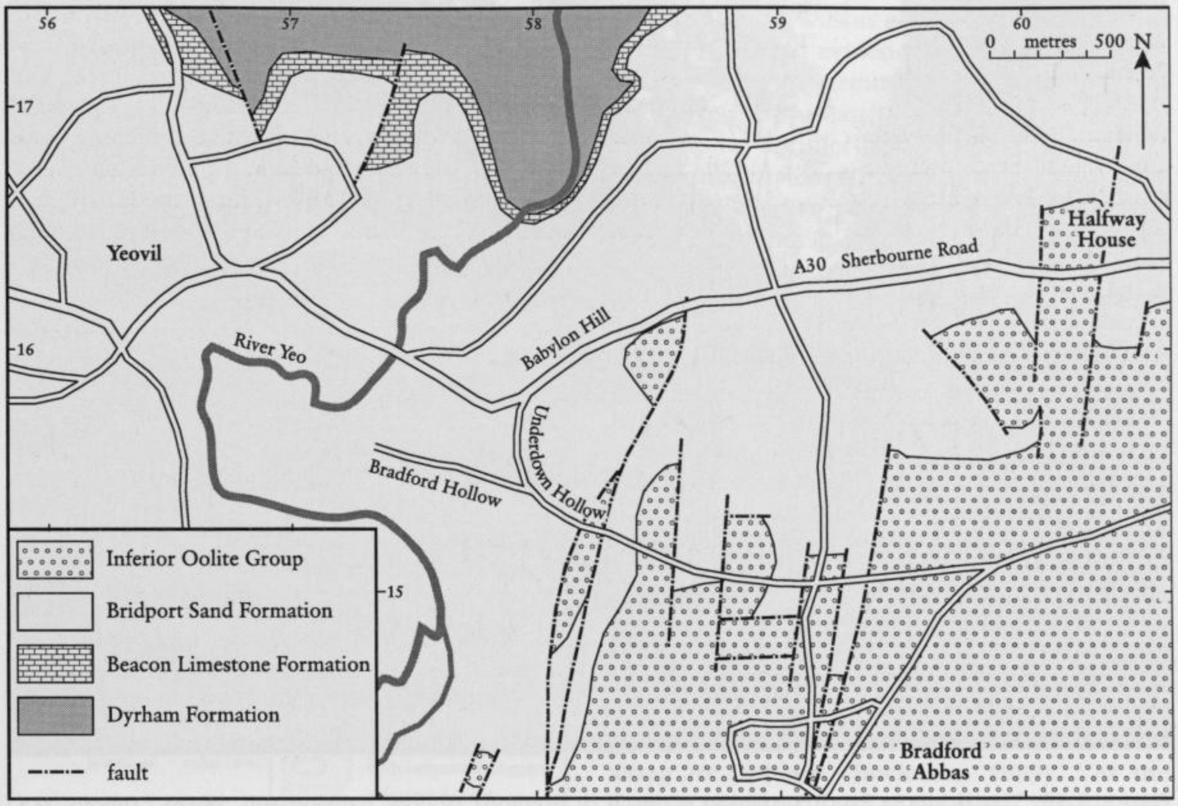

Figure 2.24 Geological map of the Babylon Hill area.

Description

Exposures of the Bridport Sand Formation occur in three areas along the scarp of Babylon Hill, all of which are part of the GCR site. At the western end of the scarp an unmetalled trackway, Bradford Hollow (centred on ST 577 155), exposes more than 30 m of the formation in faces up to 8 m high (Figure 2.25; Wilson *et al*., 1958, pl. IV). To the east the formation is exposed, in faces up to 5 m high, along a minor metalled road at Underdown Hollow (centred on ST 578 156). A third area of exposures, on the south side of the A30 Sherborne Road (centred on ST 583 161) was created during construction of the dual carriageway along this section of road (Figures 2.24 and 2.26).

Wilson *et al*. (1958) suggested a total thickness of about 60 m (200 ft) for the Bridport Sand Formation in the Yeovil district. James Buckman (1874) logged about 30 m (100 ft) of the succession, comprising 'fine yellow sands' with at least ten 'bands of stone', in either Bradford Hollow or Underdown Hollow but neither he nor S.S. Buckman, who subsequently reproduced the section (Buckman, 1887–1907), specified which. In the latter work Buckman (1887–1907) indicated that only about an additional 3 m (10 ft) of the Bridport Sand Formation lay above the highest unit recorded by his father (Buckman, 1874), with the formation being capped by a 'hard, blue centred stone' known as the 'Dew Bed' that was exposed in quarries at Bradford Abbas and Halfway House (Figure 2.24).

James Buckman (1874) noted that some of the indurated bands within the sands were richly fossiliferous, although well-preserved fossils were rare. Wilson *et al*. (1958) recorded *Dumortieria falcofila* and *D. tabulata*, together with the bivalves *Grammatodon* and *Cucullaea*, from a 'roadside on Babylon Hill', probably the old route of the A30. Mr Hugh Prudden logged about 20 m of the upper

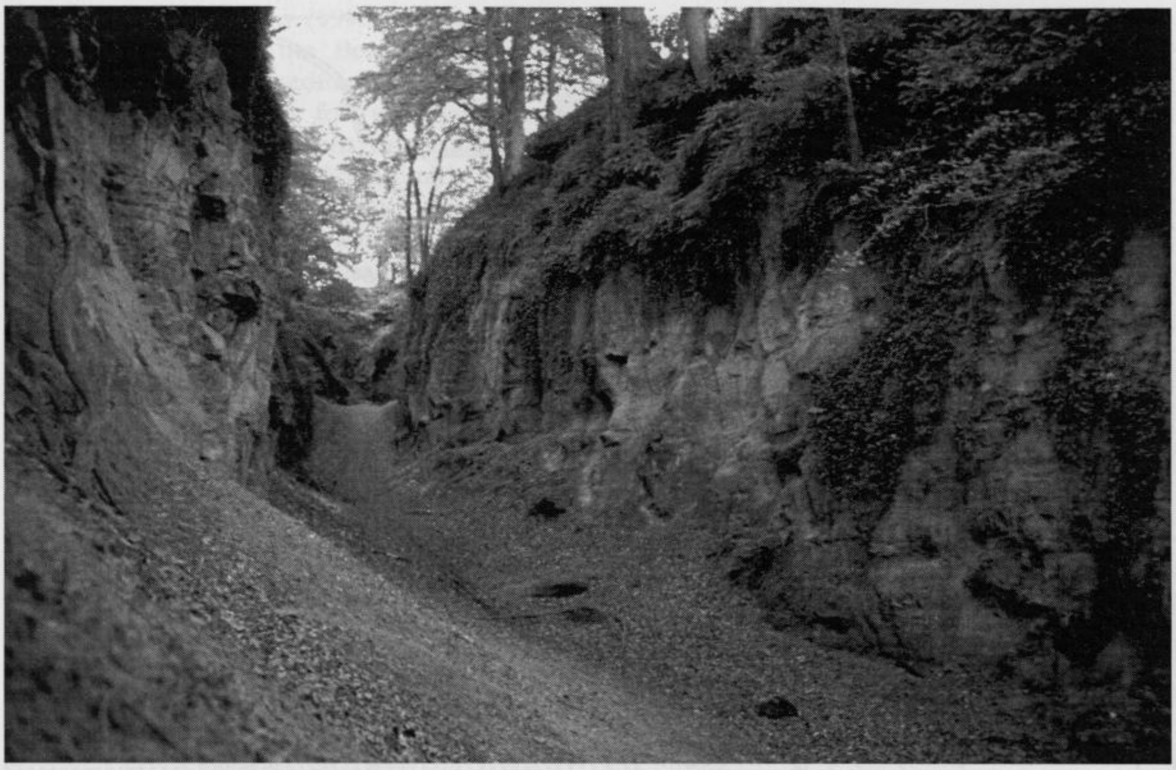

Figure 2.25 The Bridport Sand Formation exposed in Bradford Hollow, Babylon Hill, Yeovil. (Photo: M.J. Simms.)

part of the Bridport Sand Formation at the GCR site on the south side of the A30 (Torrens, 1969) (Figure 2.26). The succession is dominated by poorly cemented sands with irregular bands or doggers of well-cemented sandstone, and a thin bed of shelly calcareous shale near the top of the section (Bed U14). Although planar bedding was noted in beds L2 and U15, few sedimentary structures were observed. Prudden recorded loose specimens of *Pleydellia* cf. *fluens* from this horizon or from Bed U12, and in-situ *Pleydellia* cf. *aalensis* grp. and *Pleydellia* sp. from Bed U12, indicating the presence of the late Toarcian Aalensis Zone, and also reported unidentified ammonites from Bed U10. Numerous ammonites from the sandstone of Bed L8 were mostly *Dumortieria pseudoradiosa* and *D. costula*, with rarer *Dumortieria moorei*. This assemblage is indicative of the Pseudoradiosa Zone and Subzone. Prudden (pers. comm.) has also found crustacean fragments associated with large burrow systems in the uppermost row of sandstone doggers at Bradford Hollow.

Interpretation

Although probably up to 60 m thick at Babylon Hill, the Bridport Sand Formation in the Yeovil area encompasses at most only part of three late Toarcian ammonite zones. The underlying Barrington Limestone Member of the Beacon Limestone Formation, as seen at the **Hurcott Lane Cutting** GCR site, spans the remainder of the Toarcian Stage. At Barrington, near Ilminster, 1.5 km north of the Hurcott Lane Cutting GCR site (Figure 2.21) and some 20 km to the west of Babylon Hill, the lowest 1.8 m of the Bridport Sand Formation has yielded *Phlyseogrammoceras dispansum*, indicating that the lowest part of the formation is of Dispansum Zone age, with indeterminate ?*Dumortieria* suggesting that succeeding strata in the lower part of the formation lie within the lower part of the Pseudoradiosa Zone (Howarth, 1992).

At Babylon Hill only the upper part of the Bridport Sand Formation is well exposed. James Buckman (1874) considered the sands there to correlate with the Ham Hill Limestone Member

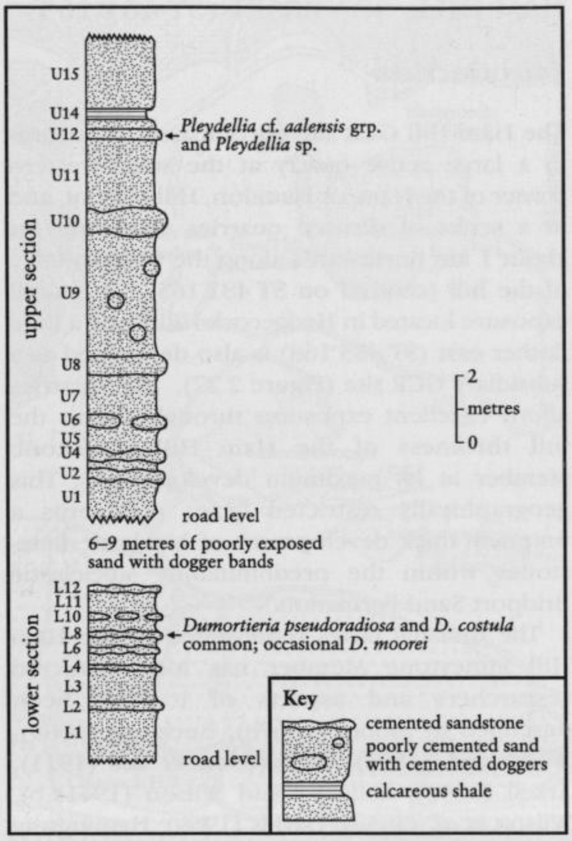

Figure 2.26 Sections through the Bridport Sand Formation on the south side of the A30 Sherborne Road (centred on ST 583 161) at Babylon Hill, Yeovil. After Prudden in Torrens (1969b).

and with the lower part of the Inferior Oolite Group in the Cotswolds, although Wright (1856) had already contested that the sands were part of the Lias. The latter view has long since been firmly established. The preponderance of coarsely ribbed species of *Dumortieria* ammonite faunas collected by Prudden (in Torrens, 1969) from the lower part of the succession at Babylon Hill suggests a position low in the Pseudoradiosa Subzone. In general, coarse-ribbed species of *Dumortieria* characteristic of the Levesquei Subzone are superseded by fine-ribbed species typical of the Pseudoradiosa Subzone but Prudden (1966) noted the difficulty of distinguishing Pseudoradiosa and Levesquei subzone faunas without adequate sample sizes.

Prudden's record of *Pleydellia* from the upper part of the succession establishes that at least the upper 3 m of the Bridport Sand Formation at Babylon Hill lies within the Aalensis Zone. Wilson *et al*. (1958) and White (1923) also cited evidence of an Aalensis Zone age for the uppermost few metres of the Bridport Sand Formation in the Yeovil area. This appears to conflict with earlier records of *Dumortieria moorei* from the Dew Bed, an important marker bed that caps the Bridport Sand Formation in the Yeovil area (Buckman, 1887–1907; Richardson, 1930). Gabilly (1976) has reported the co-occurrence of *Dumortieria moorei* with species of *Pleydellia* of the Aalensis Zone but these records from the Dew Bed cannot easily be resolved without re-examination of the material, which may have been mis-identified or reworked from older strata. However, they are more in support of an Aalenian Stage Scissum Zone age for the Dew Bed, as proposed by Chandler and Sole (1996), rather than a Pseudoradiosa Subzone age suggested by Wilson *et al*. (1958) and Callomon and Cope (1995).

Identifying the ages of the base and top of the Bridport Sand Formation in the Yeovil area has demonstrated the diachroneity of the formation along its outcrop (Buckman, 1889). At the **Coaley Wood** GCR site in the mid-Cotswolds the base of the formation lies in the upper part of the Bifrons Zone and the condensed carbonate-dominated facies of the Cotswold Cephalopod Bed Member commences in the lower part of the Thouarsense Zone. In the Yeovil area the formation spans the interval from the uppermost Dispansum Zone to the Aalensis Zone, while at the **East Cliff** and **Cliff Hill Road Section** GCR sites on the Dorset coast it extends from the lower part of the Pseudoradiosa Zone to the top of the Aalensis Zone.

In the Yeovil area the contrast in thickness of the Bridport Sand Formation with contiguous sequences above and below, in thickness, duration and facies is striking, though comparable to that of the Dorset coast. The condensed carbonate-dominated facies of the Barrington Limestone Member of the Beacon Limestone Formation encompasses most of the Toarcian Stage in a sequence that in the Yeovil area may be reduced locally to less than 3 m (Wilson *et al*., 1958). The overlying clastic-dominated Bridport Sand Formation spans barely more than two ammonite zones yet is about 60 m thick. The condensed, carbonate-dominated, Inferior Oolite Group that succeeds it represents the combined Aalenian and Bajocian stages yet barely exceeds 4 m in thickness (Cope *et al.*, 1980b). In the correlative succession in the Severn Basin the Bridport Sand Formation is underlain by thick mudstones and overlain by an equally thick carbonate-dominated succession. The only condensed part of the sequence in the Severn Basin is the late Toarcian Cotswold Cephalopod Bed Member, as seen at the **Wotton Hill**, **Coaley Wood** and **Haresfield Hill** GCR sites. This can be correlated with the upper part of the Bridport Sand Formation at Babylon Hill. The lack of correspondence between the ages of the condensed units in the Wessex and Severn basins probably reflects differences in local tectonism that caused lower subsidence rates in parts of the Wessex Basin through much of the Toarcian to Bajocian interval.

In contrast, the similarity in facies and thickness of the Bridport Sand Formation across the Dorset, central Somerset and Severn basins suggests that the controlling factor in its development was sediment supply. A eustatic fall in sea level in late Toarcian times (Hesselbo and Jenkyns, 1998) may have increased the sediment supply from adjacent land areas. Boswell (1924) noted that the heavy-mineral assemblages in the Bridport Sand Formation were similar to those of Armorican metamorphic rocks of Brittany, which he considered to be a likely source. Davies (1969) used this evidence to suggest that sediment derived from these rocks was carried north-eastwards by longshore currents to form sand-bars. Other possible sources of sediment include the reworking of existing Toarcian sediments, which is known to have occurred from Oxfordshire to Yorkshire prior to the Aalenian Age (Bradshaw *et al.* 1992), or erosion of Palaeozoic rocks on the London Platform.

Conclusions

The sections around Babylon Hill expose the best-documented inland succession through the Bridport Sand Formation. Its location between correlative GCR sites on the Dorset coast, around Burton Bradstock, and on the Cotswold scarp, around Wotton-under-Edge, is important for demonstrating the diachronous nature of the formation. Along with the strikingly different facies developed at the **Ham Hill** GCR site, these sections provide essential comparative data for interpreting the history of this part of the Wessex Basin during late Toarcian times.

HAM HILL, SOMERSET (ST 481 165)

Introduction

The Ham Hill GCR site encompasses exposures in a large active quarry at the south-western corner of the Ham, or Hamdon, Hill plateau, and in a series of disused quarries extending for about 1 km northwards along the western edge of the hill (centred on ST 481 165). A natural exposure located in Hedgecock Hill Wood a little farther east (ST 485 168) is also designated as a subsidiary GCR site (Figure 2.27). The quarries afford excellent exposures through almost the full thickness of the Ham Hill Limestone Member at its maximum development. This geographically restricted facies represents a uniquely thick development of bioclastic limestones within the predominantly siliciclastic Bridport Sand Formation.

The unusual facies represented by the Ham Hill Limestone Member has long attracted researchers and aspects of it have been described by Moore (1867b), Buckman (1889), Woodward (1893), Richardson *et al.* (1911), Arkell (1933), Kellaway and Wilson (1941a,b), Wilson *et al.* (1958), Davies (1969), Hemingway *et al.* (1969), Knox *et al.* (1982), Jenkyns and Senior (1991) and Hart *et al.* (1992). None of these accounts has provided a detailed description of the succession. A popular guide book to the Ham Hill quarries has been produced by Prudden (1995). Ham Hill stone has been quarried since at least Roman times and was used widely in Dorset and Somerset as a prestige building stone from Norman times onward. The working quarry at the south end of the hill still produces stone for new buildings and for restoration.

Description

The quarries at Ham Hill, all within the Ham Hill Limestone Member, expose up to 27 m of bioclastic limestone within the upper part of the Bridport Sand Formation (Figure 2.28). This facies is peculiar to the Hamdon Hill outlier and others up to 10 km to the south, at Chiselborough Hill and Chinnock Hill (Figure 2.27), where it is significantly thinner.

Patchily cemented, yellow-brown, micaceous, silty sands of the Bridport Sand Formation (= 'Yeovil Sands' of earlier authors) crop out on the lower slopes of Hamdon Hill. These are not

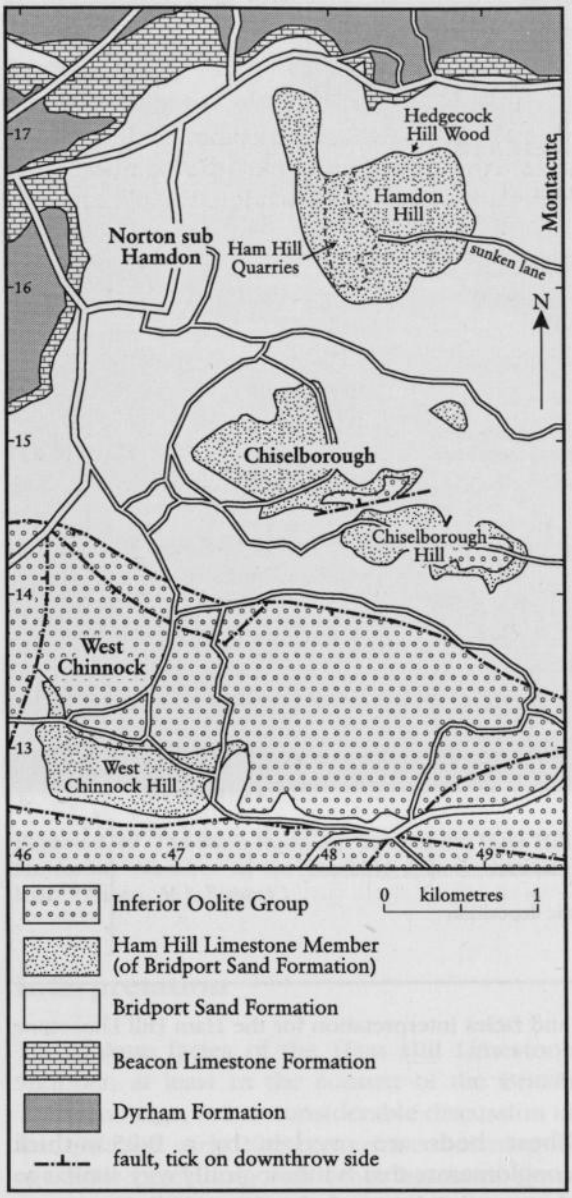

Figure 2.27 Geological map of the known outcrop area of the Ham Hill Limestone Member of the Bridport Sand Formation. After Wilson *et al.* (1958).

exposed within the quarry complex but the topmost few decimetres are visible beneath the base of the Ham Hill Limestone Member exposed in Hedgecock Hill Wood. Extensive, but discontinuous, exposures of sands with lines of sandstone doggers are exposed in the sunken lane that ascends the hill from Montacute (ST 494 164). Winwood (in Richardson *et al.*, 1911) noted that the full thickness of the sandy part of the Bridport Sand Formation was formerly exposed in this lane. He estimated the thickness of the formation (excluding the Ham Hill Limestone Member) to be about 25 m (80 ft), while Buckman (1889) estimated it at 31 m (100 ft) and Kellaway and Wilson (1941a) at 38 m (125 ft).

The lowest unit of the Ham Hill Limestone Member, exposed in Hedgecock Hill Wood (ST 485 168) and occasionally in the floor of the working quarry, is a 0.5 m-thick conglomerate containing rather poorly rounded clasts, up to 0.2 m across, of hard, micaceous, silty sandstone derived from the underlying Bridport Sand Formation (Hart *et al.*, 1992). Most of these are ovoid but some are cylindrical and may represent reworked *Thalassinoides* burrows (Hugh Prudden, pers. comm.). The clasts are penetrated by numerous bivalve crypts and other borings, and some are encrusted with serpulid tubes. The matrix is richly fossiliferous with abundant, though often fragmentary, remains of bivalves, particularly oysters, belemnites, ammonites, crinoids, echinoids and asteroids. Prudden (in Torrens, 1969) recorded *Dumortieria moorei*, *D. pseudoradiosa* and *Plagiostoma* cf. *schimperi* from this bed, and Simms (1989) figured fragmentary *Isocrinus rollieri* from here.

The conglomerate is succeeded by the Main Building Stone, which here is about 12 m thick (Figures 2.28 and 2.29). Richardson *et al.* (1911) divided this part of the sequence into a lower series of 'Grey Beds' and an upper series of 'Yellow Beds', a division that is still evident in the quarries. The Main Building Stone succession is composed of coarsely bioclastic sparry limestones with conspicuous trough cross-bedding. Shell debris is abundant, commonly forming the dominant component, but intact bivalves, brachiopods and other fossils generally are scarce (Wilson *et al.*, 1958). Buckman (1887–1907), Winwood (in Richardson *et al.*, 1911), Kellaway and Wilson (1941b) and Torrens (1969) all reported *Dumortieria* from this part of the succession indicating the late Toarcian Pseudoradiosa Zone. Quartz sand grains are absent from the lower part of the Main Building Stone, appearing only in the top 3 m or so (Davies, 1969, fig. 11). The Main Building Stone is overlain, with an abrupt transition, by a 4.5 m-thick sequence of very fine-grained, cross-laminated sands indistinguishable from parts of the typical sandy facies of the Bridport Sand Formation. These are interbedded with

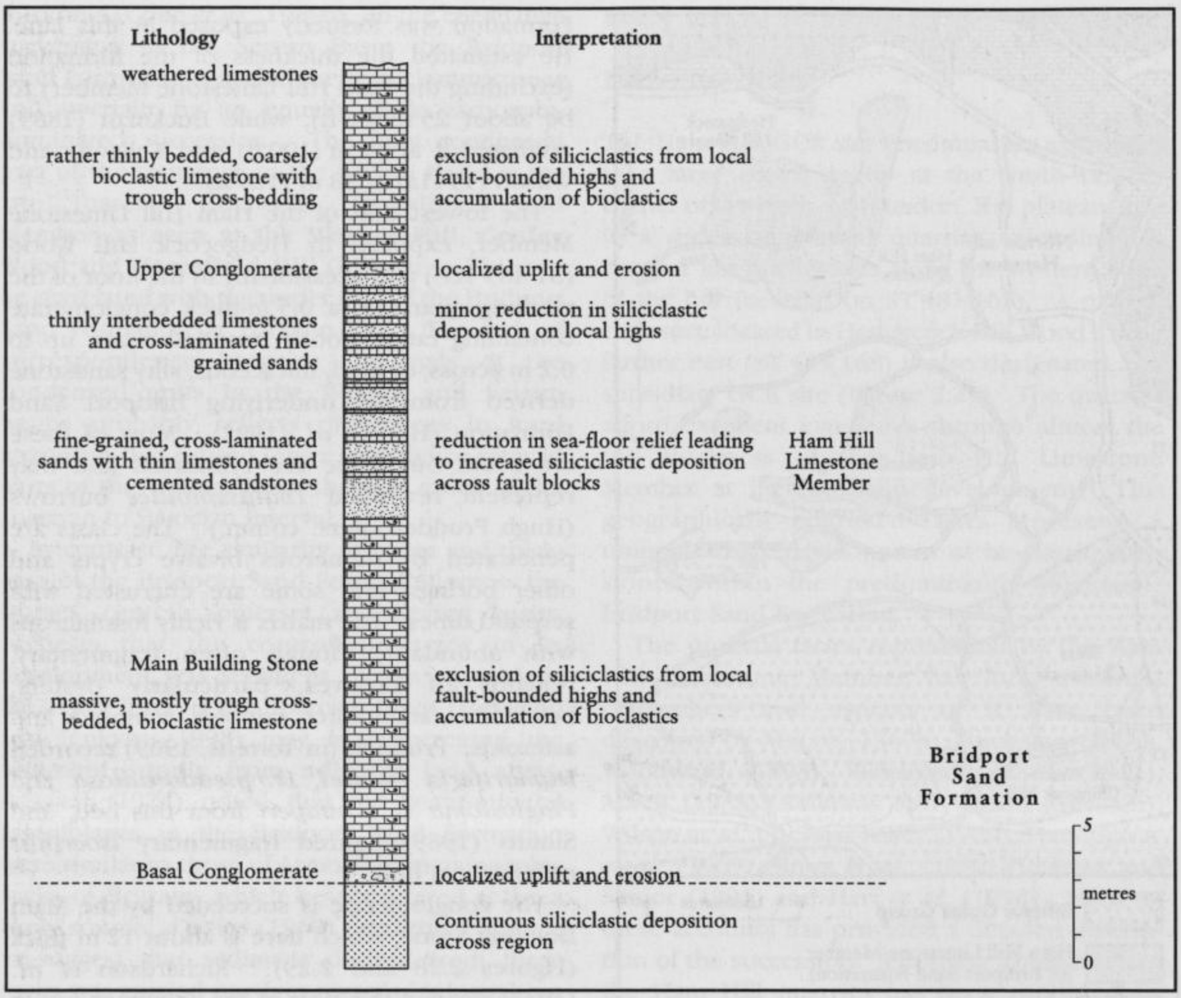

Figure 2.28 Generalized lithostratigraphical succession and facies interpretation for the Ham Hill Limestone Member of the Bridport Sand Formation.

thin beds of cross-bedded limestone and bioturbated sandstone. The sands are commonly bioturbated, sometimes with distinct burrows, though evidence of bioturbation is largely absent from the cross-bedded limestone units. This passes up into 3.9 m of thinly interbedded bioclastic limestone and cross-laminated fine-grained sands. A brachiopod bed, with *Homoeorhynchia cynocephala meridionalis*, forms a marker bed about 1.8 m below the top and was the source of material figured by Ager (1956–1967). It has also yielded a specimen of *Dumortieria* sp. (Torrens, 1969). Richardson (in Richardson *et al*., 1911) also mentioned that this brachiopod (then *Rhynchonella cynica*) was abundant in several sandy layers between the beds of limestone. These beds are overlain by a 0.25 m-thick conglomerate that is lithologically very similar to that at the base of the Ham Hill Limestone Member. Above this is about 6 m of coarsely bioclastic limestone that is more thinly bedded than those of the Main Building Stone in the lower part of the succession but, like them, they show trough cross-bedding and lack quartz sand grains in the lower part. The highest beds seen on Ham Hill are weathered limestones referable to this unit. At Chiselborough Hill, less than 2 km to the south, the Ham Hill Limestone Member is overlain by marly beds with *Leioceras* sp., indicating the Opalinum Zone of the basal Aalenian Stage of the Middle Jurassic Series (Kellaway and Wilson, 1941a; Wilson *et al*., 1958).

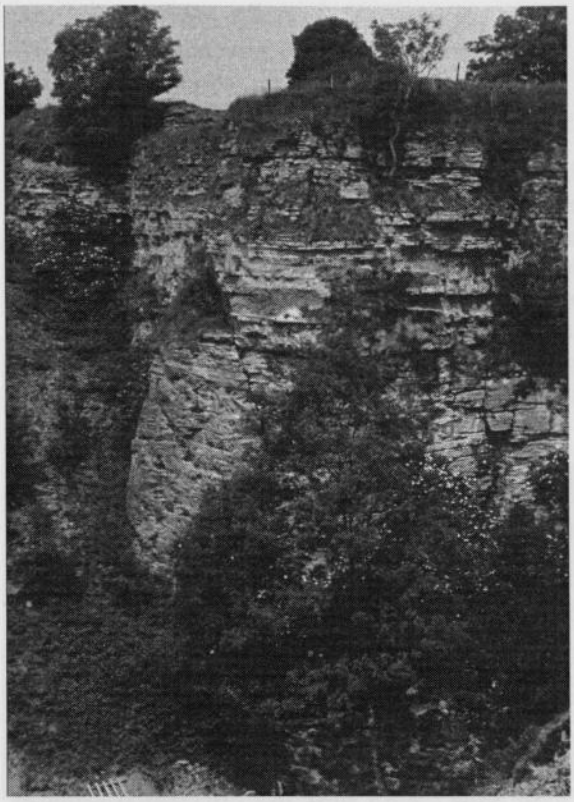

Figure 2.29 The Main Building Stone of the Ham Hill Limestone Member in the working quarry on Ham Hill. (Photo: M.J. Simms.)

Interpretation

The unique facies of the Ham Hill Limestone Member, at least in the context of the British Toarcian Stage, led to considerable discussion in the 19th and early 20th centuries concerning its age and correlation with other bioclastic limestones around the Lower–Middle Jurassic boundary. Moore (1867b) included the Ham Hill Limestone Member and the underlying Bridport Sand Formation in the 'Oolitic Series' (Middle Jurassic), but noted that the ammonites indicated that these strata were the correlative of part of the Upper Lias. James Buckman (1874) held the same view and erroneously correlated the lower, greyer, beds of the Ham Hill Limestone Member with the Pea Grit of the Cotswolds and the upper, yellow and ochreous, beds at Ham Hill with the Freestones of the Cotswolds. He correctly correlated the Ham Hill Limestone Member with the sands at **Babylon Hill**. Woodward (1887) concluded that the Ham Hill Limestone Member should be correlated with the 'upper part of the Midford or Inferior Oolite Sands', the Bridport Sand Formation of modern terminology. S.S. Buckman (Buckman, 1887–1907) initially considered that the Ham Hill Limestone Member lay within the lower part of his Opalinum Zone, now considered to be equivalent to the upper part of the Pseudoradiosa Zone. Subsequently Buckman (1889) correlated the Ham Hill Limestone Member with the Bridport Sand Formation at Babylon Hill but, in the same paper, he also correlated the member with the lower beds of the Inferior Oolite Group in Gloucestershire. Richardson and Winwood, within the same paper (Richardson *et al.*, 1911), disagreed as to whether the Ham Hill Limestone Member should be assigned to the Upper Lias (Richardson's view) or the basal Inferior Oolite (Winwood's opinion), largely based on the identity and stratigraphical significance of the common rhynchonellid (*Homoeorhynchia cynocephala meridionalis*, then *Rhynchonella cynica*) found in the Ham Hill Limestone Member. Arkell (1933) recognized a late Toarcian Moorei Subzone age (= Pseudoradiosa Zone of the scheme used here) for the Ham Hill Limestone Member, following Winwood's (in Richardson *et al.*, 1911) record of *Dumortieria moorei*, and so correlated the member with the 'Dew Bed' of the Yeovil–Sherborne area, a hard, sandy, bioclastic limestone less than 1 m thick that caps the local Toarcian succession (Wilson *et al.*, 1958). Howarth (in Prudden, 1966) considered that the coarse-ribbed, stout-whorled species of *Dumortieria* in the basal conglomerate also indicated the Pseudoradiosa Subzone while higher parts of the Ham Hill Limestone Member also appear to lie within the Pseudoradiosa Zone. Evidence from the **Babylon Hill** GCR site indicates that the upper part of the Bridport Sand Formation, below the Dew Bed, is of Aalensis Zone age (Torrens, 1969) while more recent work places the Dew Bed within the Scissum Zone at the base of the Aalenian Stage (Chandler and Sole, 1996). Hence the Ham Hill Limestone Member and the Dew Bed cannot be considered correlatives.

There have been several interpretations of the environment of deposition of the Ham Hill Limestone Member. James Buckman (1874) noted the similarity in facies between the Ham Hill Limestone Member and richly bioclastic units within the Bridport Sand Formation at **Babylon Hill**, implying that depositional environments represented by these thin shelly bands at Babylon Hill might have been similar to those that produced the bioclastic limestones at Ham Hill. Davies (1969) interpreted the conglomerates as channel lags and the sand-dominated sequence between the two main limestone units as a tidal flat sequence. He found fairly consistent north to north-easterly current orientations for the trough cross-beds throughout the Ham Hill Limestone Member that, combined with the minor 'channel lag conglomerate' towards the top of the sequence, and the dramatic east–west thickness changes, he interpreted as evidence for deposition in a flood-tide channel. The current directions contrast with the predominantly south-west current orientations observed in the Bridport Sand Formation in areas to north and south, and more obviously tidal bimodal orientations in the sands to east and west. Davies (1969) considered that the Bridport Sand Formation was deposited as a sand-bar, breached by tidal channels that migrated more than 100 km southwards from the Cheltenham area to the Dorset coast during the course of the Toarcian Stage. In Davies' (1969) interpretation the exposures at the Ham Hill GCR site, and the adjacent outliers of the Ham Hill Limestone Member, represent the only remaining example of the tidal-channel facies within the Bridport Sand Formation.

Knox *et al.* (1982) suggested that the Ham Hill Limestone Member might have formed as a shell-rich sand wave sweeping across the area after a brief period of non-deposition and erosion represented by the basal conglomerate. Jenkyns and Senior (1991) commented on the prevailing east–west orientation of the clastic sedimentary environments postulated by Davies (1969) and suggested that this was consistent with fault control of the submarine topography. In particular they noted the marked thinning of the Ham Hill Limestone Member southwards across the east–west Coker Fault and suggested that the limestones may have been deposited on fault-controlled topographic highs on which there was little siliciclastic deposition. The absence of the Ham Hill Limestone Member facies to the west of the River Parrett, where the Inferior Oolite Group rests directly on typical Bridport Sand Formation facies (Wilson *et al.*, 1958), also suggests that fault control influenced deposition and/or preservation from pre-Aalenian erosion of the Ham Hill Limestone Member. Further support for a tectonic control on deposition in this area during the Toarcian Age may also be indicated by marked thinning of the Barrington Limestone Member, to 1.2 m at Montacute, and of the Inferior Oolite Group, to 2.4 m at Stoford, 2 km south-east of Yeovil (Hugh Prudden, pers. comm.), both adjacent to the Coker Fault.

The limited evidence appears to favour deposition on a local fault-controlled high causing clastic sediment starvation and the accumulation of a thick bioclastic sequence. The succession at Ham Hill shows two cycles, each with a siliciclastic-dominated sequence abruptly succeeded by siliciclastic-free, cross-bedded, bioclastic limestones with a marked erosion surface at the base (Figure 2.28). It is suggested here that these erosion surfaces reflect discrete episodes of localized uplift, following which siliciclastic material initially was excluded from the local highs that were created thereby allowing bioclastic limestones to accumulate from the comminuted debris derived from adjacent live shell beds. With time the differential relief of these highs was reduced by regional subsidence and there was a progressive increase in the influx of siliciclastic material from the surrounding areas to form the sand-dominated part of the succession lying between the two main bioclastic units. A second episode of uplift, erosion and carbonate deposition is represented by the upper conglomerate and the succeeding cross-bedded bioclastic limestones.

Conclusions

The importance of the quarries on Ham Hill lies in their excellent exposures of the Ham Hill Limestone Member, a thick local development of bioclastic limestone unique within the Lias Group of Britain. The member is restricted to a few outliers west and south-west of Yeovil. The Ham Hill GCR site represents the thickest development of the member and affords the best exposures. The evidence suggests the influence of syn-sedimentary fault movement during deposition. The site has been quarried for its building stone, and since roman times is one of the most famous and widely used in southern England; a working quarry still exists.

MAES DOWN, SOMERSET (ST 647 406)

Introduction

The Maes Down GCR site is a small disused quarry located 150 m south-east of the summit of Maes Down (Figure 2.30). It exposes a section through the Beacon Limestone Formation that shows no evidence for attenuation or development of marginal facies, by comparison with correlative sections farther south in the Wessex Basin, despite its location on the north margin of the basin close to the Mendip structural high. It represents a key site for early Jurassic palaeogeographical reconstructions. There are few published references to the site. The section was logged by Richardson (1906b), while investigating the Inferior Oolite Group of the Doulting area, but even at that time it was rapidly becoming overgrown. The Marlstone Rock Member at the site was referred to subsequently by Richardson (1909, 1910a), Arkell (1933), Howarth (1980) and Bristow and Westhead (1993).

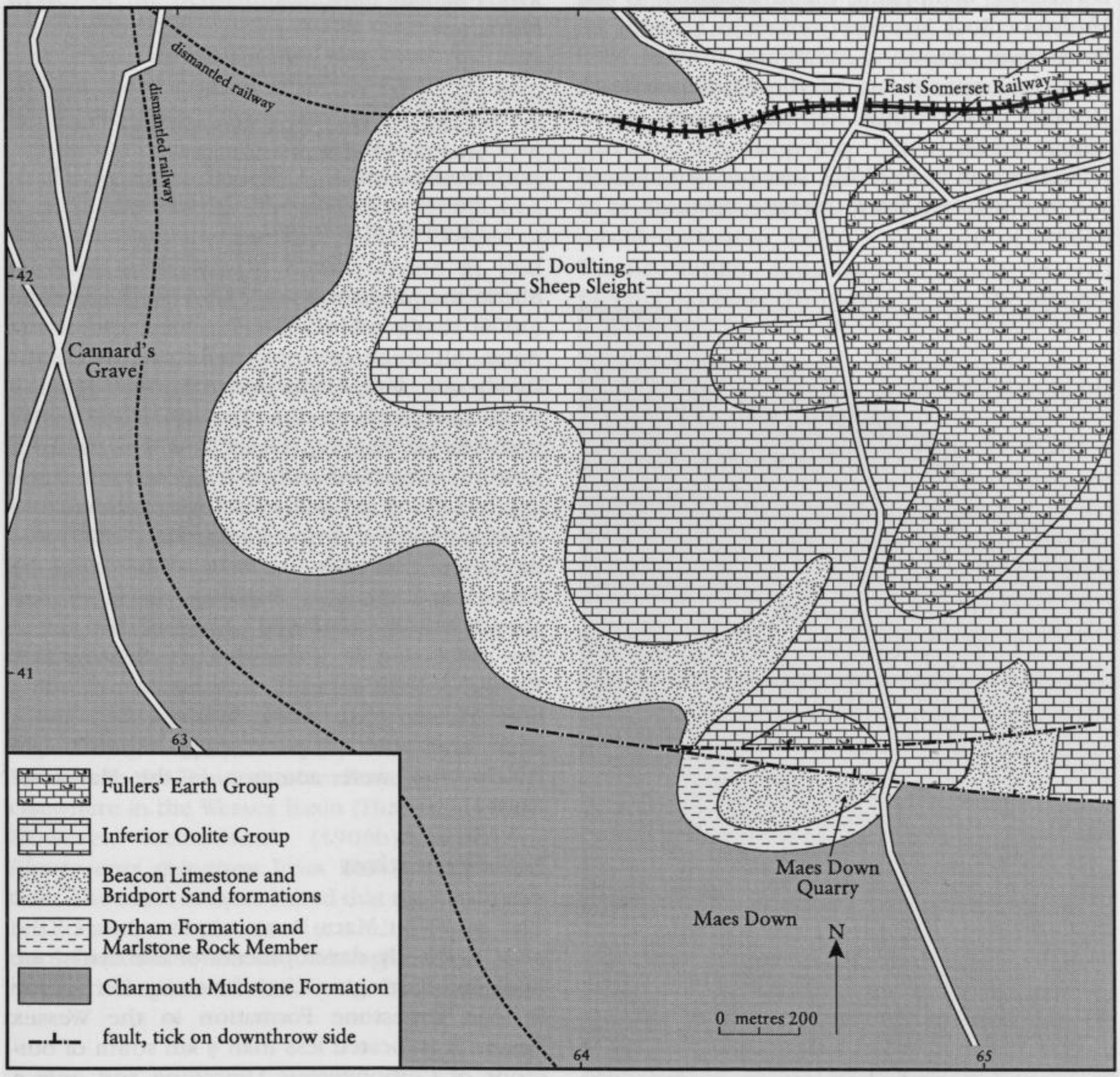

Figure 2.30 Geology and location map of the Maes Down area.

Description

The Dyrham Formation and Beacon Limestone Formation crop out only on the southern flanks of Maes Down. To the north a substantial east–west fault brings down Middle Jurassic sediments against this Lower Jurassic outcrop. North of this fault the Bridport Sand Formation appears to rest unconformably on the Charmouth Mudstone Formation and the correlatives of the succession described here are not seen again until north of the Mendips. The section as recorded by Richardson (1906b) exposed about 4.4 m of the Beacon Limestone Formation, comprising 3.2 m assigned to the Marlstone Rock Member overlain by 1.2 m of the Barrington Limestone Member. In May 2000 only the upper 1.5 m of the Marlstone Rock Member was visible, dipping gently north (Figure 2.31).

Richardson's (1906b) section, metricated and re-numbered from the base upwards, is as follows:

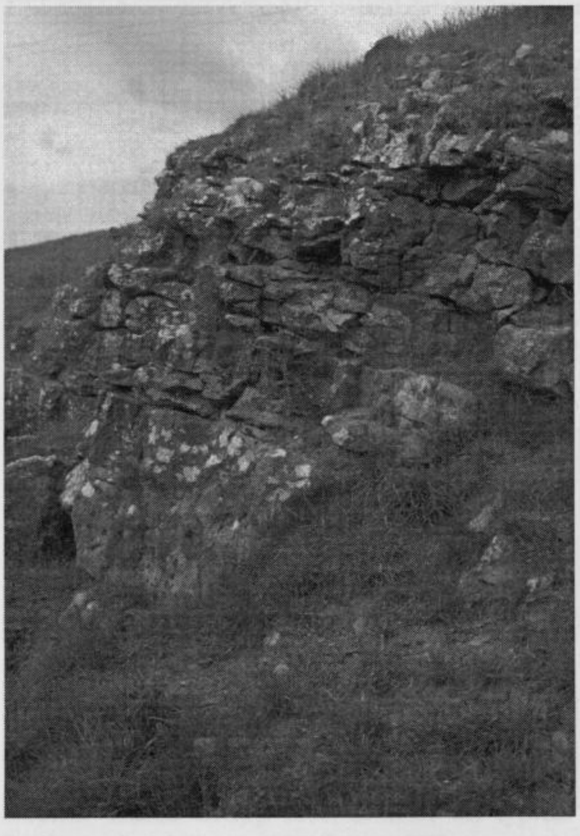

Figure 2.31 The Marlstone Rock Member of the Beacon Limestone Formation at Maes Down. (Photo: M.J. Simms.)

		Thickness (m)
Beacon Limestone Formation		
Barrington Limestone Member		
9:	Clay, brown and bluish.	
8:	Limestone, dark green, earthy, with dark-yellow specks resulting from the decomposition of the ferruginous granules. *Hildoceras* sp., *Dactylioceras* sp., *Pseudogibbirhynchia* cf. *jurensis* and *Pecten substriatus*.	0.4
7:	Limestone, brownish-grey, with a few ferruginous granules.	0.05–0.15
6:	Clay, dark-purplish.	0.45
5:	Limestone, brownish-grey, somewhat earthy, but hard in places, devoid of ferruginous granules. ?*Cleviceras elegans*, *Cryptaulax scobina*?	0.06
4:	Clay, grey and brown.	0.10
Marlstone Rock Member		
3:	Limestone, pale brown, ironshot. *Pleuroceras spinatum*.	0.08
2:	Clay, brown.	0.08
1:	Limestone, hard, dark, ironshot; top layer crowded with belemnites. *Passaloteuthis bisulcata*, *Lobothyris punctata*, *Tetrarhynchia tetrahedra*, *Cypricardia pellucida*.	3.1

Above the Marlstone Rock Member Richardson (1906b) assigned beds 5 to 7 to the Serpentinum Zone, although biostratigraphically diagnostic fossils were found only in Bed 5. Beds 8 and 9 were assigned to the Bifrons Zone. He commented that the clay of Bed 4 occupied a position consistent with a Tenuicostatum Zone age but found no palaeontological evidence to confirm this. He noted (Richardson, 1909) that the Upper Lias beds had been visible when he first visited the site, implying that they had already become obscured. None of this part of the succession is visible today. Bristow and Westhead (1993) stated that fossils, including brachiopods, gastropods, bivalves, belemnites and ammonites, particularly species of *Pleuroceras*, were common in the Marlstone Rock Member.

Interpretation

The quarry at Maes Down exposes one of the most northerly developments of the Marlstone Rock and Barrington Limestone members of the Beacon Limestone Formation in the Wessex Basin. It is located less than 4 km south of outcrops of Carboniferous Limestone and only a few hundred metres south of outcrops where Upper Pliensbachian strata are absent and the Bridport Sand Formation rests directly on the

Charmouth Mudstone Formation. Around Doulting, 3 km to the north, an attenuated Toarcian succession of sandy and ironshot limestones lies between clays presumed to represent the Charmouth Mudstone Formation and limestones of the Inferior Oolite Group above (Green and Welch, 1965). The Hettangian to Lower Pliensbachian succession in this region is also characterized by coarse marginal facies, such as are exposed at the **Viaduct Quarry** GCR site. Despite the proximity of the Maes Down GCR site to the basin margin, the Marlstone Rock Member is unusually thick (3.2 m), a fact remarked upon by Arkell (1933). The thicknesses of the Serpentinum and Bifrons zones recorded by Richardson (1906b) are comparable with those of the more condensed sections around Yeovil (Wilson *et al.*, 1958) but, unlike them, the Maes Down succession includes a significant thickness of mudstones. The similarity of the Beacon Limestone Formation here to that in the Ilminster and Yeovil area suggests that the Mendip Massif exerted a minimal influence on sedimentation at that time and that the absence of this part of the Lower Jurassic succession farther north is due largely to pre-Aalenian erosion rather than to non-deposition. However, from the absence of Upper Pliensbachian strata immediately north of the fault on Maes Down it is clear that this fault was active during early Jurassic times and that the survival of such sediments to the south reflects this. The present relationship between the strata that crop out to north and south of the fault suggests an episode of tectonic inversion, as is well established elsewhere in the Wessex Basin (Chadwick, 1993).

The biostratigraphy of the succession has yet to be fully resolved. Bristow and Westhead (1993) included the top part of the Marlstone Rock Member in the Tenuicostatum Zone, as recorded elsewhere in the Wessex Basin (Howarth, 1980). However, Richardson's (1906b) record of *Pleuroceras spinatum* from Bed 3 contradicts this. The same authors stated that the Marlstone Rock Member in this area extended down into the Subnodosus Subzone. Although this has been claimed for parts of the Severn Basin (Simms, 1990a), it has yet to be demonstrated anywhere in the Wessex Basin. The unusual thickness of the Marlstone Rock Member in the Maes Down area may therefore be due either to earlier onset of deposition of this facies here than elsewhere in the Wessex Basin or to enhanced deposition rates in late Pliensbachian times.

Within the Barrington Limestone Member Richardson (1906b) obtained ammonites from only beds 5 and 8. He assigned beds 6 and 7 to the Serpentinum Zone on the basis of their lithological similarity to Bed 5. However, the only ammonite he recorded from Bed 5, *Polyplectus capellinus*, is probably a mis-identification since this is a synonym of an Upper Toarcian species, *Polyplectus discoides* (Howarth, 1992). It might have been a *Polyplectus pleuricostata* or a *Cleviceras elegans*, both of which occur in the Serpentinum Zone (Howarth, 1992), but the specimen has been lost. Richardson (1906b) recorded *Hildoceras bifrons* and *Dactylioceras* cf. *hollandrei* in Bed 8. The latter is probably a mis-identification, being a synonym of a basal Tenuicostatum Zone species, *Dactylioceras pseudocommune* (Howarth, 1973). The identification of *Hildoceras bifrons* may also be suspect since other species of *Hildoceras*, from the Serpentinum to Variabilis zones, have commonly been mistaken for *H. bifrons*.

The ammonites recovered from the Toarcian part of the succession at Maes Down have not resolved the biostratigraphy at the site. Even though Richardson (1906b) acknowledged the assistance of the ammonite specialist S.S. Buckman, most would appear to have been mis-identified.

Conclusions

Despite the close proximity of the Maes Down GCR site to the Mendip structural high, the section through the Beacon Limestone Formation shows little stratigraphical attenuation and is not a marginal facies. The site remains under-investigated despite its importance in elucidating the early Jurassic history of the northern margin of the Wessex Basin close to the Mendip structural high.