British Lower Jurassic Stratigraphy

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Chapter 4

The Severn Basin

INTRODUCTION

M.J. Simms

The Severn Basin, sometimes also known as the 'Worcester Basin' or 'Worcester Graben', is an elongate basin trending north–south containing a thick Mesozoic succession. Its eastern and western boundaries are well defined by the Vale of Moreton Anticline and the East Malvern Fault respectively (Figure 4.1), a width of about 50 km. The north and south limits of the basin are less clearly delimited but extend probably from the Kidderminster–Bromsgrove area in the north, southward to beyond Stroud, a distance of 90 km or more (Sellwood *et al.*, 1986). Lower Jurassic rocks crop out extensively in the southern part of the basin and attain a total thickness of almost 500 m. However, details of many parts of the succession are poorly known. The Stowell Park Borehole penetrated the full succession in the eastern part of the basin and was well documented (Green and Melville, 1956; Melville, 1956; Spath, 1956), with several other boreholes subsequently penetrating parts of the Lower Jurassic sequence elsewhere, such as the Hettangian and lowermost Sinemurian successions at Twyning (Worssam *et al.*, 1989) and the Pliensbachian and Toarcian sequences on Bredon Hill (Whittaker and Ivimey-Cook, 1972). However, although virtually all ammonite zones and subzones have been proven at surface outcrop (Simms, 2003b), there are few permanent exposures. A few low cliffs and foreshore exposures occur along the banks of the River Severn and Severn Estuary downstream of Gloucester, but these expose only Hettangian and lowermost Sinemurian strata and remain mostly undocumented. Later Sinemurian strata have been exposed only in temporary excavations while Pliensbachian and Toarcian strata, which crop out mostly on or at the foot of the Cotswold scarp and its outliers, are exposed only in occasional landslip scars or in brickpits and quarries, the latter now mostly defunct. Seven sites have been selected for GCR status, representing parts of the Lower Sinemurian and the Lower Pliensbachian, almost the entire Upper Pliensbachian, part of the Lower Toarcian and the Upper Toarcian sequences (Figure 4.2). Other parts of the succession are too poorly known or exposed to warrant designation of GCR sites.

By far the finest Lower Sinemurian exposure is at **Hock Cliff**. At the still active **Blockley Station Quarry** an exceptionally thick and fossiliferous sequence through part of the Lower Pliensbachian succession is exposed. Farther south the long disused **Robin's Wood Hill Quarry** still affords a magnificent exposure through much of the Pliensbachian succession. All the quarries excavated in the Whitby Mudstone Formation of the lower part of the Toarcian Stage are long disused and heavily overgrown. The most famous of these, **Alderton Hill Quarry**, has yielded an exceptional fossil fauna including fish and insects. In the southern part of the basin three Upper Toarcian sites, namely **Wotton Hill**, **Coaley Wood** and **Haresfield Hill**, have been selected to show the range of lateral variation within the Cotswold Cephalopod Bed Member, a unique facies development of the Bridport Sand Formation.

Lithostratigraphy and facies

Data obtained from the few permanent exposures and from temporary exposures across the Severn Basin over a more than 30-year period (Simms, 2003b) have helped to build up a fairly clear picture of the stratigraphy of this thick Lias Group succession. Typical Penarth Group mudstones with thin sandstones and limestones are exposed in river cliffs at Wainlode Hill (SO 845 257) north of Gloucester, and at Westbury-on-Severn (SO 717 129) (descriptions summarized in Macfadyen, 1970) and are succeeded by poorly exposed alternating mudstones and limestones of the basal Lias Group 'Pre-Planorbis Beds'. Some of the limestones in this part of the succession are laminated and have yielded rich insect faunas from these sites and from 19th century quarries. The Planorbis and Liasicus zones are seldom well-exposed but are developed in fairly typical Blue Lias Formation facies of limestones, sometimes laminated, and mudstones. Limestone–mudstone alternations are particularly frequent in the succeeding Angulata Zone and in the Conybeari Subzone at the base of the Sinemurian Stage; this part of the succession is rather indifferently exposed on the foreshore and low cliffs along the Severn Estuary around Gatcombe (SO 685 057), Awre (SO 706 074) and Arlingham (SO 712 098). Limestones are more widely

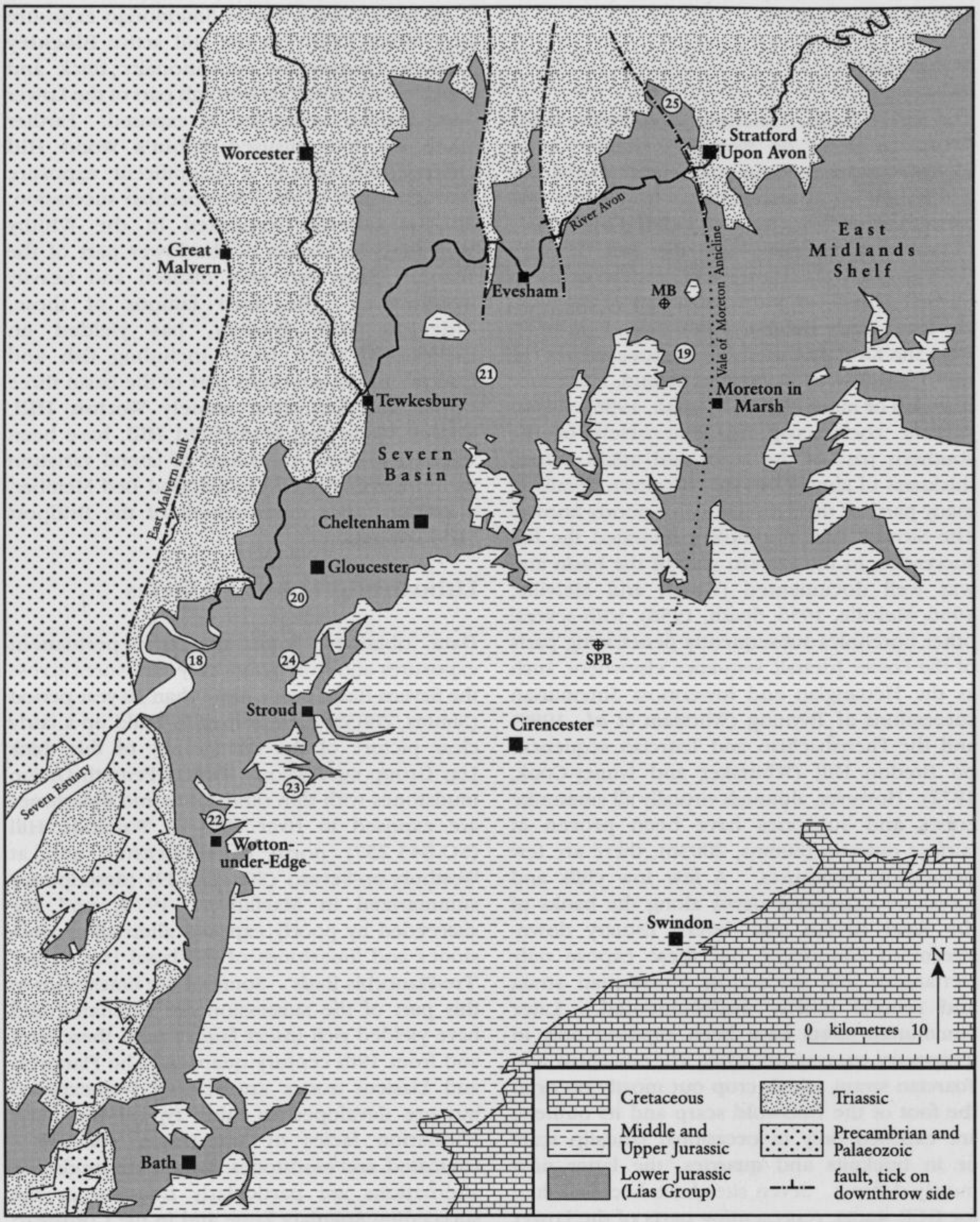

Figure 4.1 Generalized geology of the Severn Basin and western edge of the East Midlands Shelf. Only the main basin-bounding faults are indicated. Numbers correspond to the locations of the GCR sites: 18 – Hock Cliff; 19 – Blockley Station Quarry; 20 – Robin's Wood Hill Quarry; 21 – Alderton Hill Quarry; 22 – Wotton Hill; 23 – Coaley Wood; 24 – Haresfield Hill; 25 – Newnham (Wilmcote) Quarry (Chapter 5); MB – Mickleton Borehole; SPB – Stowell Park Borehole.

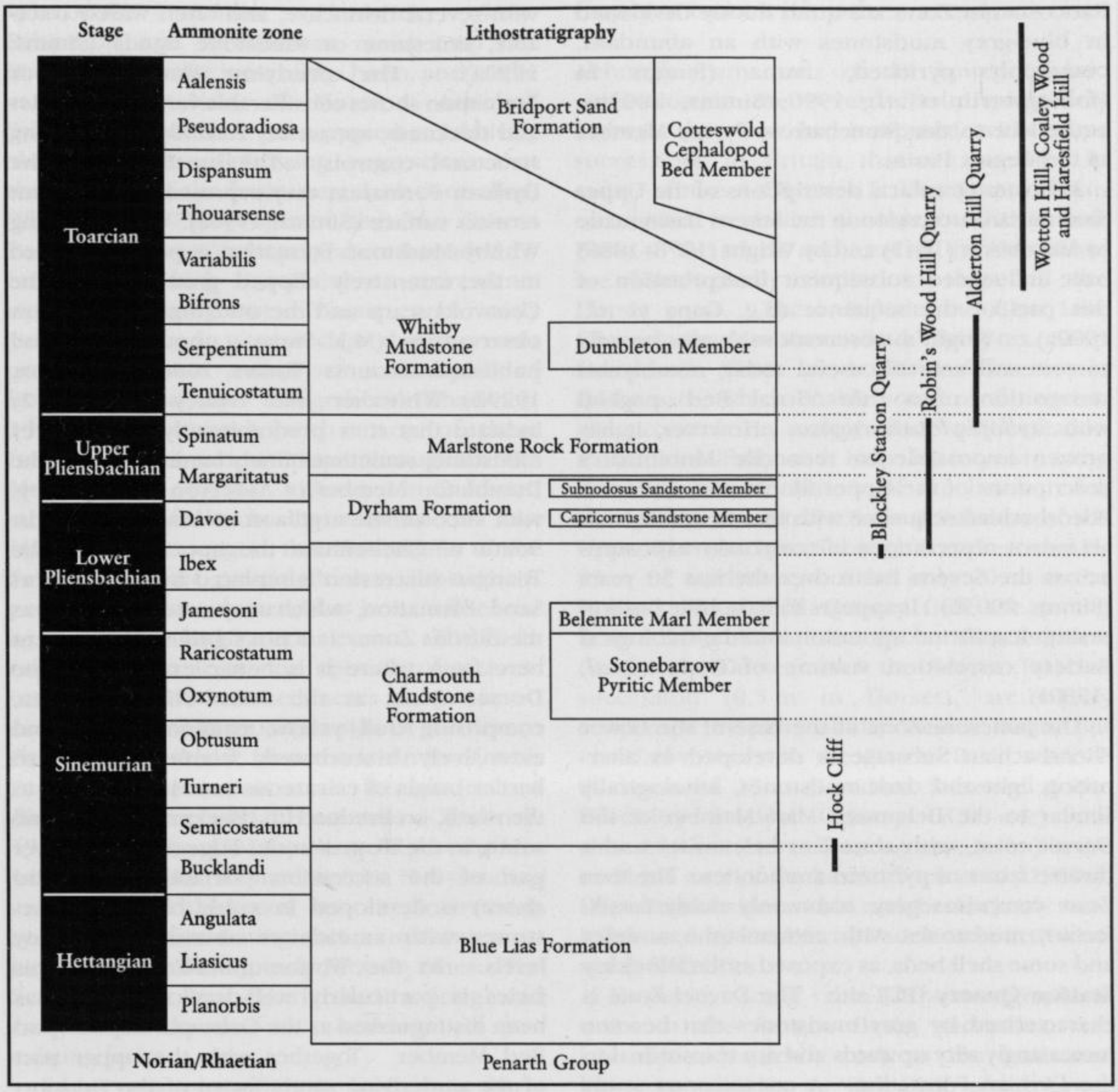

Figure 4.2 Lithostratigraphical subdivisions and stratigraphical ranges of GCR sites for the Lias Group of the Severn Basin.

spaced in the Rotiforme, Bucklandi and Lyra subzones, with dark laminated shales a conspicuous feature in the Rotiforme Subzone. This part of the succession is exposed at several points along the Severn Estuary, on the foreshore at Awre, near Arlingham (Glass Cliff), at Maisemore (SO 818 216) (Richardson, 1906c) and especially at **Hock Cliff**. The remainder of the Sinemurian Stage is only ever represented by exposures of mudstones with few limestone beds in temporary excavations. They can be assigned to the Charmouth Mudstone Formation. The Semicostatum to Obtusum zones typically comprise blue-grey clays, commonly with cementstone nodules. Phosphatic nodules and fossils are common in the lower part of the Sauzeanum Subzone, suggesting a minor hiatus. The Denotatus Subzone is less than 0.5 m thick and there is a hiatus, indicated by bored and encrusted bivalves and belemnites, at the junction with the succeeding Simpsoni Subzone. The Oxynotum Zone and the ensuing

Raricostatum Zone are quite thickly developed in blue-grey mudstones with an abundant, commonly pyritized, fauna (Simms in Hollingworth *et al.*, 1990; Simms, 2003b), equivalent to the Stonebarrow Pyritic Member of the Wessex Basin.

Lithostratigraphical descriptions of the Upper Sinemurian succession in the Severn Basin made by Murchison (1845) and by Wright (1878–1886) have influenced subsequent interpretation of this part of the sequence (e.g. Cope *et al.*, 1980a). Wright's observations were broadly correct and are still useful today, notably his recognition of a thin 'Coral Bed' packed with *Styllophylopsis rugosa*. However, it has proven impossible to reconcile Murchison's descriptions of the Upper Sinemurian to Lower Pliensbachian sequence with that deduced from abundant observations of temporary exposures across the Severn Basin over the last 30 years (Simms, 2003b). It appears to have little basis in reality, despite incorporation into the Geological Society correlation volume of Cope *et al.* (1980a).

The Jamesoni Zone at the base of the Lower Pliensbachian Substage is developed in alternating light and dark mudstones, lithologically similar to the Belemnite Marl Member of the Dorset coast, with abundant belemnites and a diverse fauna of pyritized ammonites. The Ibex Zone comprises grey, commonly richly fossiliferous, mudstones with cementstone nodules and some shell beds, as exposed at the **Blockley Station Quarry** GCR site. The Davoei Zone is characterized by grey mudstones that become increasingly silty upwards and are transitional to the Dyrham Formation. A conspicuous sandy siltstone unit around the middle of the zone, the Capricornus Sandstone, is an important marker band that can be traced from at least Bredon Hill in the north (M.J. Simms, unpublished observations) southwards to the Stroud area (Palmer, 1971) and perhaps to Hawkesbury, 5 km south of Wotton-under-Edge (Cave, 1977). The entire Davoei Zone (including the Capricornus Sandstone) and Dyrham Formation is superbly exposed at the **Robin's Wood Hill Quarry** GCR site, this being the type locality for the formation (Cox *et al.*, 1999). Poor exposures are seen occasionally along the steep scarp of the Cotswold Hills and outliers to the west. The Dyrham Formation comprises silty mudstones with several distinctive, and often widely traceable, limestone or sandstone bands (Simms, 1990a). The overlying Marlstone Rock Formation shows considerable variation in facies and thickness, apparently related to underlying structural controls. The junction with the Dyrham Formation may represent a significant erosion surface (Simms, 1990a). The overlying Whitby Mudstone Formation is poorly exposed in the extensively slipped ground along the Cotswold scarp and the outlying hills. Recent observations (M.J. Simms, unpublished) and published accounts (Tomes, 1886; Richardson, 1929b; Whittaker and Ivimey-Cook, 1972) indicate that it is predominantly of blue-grey mudstone, sometimes finely laminated as in the Dumbleton Member of **Alderton Hill Quarry**, with subordinate argillaceous limestone bands. South of Cheltenham the upper part of the Toarcian succession is replaced by the Bridport Sand Formation, which may extend as low as the Bifrons Zone. It is not significantly different here from where it is better exposed on the Dorset Coast at the **East Cliff** GCR site, comprising dull yellow, commonly silty and extensively bioturbated, friable sands with harder bands of calcareous sandstone. Both in the north, on Bredon Hill (Buckman, 1903), and south, in the Wotton-under-Edge area, the upper part of the succession (Variabilis Zone and above) is developed in sandy bioclastic limestones with ammonites abundant at many levels. In the Wotton-under-Edge area this facies is particularly well-developed and has been distinguished as the Cotswold Cephalopod Bed Member. Together with the upper part of the underlying sandy facies of the Bridport Sand Formation, it is well exposed in various disused quarries, sunken lanes and natural exposures, including the GCR sites at **Haresfield Hill**, **Wotton Hill** and **Coaley Wood**.

In conclusion, the Severn Basin preserves a thick and almost complete Lower Jurassic succession in which every ammonite zone, and almost every subzone, is represented.

Basin development

Within the Severn Basin, Permian and Mesozoic sediments reach thicknesses of more than 2 km, with no borehole having penetrated the

Palaeozoic basement (Chadwick, 1985). Palaeozoic and Precambrian rocks crop out immediately to the west of the basin, and to the east of the Vale of Moreton Anticline Palaeozoic strata have been proved at relatively shallow depth. Following suggestions that the margins of the basin were fault-controlled, Whittaker (1975) proposed that the Severn Basin was a post-Variscan graben bounded by faults on which intermittent movements occurred throughout Triassic and early Jurassic times. It is now clear that the main graben structure comprises a complex of horsts, grabens and half-grabens (Chadwick, 1985, pers. comm.), with many of these faults active at various times throughout the Mesozoic Era. Thickness changes in Cambrian strata across faults to the west of the East Malverns Fault suggest that the origins of the Severn Basin are pre-Caledonian, although its present north–south trend has been influenced by Caledonian and Variscan events. The basin experienced at least one episode of tectonic inversion. Palaeozoic sediments are preserved on footwall blocks on either side of the Severn Basin but are absent from the basin itself, with Permian and Mesozoic strata thought to rest directly on Precambrian basement (Chadwick, 1985). Whittaker (1972b) observed that the Lias within the basin thinned across N–S-trending anticlines and thickened into the intervening synclines, demonstrating that movement must have occurred during early Jurassic times. The Severn Basin has clearly had a long and complex history due to re-activation of pre-existing faults.

Facies variations within the basin must therefore reflect a range of structural controls as well as the effects of exogenous factors such as climate and sea level. In particular, major environmental changes occurred at the close of the Toarcian Stage, which affected deposition in the Severn Basin. Sea levels continued to fall and carbonate deposition expanded in response to climatic warming (Bradshaw *et al.*, 1992). A disconformity is recognized across the Severn Basin at the Early–Middle Jurassic boundary (Barron *et al.*, 1997), above which the Birdlip Limestone Formation was deposited. In the mid-Cotswolds, its base is marked by the Opaliniforme Bed, an iron-oolitic bioclastic limestone.

Comparison with other areas

Although many parts of the Lower Jurassic succession in the Severn Basin are poorly known, they can be compared with other successions in Britain that are exposed at many of the GCR sites. The Severn Basin succession is similar to that in the Wessex Basin to the south, and most of the formations are lithologically similar to those of the Dorset coast. These include the Blue Lias, Charmouth Mudstone and Bridport Sand formations. There are, however, differences in thicknesses, which enable some of the underlying controls on early Jurassic sedimentation to be identified, and help in reconstructing the early Jurassic history of the basins. For example, in Dorset the Stokesi Subzone of the Upper Pliensbachian Substage is represented by 93 m of mudstone, but by only 20 m at the **Robin's Wood Hill Quarry** GCR site in the Severn Basin. In contrast, the Luridum Subzone (0.15 m in Dorset) and the Lower Toarcian succession (0.5 m in Dorset), are highly condensed in parts of the Wessex Basin, but correlative strata in the Severn Basin attain a thickness of 17 m (Luridum Subzone at the **Blockley Station Quarry** GCR site) and almost 100 m (Lower Toarcian succession) in the northern area of the basin (Cope *et al.*, 1980a). Depositional rates within each basin clearly were influenced by local factors such as re-activation along fault lines.

However, some thin lithostratigraphical units in the Severn Basin succession are laterally widespread, such as the laminated limestone nodules, or 'Fish Bed', of the Lower Toarcian Dumbleton Member. Similar nodules occur at closely comparable stratigraphical levels in the Ilminster area of Somerset (Moore, 1867b) and on the East Midlands Shelf (Howarth, 1978), indicating a wide-scale, probably eustatic, control. The distribution of the Bridport Sand Formation also has interesting implications for the history of both the Severn and Wessex basins. Its restricted areal distribution and diachronous nature, becoming younger southwards, precludes any purely eustatic control and indicates that the Mendip Massif did not present a significant barrier to north–south movement of clastic sediment at this time.

HOCK CLIFF, FRETHERNE, GLOUCESTERSHIRE (SO 725 093)

Potential GCR site

M.J. Simms

Introduction

Exposures of upper Hettangian and Lower Sinemurian strata occur at several localities along the tidal reaches of the River Severn between Gloucester and Sharpness. These include river cliffs at Maisemore (SO 818 216) (Richardson, 1906c), Fretherne (SO 725 093) (Richardson, 1908; Henderson, 1934) and Purton (SO 695 045) (Woodward, 1728; Weaver, 1824; Woodward, 1893) and foreshore exposures at Awre (SO 706 074) (Witton, 1830), Arlingham (SO 712 098) and Gatcombe (SO 685 057). By far the most extensive of these is that at Hock Cliff, near Fretherne, about 10 km south-west of Gloucester (Figure 4.1), a site that represents the best exposure in the Severn Basin of the Blue Lias Formation. It exposes limestone–mudstone rhythms that pass up into a sequence with more widely spaced limestones, transitional to the Charmouth Mudstone Formation. The site has yielded an exceptionally diverse macro- and microfauna, including the type specimens of several bivalve species and holothurian morphospecies, undescribed species of asteroid and ophiuroid, and two ammonite genera unique in the British Lias.

The earliest description of the site was by George Cumberland in 1822. Brodie (1853) gave a further short account; a fuller description, with coloured sections, was published by Lucy (1883). The site was mentioned briefly by Woodward (1893), who ascribed the strata to the Angulata, Bucklandi and possibly higher zones. Richardson (1908) provided the first detailed stratigraphical description, concluding from ammonite evidence that the strata could be assigned a 'marmorae–birchi' age (= Angulata to Turneri zones of the present system) or even a 'possible extension to megastomatos–obtusi' (= Laqueus to Obtusum subzones). However, he stated subsequently (Richardson, 1910a) that 'the topmost limestones of marmorea hemera are just visible at low tide and are succeeded by nodule-lined clays of rotiformis–gmuendensis and possibly later hemerae' (= topmost Angulata Zone to Lyra Subzone). In a short note on the section Trueman (1922a) stated that 'it appears from recent observations that no beds lower than the bucklandi zone are present'. Henderson (1934) gave a more detailed account of the fauna although her stratigraphical section was essentially the same as that of Richardson (1908). Other accounts have been concerned solely with aspects of the fossil fauna. Ager (1954) figured material of two rhynchonellid species from here and Simms (1989) described crinoid material from the site. Gilliland (1992) gave a summary graphic log of the succession and figured numerous holothurian spicules, including several new species based on material from the site.

Description

The Lower Lias exposed at Hock Cliff extends for almost 1 km along the shore of the Severn Estuary a few hundred metres to the south-west of the village of Fretherne (Figure 4.3). At low tide a more than 17 m-thick succession of mudstones with subordinate limestone bands is exposed in the cliff and foreshore (Figures 4.4 and 4.5), with the lowest limestone forming a ledge extending more than 100 m into the river. A minor anticlinal fold occurs in the middle part of the section, and a small but conspicuous asymmetric anticline is present towards the eastern end of the cliff. Slight flexuring occurs at the extreme western end, but the strata in the

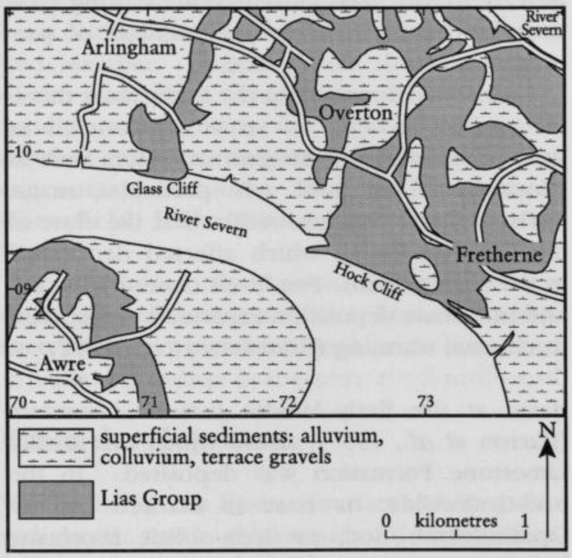

Figure 4.3 Geology and location map for the Hock Cliff GCR site.

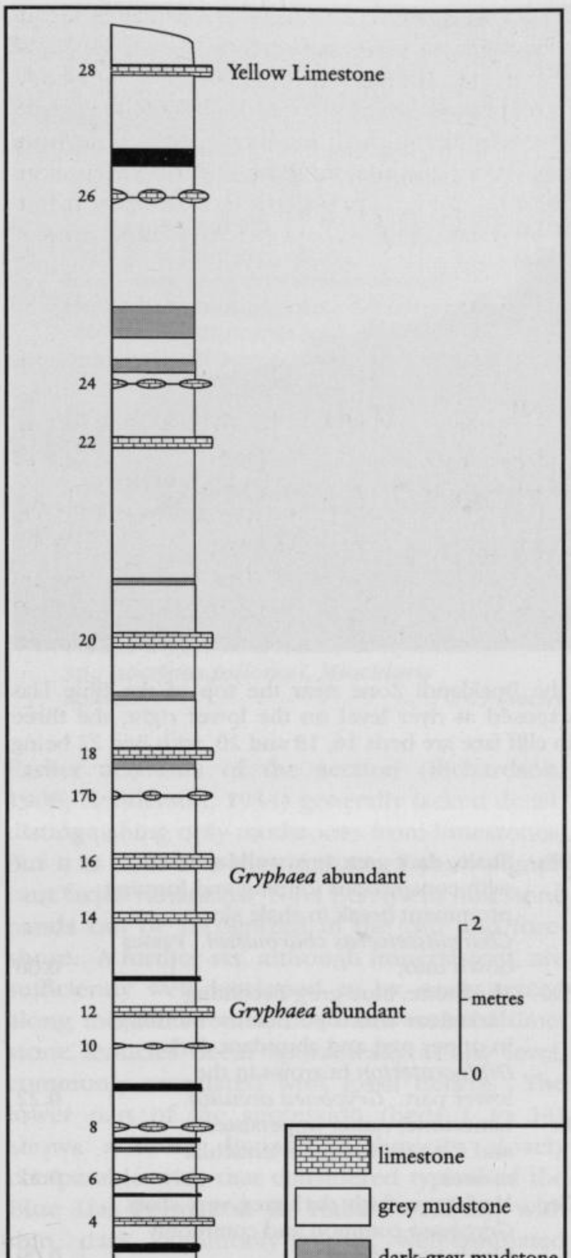

Figure 4.4 Simplified graphic log of the succession exposed at Hock Cliff, Fretherne.

western half of the cliff are almost horizontal. East of the central anticline they dip gently east so that the highest part of the succession is present only towards the eastern end. The section reproduced here is based on measurements made in 1999 and 2002 and observations made on numerous visits since 1976. Equivalent bed numbers used by Richardson (1908) are included in parentheses; these are the same as those used subsequently by Henderson (1934).

		Thickness (m)
29:	Mudstone, yellowish-weathered (Bed 1).	0.45
28:	Yellow Limestone. Limestone, grey, shelly, weathering yellow (Bed 2). *Arietites bucklandi*, *Coroniceras lyra*, *Arnioceras ceratitoides*. *Cuneirhynchia oxynoti* abundant, *Cenoceras* sp., *Plagiostoma giganteum*, *Gryphaea arcuata*, *Chlamys*.	0.15
27c:	Mudstone, grey- to yellow-weathered.	*c.* 1.2
27b:	Paper shale, dark grey-brown, well laminated. Fish debris.	0.22
27a:	Mudstone, grey, shaly.	0.45
26:	Limestone, impersistent, grey, earthy.	0.20
25e:	Mudstone, grey, shaly.	1.50
25d:	Mudstone, dark grey, shelly.	0.40
25c:	Mudstone, grey, shaly, passing downwards into;	0.30
25b:	Shale, dark grey, passing downwards into;	0.10
25a:	Mudstone, grey, shaly.	0.10
24:	Limestone, impersistent.	0.12
23:	Mudstone, grey, shaly, with pyritized burrows.	0.65
22:	Limestone, fairly persistent.	0.15
21c:	Mudstone, grey, shaly.	1.80
21b:	Shale, dark grey.	0.08
21a:	Mudstone, blue-grey, with occasional limestone lenticles.	0.65
20:	Limestone, persistent (Bed 10). In places with an abundant benthic fauna including *Gryphaea*, *Plagiostoma*, *Antiquilima*, *Chlamys*, *Oxytoma*, *Isocrinus* and *Miocidaris*.	0.20
19c:	Mudstone, grey, shaly, with burrow mottling towards top. Spines of *Miocidaris lobatum* abundant at base.	0.60
19b:	Mudstone, dark grey, shaly.	0.10
19a:	Mudstone, grey, shaly, with burrow mottling towards base. *Hybodus* tooth. Pyritized *Arnioceras* sp. common throughout beds 19a–c.	0.65
18:	Limestone, persistent (Bed 12). *Eucoroniceras sinemuriense*.	0.16
17d:	Clay, dark grey, shaly. Pyritized multi-costate *Coroniceras*.	0.11
17c:	Clay, grey, shaly, with occasional shelly limestone lenses.	0.36
17b:	Limestone, impersistent, lenticular. Fossiliferous on upper surface.	0.12
17a:	Clay, grey, shaly. *Charmasseiceras charmassei*.	0.72
16:	Limestone, persistent (Bed 14).	0.20
15:	Mudstone, grey, with occasional shelly limestone lenticles (Bed 15). *Charmasseiceras charmassei*. *Piarorhynchia juvensis* abundant throughout. *Gryphaea arcuata* abundant 0.3 m below top, commonly as intact specimens. *Zeilleria* sp..	0.60

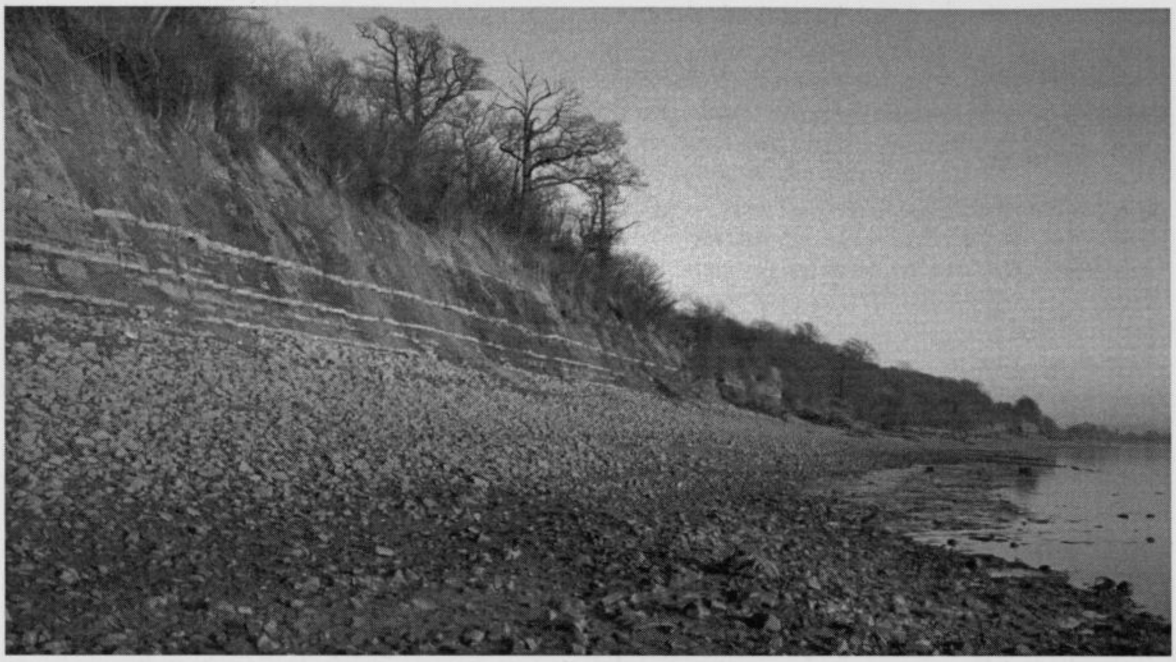

Figure 4.5 Alternating mudstones and limestones of the Bucklandi Zone near the top of the Blue Lias Formation at Hock Cliff, looking eastwards. Bed 2 is exposed at river level on the lower right; the three conspicuous limestone bands in the lower half of the main cliff face are beds 16, 18 and 20, with Bed 22 being the fainter band about 2 m higher. (Photo: M.J. Simms.)

		Thickness (m)
14:	Limestone, fairly persistent (Bed 16). *Cenoceras striatus*.	0.12
13c:	Mudstone, grey, shaly, with abundant, dark, burrow mottling. *Charmasseiceras charmassei*, abundant *Piarorhynchia juvensis*, occasional bio-eroded *Gryphaea* valves, *Pleurotomaria anglica*, *Oxytoma inequivalvis*, *Camptonectes* sp., *Isocrinus psilonoti*.	0.72
13b:	Shale, dark grey, very well-laminated. Many pyritized burrows.	0.05
13a:	Mudstone, blue-grey. *Oxytoma inequivalvis*, intact *Gryphaea arcuata* and plesiosaur rib.	0.35
12:	Limestone, rather constant, tabular (Bed 18). Abundant *Gryphaea arcuata*. *Cenoceras striatus*.	0.12
11:	Mudstone, blue-grey, darker and more shaly in top 0.12 m. Abundant shell debris and darker *Diplocraterion* burrows. *Charmasseiceras charmassei*.	0.36
10:	Limestone, rather impersistent (more so than beds 6 or 8). *Charmasseiceras charmassei*.	0.08
9c:	Mudstone, blue-grey, shaly, darker towards base and with paler burrow mottling. Worn ichthyosaur vertebra and bio-eroded *Gryphaea*. Passes down into;	0.28
9b:	Shale, dark grey, very well-laminated, with conspicuous jointing and forming prominent break in shale slope. *Charmasseiceras charmassei*. Passes down into;	0.08
9a:	Mudstone, blue-grey, becoming darker towards top. Burrow mottling in upper part and abundant dark *Diplocraterion* burrows in the lower part. *Gryphaea arcuata*.	0.22
8:	Limestone, rather impersistent and forming irregular lenticular masses.	0.12
7e:	Mudstone, fairly dark-grey, very shaly. *Gryphaea* common and commonly highly bio-eroded.	0.09
7d:	Shale, dark-grey, well laminated.	0.05
7c:	Mudstone, blue-grey, shaly. *Gryphaea* common and commonly highly bio-eroded.	0.08
7b:	Mudstone, dark grey, shaly. Forms conspicuous break on shore.	0.04
7a:	Mudstone, blue-grey, shaly. *Charmasseiceras*, *Gryphaea* common, sometimes bio-eroded.	0.30
6:	Limestone, rather impersistent and forming irregular lenticular masses (Bed 20). Driftwood.	0.12
5c:	Shale, fairly dark-grey. *Charmasseiceras*, *Gryphaea* common.	0.15
5b:	Shale, dark grey, well laminated, forming break on shore.	0.03

		Thickness (m)
5a:	Mudstone, blue-grey, shaly, with occasional limestone lenticles and nodules. Crinoid and echinoid debris common, particularly in limestone lenticles. Pyritized and crushed 0.3 m-diameter *Coroniceras* cf. *rotiforme*.	0.30
4:	Limestone (Bed 22).	0.10
3c:	Mudstone, blue-grey, shaly.	0.25
3b:	Shale, dark grey, very well-laminated, particularly in upper part. *Coroniceras* ? *rotiforme*, *Vermiceras scylla*.	0.10
3a:	Mudstone, blue-grey, shaly. Crinoid and echinoid debris common in shelly patches.	0.22
2:	Limestone, grey, persistent, forming conspicuous wide ledge at northern end of cliff at low tide (Bed 24). Upper 0.05 m bluish and rather softer and contains common *Vermiceras scylla*.	0.25
1:	Mudstone, grey, fossiliferous, exposed only at northernmost end of foreshore during low tides (Bed 25). *Vermiceras scylla*, *Gryphaea arcuata*, *Camptonectes* sp., *Isocrinus psilonoti*, *Miocidaris* spines.	0.45 (seen)

Earlier accounts of the section (Richardson, 1908; Henderson, 1934) generally lacked detail, distinguishing only mudstones from limestones, but it is clear that the mudstones show significant facies variations. Nine persistent limestone bands can be recognized in the cliff and foreshore. A further six, although impersistent, are sufficiently well-developed to be easily traced along the cliff section, but other isolated limestone lenticles occur sporadically at any level, commonly associated with fossil debris. The lower part of the succession (beds 1 to 14) shows a fairly distinct rhythmicity closely comparable with that considered typical of the Blue Lias Formation by Hallam (1964a), with thin, dark, commonly pyritic, well-laminated shale units occurring towards the middle of the paler, bioturbated mudstones that separate the limestones. Above Bed 14 these rhythms are indistinct or absent and the limestone bands are, in general, more widely spaced. The abundance of *Gryphaea* in Bed 12 and towards the top of Bed 15 render these useful marker horizons for both the eastern and western parts of the cliff. The yellow-weathering shelly limestone of Bed 28 is particularly conspicuous as fallen blocks towards the eastern end of the section, although it may be difficult to locate *in situ*.

Other than Bed 28, which contains fairly abundant brachiopods, bivalves, ammonites and echinoderm debris, the limestone bands are, in general, rather poorly fossiliferous. With the exception of ammonites, large specimens of the nautilus *Cenoceras*, and *Gryphaea*, fossils are largely confined to localized patches on the upper surface of the limestones and commonly are associated with these large cephalopods or with large pieces of driftwood. Within the mudstones benthic macrofossils also tend to be concentrated at certain horizons or in localized patches. For example, the brachiopod *Piarorhynchia juvensis* is abundant throughout Bed 15 whereas spines of the echinoid *Miocidaris lobatum* are abundant at the base of Bed 19c. The richest accumulations tend to be associated with shelly and crinoidal limestone lenses that have a flat top and irregular base. Although much of the fossil material is broken and disarticulated, intact crinoids and ophiuroids have been found on the upper surface of some of these lenses. The thin, dark, well-laminated mudstone units in the lower part of the succession have yielded only ammonites, although vertical pyritized burrow-fills are common in Bed 13b. The other mudstones show varying degrees of bioturbation, with darker mudstones showing less disruption of lamination than paler units. Distinct *Chondrites* and *Diplocraterion* burrows are visible at several levels.

Most of the beds have only a limited foreshore outcrop and fossil material can be difficult to find *in situ* in the cliff. Nonetheless an exceptionally rich and diverse macrofauna has been recovered, primarily from loose material on the shore. Ammonites are common but often rather poorly preserved, immature and of poorly understood arietitid taxa. *Charmasseiceras charmassei* is not uncommon in the lower part of the section, while various small arietitids and *Arnioceras* dominate the upper part of the section. Large specimens of both *Arietites bucklandi* and *Coroniceras lyra* have been recovered from Bed 28, which also commonly contains *Arnioceras ceratitoides* (Spath, 1956). A large specimen of *Coroniceras* cf. *vercingetorix* was also figured from here by Wright (1878–1886) (as *Arietites bisulcatus*; see Donovan, 1954). More than 30 specimens of the Tethyan micromorph *Canavarites*, together with a few of the closely related genus *Pseudotropites*, have been found towards the eastern end of this site and appear confined to the upper part of the section. As such they represent unique records of these genera in the British Lower Jurassic sequence.

Bivalves are a common, and often conspicuous, element of the fauna with many typical Blue Lias Formation taxa represented. The site has long been known for the occurrence of numerous large examples of *Gryphaea arcuata* with both valves articulated, and articulated examples at all stages of growth are common. Indeed, this is the type locality for the subspecies *Gryphaea arcuata incurva* (Sowerby, 1815), one of the best known of British Lower Jurassic fossils; the holotype was re-figured by Hallam (1968b) and material from here has been used in investigations of the evolution of this genus (Hallam, 1968b; Johnson, 1993; Jones and Gould, 1999). The holotype of *Antiquilima antiquata* (Sowerby, 1815) was also from here, as were three nominal species of *Cardinia* – *C. cuneata*, *C. ovalis* and *C. imbricata* – described by Stutchbury (1842) and re-figured by Palmer (1975).

Brachiopods are fairly common, particularly at two horizons; with *Piarorhynchia juvensis* abundant in the mudstones of Bed 15 and *Cuneirhynchia oxynoti* in the uppermost limestone, Bed 28. Ager (1956–1967) used material from this site to obtain serial sections of both species. The terebratulid *Zeilleria perforata* has been recorded occasionally, from Bed 18 (Richardson, 1908) and from Bed 15. Davidson (1851–1852, 1876–1878) described a new species of inarticulate brachiopod, *Discinisca* (= *Orbicula*) *townshendi* from here although initially he incorrectly attributed it to the Oxford Clay of southern England. With a diameter of 42 mm and height of 16 mm this was the largest species known to him.

The echinoderm fauna recorded from this site is the most diverse in the British Lias from such a limited stratigraphical interval, with three species of crinoid (Simms, 1989), at least three species of echinoid, three species of asteroid, two species of ophiuroid and at least six holothurian sclerite morphospecies (Gilliland, 1992). Two of the holothurian sclerite morphospecies were based on material from here, while undescribed species of an asteroid, *Terminaster*, and an ophiuroid, *Ophiocantha*, are the earliest known representatives of the family Zoroasteridae and suborder Laemophiurinae respectively (Simms *et al.*, 1993). Most of the echinoderm material is disarticulated, with columnals of *Isocrinus psilonoti* and plates and spines of *Miocidaris lobatum* being by far the dominant component of this fauna, but examples of all but the holothurians have also been found articulated, sometimes preserved in the finest detail (Figure 4.6). The site is of key importance for understanding the evolution of the *Isocrinus* clade, having yielded material transitional between *Isocrinus psilonoti* and *Isocrinus tuberculatus* (Simms, 1988).

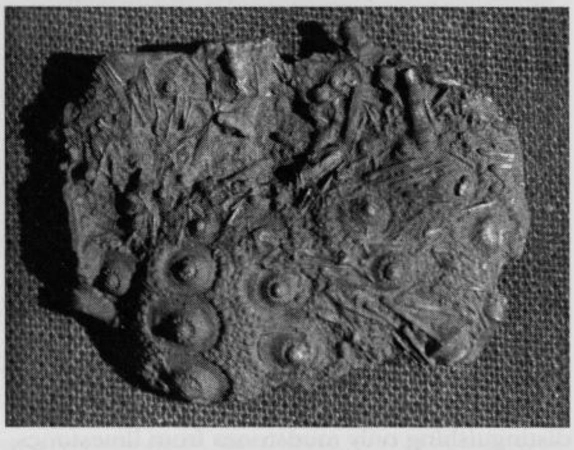

Figure 4.6 Intact test (32 mm across) of the echinoid *Miocidaris lobatum*, from the lower part of the Bucklandi Subzone at Hock Cliff. Isolated plates and spines of this species are one of the most common elements of the exceptionally rich and diverse echinoderm fauna at this site. (Photo: M.J. Simms.)

Other more occasional elements of the macrofauna include encrusting bryozoa (Richardson, 1908), the solitary coral *Montlivaltia haimei*, decapod crustacea and the belemnite *Nannobelus acutus*. A rich fauna of small pyritic gastropods and bivalves remains to be investigated. The vertebrate fauna is known only from fragmentary remains since little in-situ material has been found. Isolated bones and teeth of ichthyosaurs and, less frequently, plesiosaurs are not uncommon; most are from rather small individuals, with vertebral centra rarely exceeding 5 cm in diameter. The most frequently found fish remains are the teeth of *Acrodus*, but fragmentary remains of several other typical Lower Jurassic genera have also been found. Of these the most significant are a fin spine and part of a head spine of the early chimaeroid *Metopacanthus granulatus*.

A rich and diverse microfauna is present and has formed a topic of discussion from some of the earliest publications pertaining to this site (Brodie, 1853), though much of this early work needs to be re-interpreted in terms of modern taxonomy. Both Richardson (1908) and Henderson (1934) gave lists of species of foraminifera from several of the mudstone units; this was one of many GCR sites investigated by Copestake (1989). Gilliland (1992) also reported very high yields of holothurian spicules from some mudstones at this site.

Interpretation

Correlation between the section recorded here and those published by Richardson (1908) and Henderson (1934) is straightforward for parts of the succession but less clear for others. In the lower part of the section there is a good match from beds 1 to 7 of this account, correlating with beds 25 to 19 of Richardson (1908). However, more than 1 m of strata above this, corresponding to beds 8 to 11 of this account, is unrepresented in the earlier descriptions. Presumably this was due to an oversight by Richardson, an error unfortunately perpetuated by Henderson (1934) who appears merely to have transcribed Richardson's bed thicknesses without actually re-measuring the section. Beds 12 to 22 of the section here correlate fairly well with beds 18 to 8 of Richardson (1908), based on his description and photograph of the western end of the cliff. The highly distinctive limestone of Bed 28 here obviously correlates with Richardson's Bed 2, but it has proven impossible to resolve his description of beds 3 to 7 with beds 23 to 27 of the present section.

The age range of the succession exposed at Hock Cliff is now well-constrained, although further work is needed to refine the ammonite sequence within these limits. *Vermiceras scylla* occurs in beds 1, 2 and 3b, and poorly preserved *Coroniceras* cf. *rotiforme* in Bed 5a, establishing that the lowest 1.5 m of the succession lies within the Rotiforme Subzone. *Coroniceras lyra* in Bed 28 demonstrates that at least the top 0.6 m of the section can be assigned to the Lyra Subzone (Page, 1992). The remainder, more than 14 m, is assumed to lie entirely within the Bucklandi Subzone. Although the succession here is obviously less condensed than the well-documented type succession of the Blue Lias Formation in the Keynsham area, near Bristol, where the combined Bucklandi and Semicostatum zones may be only 6 m thick and packed with ammonites (Donovan, 1956), the occurrence at Hock Cliff of *Arietites bucklandi* and *Coroniceras lyra* in the same limestone, Bed 28, is unique in the British Lias. Further work on the ammonite faunas at this site may help to identify some of the biohorizons within the Bucklandi Subzone described by Page (1992); the highest of these is known to be present from the occurrence here of *Coroniceras vercingetorix*. The presence at this site of the Tethyan micromorphs *Canavarites* and *Pseudotropites* is unique for the British Isles: it may relate to the widely observed eustatic sea-level rise in early Sinemurian times (Hallam, 1978, 1981; Hesselbo and Jenkyns, 1998) allowing dispersal of these southern taxa into the region. Their apparent absence from other well-documented sites of this age in southern Britain may reflect preservation or collection failure.

At more than 14 m, the Bucklandi Subzone here is substantially thicker than on the Dorset coast or in the Bristol district (Donovan and Kellaway, 1984), though less than a fifth of that on the north Somerset coast and only about half of that in the Stowell Park Borehole (Spath, 1956). This suggests that during early Sinemurian times Hock Cliff lay in a less actively subsiding graben or half-graben within the Severn Basin, perhaps reflecting its position less than 4 km from the western margin of the basin (Figure 4.1).

The succession at Hock Cliff appears to record the upward transition from facies typical of the Blue Lias Formation to those more typical of the Charmouth Mudstone Formation. The pattern of limestone–mudstone rhythmicity described by Hallam (1964a) becomes increasingly indistinct above Bed 14 while the limestone bands become more widely spaced. These changes probably reflect an interplay between several factors, such as climate, sea level and basin subsidence rates. The ubiquity of the transition to Charmouth Mudstone Formation facies suggests exogenic control, such as climate or sea-level change; Hesselbo and Jenkyns (1998) suggest a sharp rise in sea level from the late Bucklandi Zone to the early

Semicostatum Zone. However, since the formational boundary appears to be diachronous, for instance occurring earlier here in the Severn Basin than on the Dorset coast in the Wessex Basin, endogenic factors, in the form of differences in basin subsidence rates or sediment supply, must also be significant. The succession at Hock Cliff shows that sedimentation rates were not constant in this part of the Severn Basin. Reduction or cessation of sedimentation for brief periods is indicated by burrowed horizons within several of the mudstone units and by the severely bio-eroded *Gryphaea* in beds 7, 9 and 13. Irregular shallow scours up to 1–2 m across and 0.15 m deep are not uncommon, typically now occupied by flat-topped shelly and crinoidal limestone lenticles. Concentrations of intact *Miocidaris* tests (Figure 4.6) or articulated crinoid or ophiuroid remains are sometimes associated with these scour infills, either at their base or top. They are classic obrution deposits (Seilacher *et al.*, 1985) and testify to sudden influxes of fine-grained sediment, perhaps generated by storm activity. Hallam (1968b) noted a much higher proportion of specimens of *Gryphaea* with the valves articulated than was typical of other sites. This appears to hold true for all growth stages of this bivalve, suggesting sedimentation rates often were sufficiently high to prevent the valves disarticulating. Benthic oxygen levels also experienced significant variation, from the thin, dark, finely laminated mudstones deposited under anoxic conditions to the paler, bioturbated mudstones with a locally abundant benthic fauna, deposited in well-oxygenated conditions.

Conclusions

The exposure at Hock Cliff represents the finest (Lower Sinemurian) Blue Lias Formation and basal Charmouth Mudstone Formation section in the Severn Basin. It differs substantially in thickness from correlative strata on the Dorset coast, north Somerset coast and the Bristol–Bath area, thereby providing information on regional differences in subsidence rates and palaeoenvironments between three adjacent depositional basins and their margins. The unusually rich fauna from this site provides critical information on the palaeoecology, evolution and migration of several fossil groups.

BLOCKLEY STATION QUARRY, GLOUCESTERSHIRE (SP 180 370)

M.J. Simms

Introduction

Blockley Station Quarry is a large, currently active, brickpit, located on the western side of the main Oxford–Birmingham railway line 4 km to the NNW of Moreton-in-Marsh (Figure 4.1 and 4.7). The quarry is an outstanding site, exposing a mudstone-dominated succession in virtually horizontal strata (Figure 4.8), comprising part of the Charmouth Mudstone Formation and representing the best-developed Luridum Subzone succession in the Lower Pliensbachian Substage of Britain.

Unlike most occurrences of this interval, which are condensed, incomplete or poorly known, the section at Blockley Station Quarry is thick, abundantly fossiliferous and well documented. The rich ammonite fauna has been of considerable significance in the development of ideas concerning sexual dimorphism and evolution,

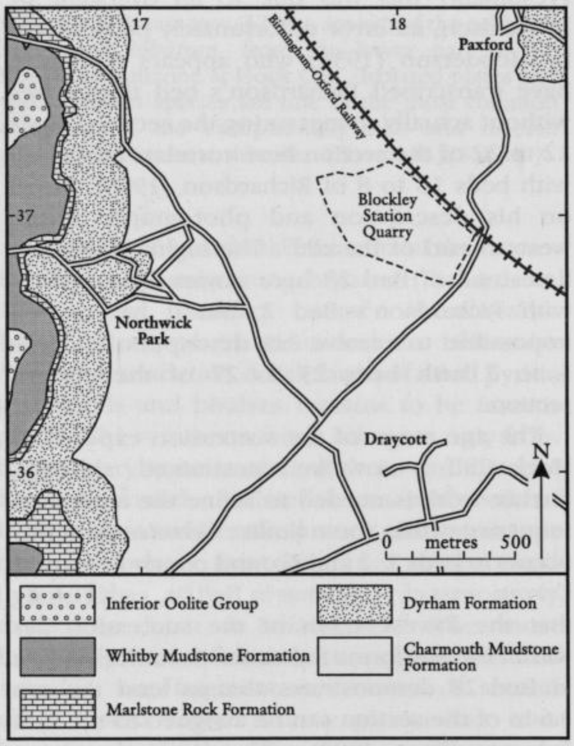

Figure 4.7 Geology and location map for the Blockley Station Quarry GCR site.

Figure 4.8 The exceptionally thick development of Luridum Subzone clays at Blockley Station Quarry. The floor of the pit is at about the level of the top of the Crinoid–Belemnite Bed (Bed Z); the projecting, and slightly undercut, band above the second terrace is formed by beds 2–4; the remainder of the succession comprises beds 5 and 6. (Photo: C.J. Underwood.)

and will continue to be invaluable in refining the biostratigraphy of this interval.

The quarry was opened in 1925 and first recorded by Richardson in 1929. It was described briefly by Channon (1950), who was the first to appreciate the richness of the fauna. It was cited by Dean *et al.* (1961) as exposing a good section through the Luridum Subzone. Callomon (in Hallam, 1968a; in Hemingway *et al.*, 1969) gave a more detailed description of the lithological succession and sequence of ammonites, together with an updated list of bivalves and gastropods from the site. This faunal list was expanded by Ager *et al.* (1973). Hewitt and Hurst (1977) described the section, and analysed size changes and ecology of various molluscs through the middle part of the succession. Aspects of the fauna and sedimentology were discussed in subsequent papers by Hewitt (1980a,b, 1989, 1996) who has undertaken a detailed study of the site; some of his observations are reported here for the first time. A longer lithostratigraphical log was published by Phelps (1985), who tied the section into the ammonite biostratigraphy and found the site invaluable in subdividing the Luridum Subzone into zonules. Callomon and Oates (1993) provided an updated account, and Bessa and Hesselbo (1997) published a gamma-ray log of the section. The most recent account, which reproduces the section by Callomon and Oates (1993), is in the *Fossil Fishes of Great Britain* GCR volume (Dineley and Metcalf, 1999). Other papers have been concerned largely with palaeontological aspects of the site. It has provided material for interpreting the evolution of the liparoceratid ammonites (Callomon, 1963; in Hemingway *et al.*, 1969) and the bivalve

Gryphaea (Jones and Gould, 1999), for estimating the depth limits in life of several ammonite species (Hewitt, 1996), for investigating echinoid lantern morphology in relation to the origin of irregular echinoids (Smith, 1981), and for providing a control sample for belemnite abundance in Jurassic clays (Hewitt, 1980b). Johnson (1984) figured specimens of the bivalve *Pseudopecten equivalvis* from the locality, and Simms (1989) figured some of the crinoid material. Howarth and Donovan (1964) figured two specimens of *Tragophylloceras carinatum* from here as paratypes of this rare ammonite species. Aspects of the microfauna were described by Malz and Lord (1976) and by Macfadyen (1941).

Description

The most complete section of Blockley Station Quarry is that of Callomon and Oates (1993; reproduced in Dineley and Metcalf, 1999). They recorded just over 20 m of, predominantly, mudstones divided into nine distinct beds (Figure 4.9). The log by Phelps (1985) was divided into 12 lithostratigraphical units in a 17 m-thick section. The lower six of his units correspond to a section described by Callomon (in Hallam, 1968a). The description of Hewitt and Hurst (1977) adds lithological detail, but less of the succession was exposed at that time.

The present-day working floor of the brickpit lies on a moderately well-cemented shelly

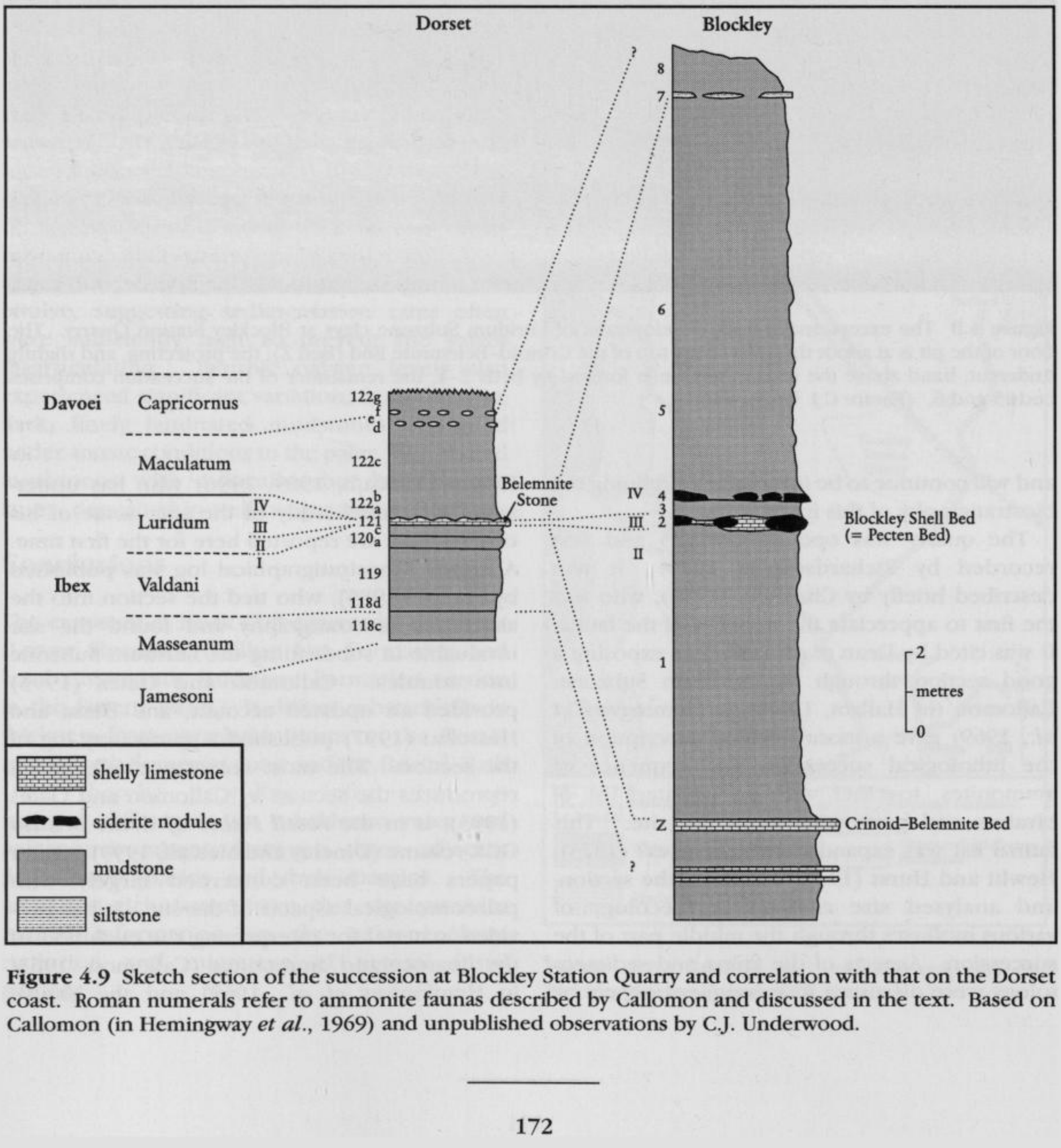

Figure 4.9 Sketch section of the succession at Blockley Station Quarry and correlation with that on the Dorset coast. Roman numerals refer to ammonite faunas described by Callomon and discussed in the text. Based on Callomon (in Hemingway *et al.*, 1969) and unpublished observations by C.J. Underwood.

limestone referred to as the 'Crinoid–Belemnite Bed' (Callomon and Oates, 1993), or 'Bed Z' (Dineley and Metcalf, 1999). This bed is richly fossiliferous with several species of bivalve and abundant belemnites, crinoid and comminuted shell and fish debris. Glauconite grains and ?phosphatic nodules are present, and some of the thick-shelled bivalves are somewhat worn and bio-eroded (R.G. Clements, pers. comm.). Ammonites are relatively common, but poorly preserved. They appear to be referable to *Acanthopleuroceras* (R.G. Clements, pers. comm.), corresponding to Fauna I of Callomon (in Hemingway *et al.*, 1969). Older strata have been exposed in a drainage sump (C.J. Underwood, pers. comm.). Bed Z is underlain by 0.9 m of dark-grey shelly marl, with irregular cemented patches up to 0.2 m across. Below are two 0.1 m-thick nodular shelly limestones, the upper one with abundant *Gryphaea*, separated by 0.15 m of grey shelly clay. Below this, the succession was largely flooded: it comprises grey clay with relatively few shells.

Above Bed Z, Bed 1 of Callomon (in Hallam, 1968a; Callomon and Oates, 1993) comprises 8.5 m of richly fossiliferous grey silty micaceous mudstone with scattered nodules and francolite-cemented *Thalassinoides* burrows. It has yielded species of *Liparoceras* and *Aegoceras*, which Callomon grouped together as his Fauna II. The upper 1.5 m shows an increase in silt content and a marked increase in the abundance of fossil material and pyrite (Hewitt and Hurst, 1977). Bed 2 is the 'Blockley Shell Bed', referred to by Callomon (in Hallam, 1968a) and Hewitt and Hurst (1977) as the 'Pecten Bed'. This is a highly fossiliferous mudstone or series of siderite nodules set in the top of a shell gravel. Small francolite concretions, containing crustacean fragments and encrusted with *Plicatula* and millimetre-scale borings, occur at the base of this bed (R. Hewitt, pers. comm.). Bed 2 is up to 0.5 m in thickness and forms the most important marker band of the succession. It contains *L. fimbriatum* and *T. loscombi* together with liparoceratids of Callomon's Fauna III. Phelps (1985) placed the boundary between his Rotundum and Crassum zonules at the base of Bed 2. The Blockley Shell Bed is separated by 0.3 m of grey mudstone from Bed 4, a second horizon of siderite nodules in a mudstone matrix. This has yielded a distinct assemblage of liparoceratids (Callomon's Fauna IV). Bed 4 is succeeded by 10 m of silty mudstone with scattered nodules and layers of shell debris, divided into two distinct beds by Callomon (in Hallam, 1968a). There is a marked change in the diagenetic mineral content of the sediments, from francolite and pyrite in beds 1 and 2 to siderite in beds 3 to 6 (R. Hewitt, pers. comm.). The exposed succession is capped by an impersistent, buff, bioturbated siltstone up to 0.2 m thick overlain by 1–2 m of weathered clay. These two units (beds 7 and 8) have been tentatively assigned to the Maculatum Subzone (Callomon and Oates, 1993).

The abundant and diverse fauna at this site is dominated by molluscs. There are at least 44 species of bivalve, 9 species of gastropod, 14 species of ammonite, and scaphopods and belemnites (Callomon in Hallam, 1968a; R. Hewitt, pers. comm.). Most of the liparoceratid species have a restricted vertical range within the succession while *Lytoceras fimbriatum* and *Tragophylloceras loscombi* occur commonly throughout. Hewitt (pers. comm.) noted that the mudstones of Bed 1 are dominated by *Cardinia*, including large numbers of juveniles only a few millimetres across, whereas the shell gravels of Bed 2 support an adult-dominated population of the bivalve *Astarte*. Other common invertebrate macrofossils include brachiopods, crustaceans, crinoids and echinoids. Scaphopods are particularly common in Bed 5. Preservation is often extremely good, with many bivalves and ammonites crushed flat but with their original aragonitic shells preserved intact and unworn. Ammonites and other fossils preserved in nodules typically retain their three-dimensional shape although the septa of ammonites are commonly fragmented. The hollow gas chambers of the ammonites, and some of the unfilled fractures in septaria, are commonly lined with small crystals of pyrite and, more rarely, sphalerite. Crustacean remains in the francolite nodules of Bed 1 preserve parabolic chitin fibre patterns, but these are lacking in the francolite nodules of Bed 2. Although articulated crinoid and ophiuroid material has been found, echinoderm material is more typically disarticulated. Nonetheless, it is commonly unworn and shows exquisite stereom preservation (Smith, 1981; Simms, 1988, 1989). Vertebrate material is scarce but has included partial skeletons of at least three plesiosaurs, one of which is now in Gloucester City Museum. The most recently discovered of these, now in New Walk Museum, Leicester (cat. no. LEICT G1.2002), is the most complete, comprising more than 80% of a 3 m-long skeleton including parts of the skull. It was recoverd from the mudstones of Bed 1, just above the Crinoid–Belemnite Bed.

The microfauna includes foraminifera and abundant ostracods, together with disarticulated ophiuroid and asteroid debris, and the microfossils are also abundant, diverse and very well-preserved. This was one of many GCR sites investigated for foraminifera by Copestake (1989) and was the source of paratype material for *Haplophragmoides lincolnensis* (Copestake, 1986). Microshark and semionotid teeth, denticles and scales are common in the Crinoid–Belemnite Bed (Dineley and Metcalf, 1999), and at least two taxa of fish otoliths have been recovered from the clays of Bed 1 (C.J. Underwood, pers. comm.).

Interpretation

The biostratigraphical significance of the succession exposed at Blockley Station Quarry has been recognized for several decades. Dean *et al*. (1961) referred to the site in their description of the Luridum Subzone, contrasting its thick development there with the highly condensed sequence on the Dorset coast (Figure 4.9). Callomon (in Hemingway *et al*., 1969) recognized the importance of the liparoceratid faunas in subdividing the succession, identifying four distinct assemblages (Faunas I–IV). Subsequently Phelps (1985) subdivided the Luridum Subzone into what he termed 'zonules'. He assigned Bed 1 at Blockley Station Quarry to his 'Rotundum Zonule' and the remainder of the exposed succession, some 11 m in total at that time, to his 'Crassum Zonule'. However, there are doubts surrounding the identity of the specimens Phelps identified as *Beaniceras crassum* (J.H. Callomon, pers. comm.); they represent a form distinct from *B. rotundum* but are also distinct from S.S. Buckman's holotype of *B. crassum*. The latter almost certainly came from a level lower in the Ibex Zone. Callomon (pers. comm.) has recorded forms close to *Beaniceras luridum* in beds 2, 3 and 4. Evidence from the **Napton Hill Quarry** GCR site indicates that *Liparoceras naptonense* and *L. kilsbiense*, constituents of Callomon's Fauna IV at Blockley Station Quarry, occur close to the Luridum–Maculatum subzone boundary. Here there is an apparent conflict between the interpretation of Phelps (1985) of the biostratigraphical succession at Blockley Station Quarry and the evidence from ammonite species other than *Beaniceras*.

Nonetheless, it is probable that the entire Luridum Subzone is exposed. The presence of *Acanthopleuroceras* in the Crinoid–Belemnite Bed exposed in the floor of the quarry suggests a correlation of this indurated bed with the '85' Marker Member of Horton and Poole (1977), which is, for convenience, taken to mark the boundary between the Valdani and Luridum subzones (Bessa and Hesselbo, 1997). The presence of Callomon's Fauna IV in Bed 4, and possibly Bed 5, suggests that the section extends up into the lower part of the Davoei Zone, Maculatum Subzone. If so, Blockley Station Quarry offers the best exposure anywhere in Britain of the Luridum Subzone. Despite its exceptional thickness at this site, there is clear evidence that the succession is not complete. The bored and encrusted francolite concretions noted by Hewitt (1980a, 1989) at the base of Bed 2 are similar to the francolite-cemented *Thalassinoides* burrows seen lower in the succession. Both testify to periods of non-deposition and/or erosion. Similarly, the presence of phosphate nodules and bio-eroded shells in the Crinoid–Belemnite Bed (Bed Z) indicate that this too represents a condensed deposit.

The comparison by Phelps (1985) of the Blockley Station Quarry succession with that of the Stowell Park Borehole (SP 084 118), 25 km to the SSW (Figure 4.1), indicates that the former succession is slightly thicker. This probably reflects its position close to the axis of the Mickleton Syncline where 293 m of Lower Lias was proved in the Mickleton Borehole (SP 174 433). Near Ilmington, less than 5 km to the east on the East Midlands Shelf, the Lower Lias succession is 61 m thick (Whittaker, 1972b; Williams and Whittaker, 1974). The contrast between the succession at Blockley Station Quarry and that in the Wessex Basin is particularly striking (Figure 4.9). On the Dorset coast the Luridum Subzone is represented by the Belemnite Stone (Bed 121 of Lang *et al*., 1928), 0.1 m of condensed limestone. Callomon (in Hemingway *et al*., 1969) correlated Bed 2 of Blockley Station Quarry with the Belemnite Stone, and Bed 1, tentatively, with the 0.02 m-thick Crumbly Bed, Bed 120e of Lang *et al*. (1928). The presence of a hiatus above the Belemnite Stone is significant in that several conspicuous species of ammonite in beds 3 to 5 at Blockley Station Quarry (Callomon's Fauna IV) are absent from the Dorset coast. These thickness differences between Blockley Station Quarry and Dorset demonstrate that subsidence rates in the Severn Basin were greater than in the Wessex Basin during this time interval, with 0.17 m in Dorset equivalent to some 9 m at Bockley Station Quarry (Callomon in Hemingway *et al.*, 1969).

The abundantly fossiliferous mudstones at Blockley Station Quarry are similar to correlative mudstones seen at the base of the succession exposed at the **Robin's Wood Hill Quarry** GCR site. Both contain a fauna that is significantly more diverse than that of the Davoei and Margaritatus zones, indicating that Luridum Subzone conditions were less inimical to the benthic fauna. Hewitt and Hurst (1977) have published the only palaeoecological description of the Blockley Station Quarry succession. They noted a significantly greater diversity and larger size for molluscs from the Blockley Shell Bed, than from the mudstones of Bed 1, an observation in keeping with that made by Callomon (1963; in Hallam, 1968a) on the liparoceratid ammonites. Fossil material is worn and disarticulated in the lower part of the Blockley Shell Bed, compared with the same species higher in the Blockley Shell Bed and in the mudstones. This indicates that the lower part of the Blockley Shell Bed is a winnowed deposit and this appears to have allowed a greater diversity of benthic taxa to flourish on the shell gravels. This is particularly evident among the bivalves, where the *Cardinia*-dominated, r-selected, population in the mudstones of Bed 1 is replaced by the *Astarte*-dominated, K-selected, populations on the shell gravels in Bed 2. The change in diagenetic minerals, from francolite and pyrite in beds 1 and 2 to siderite in beds 3 to 6, also indicates an increase in sedimentation rate. Palmer (1973) noted a similar increase in mollusc size and diversity in the nodule bands in the sequence at **Robin's Wood Hill Quarry**, and considered that this indicated that substrate firmness was a major control on benthic diversity during this interval. Malz and Lord (1976) noted that the ostracod assemblage at Blockley Station Quarry was dominated by smooth species, contrasting with that from broadly correlative beds at Robin's Wood Hill Quarry where they found a much higher incidence of ornamented and heavily calcified ostracods. They considered this as evidence for deeper and quieter water conditions at Blockley Station Quarry, perhaps lending support for the greater subsidence rate deduced for this area. Hewitt (1996) analysed septal strength in several common ammonite species at Blockley Station Quarry, from which he was able to calculate the maximum depth limit in life. Since ammonites are considered to have been nektobenthic, this gives a minimum water depth in which the various units were deposited. Hewitt (1996) obtained figures of 94 m for *Liparoceras cheltiense* in concretions from Bed 1, 45 m for *Liparoceras elegans* in Bed 2 and 60 m for *Lytoceras fimbriatum* from Bed 4.

The abundance and excellent preservation of many elements of the fauna at Blockley Station Quarry has attracted palaeontological research. The expanded succession here was crucial to Callomon's (1963) research on the ammonite family Liparoceratidae. In this he was able to demonstrate that the evolutionary sequences proposed by Trueman (1918) and by Spath (1938), from capricorn *Aegoceras* to sphaerocone *Liparoceras* and vice-versa, were untenable. Callomon (1963) proposed that these morphotypes, which occur together at Blockley Station Quarry, represent sexual dimorphs. Subsequently, Hewitt (1989) concluded, from differences in the ontogeny of the sutures in the two morphological groups, that they represented distinct evolutionary lineages. This interpretation was supported by Phelps (1985). However, unless repeated iterative evolution is invoked, the close parallelism in the evolution of both morphological groups supports Callomon's original proposal for sexual dimorphism in the Liparoceratidae.

Only a small proportion of the remaining fauna has been described. Simms (1989) covered the crinoids, and the lantern of an echinoid, *Eodiadema minuta* was described by Smith (1981). Johnson (1984) figured examples of the abundant and exceptionally well-preserved pectinids. Differential wear on the upper and lower valves of specimens of *Pseudopecten equivalvis* from this site suggest that these were among the earliest pectinids to adopt a swimming habit (A.L.A. Johnson, pers. comm). Harper *et al.* (1998) figured examples of predatory borings in the bivalves *Astarte gueuxii* and *Plicatula spinosa*. The most recently discovered plesiosaur (LEICT G1.2002), yet to be formally described (Mark Evans, pers. comm.) is of considerable importance since no valid plesiosaur taxa are known between Upper Sinemurian and Toarcian times, a key time for the evolution of this group.

Conclusions

Blockley Station Quarry is one of the few inland sites in Britain to expose a section through the Charmouth Mudstone Formation of the middle part of the Lower Pliensbachian Stage, and has yielded data for comparison with the well-documented coastal sections in Dorset, Yorkshire and the Hebrides. It provides one of the thickest and most fossiliferous developments of the Luridum Subzone of the Ibex Zone and as such will be of crucial importance for any future refinement of the ammonite biostratigraphy of this interval. It has yielded an abundant and diverse fauna, elements of which have been figured and described. In particular, ammonites from this site have been central to the debate on sexual dimorphism in the family Liparoceratidae.

ROBIN'S WOOD HILL QUARRY, GLOUCESTERSHIRE (SO 835 148)

M.J. Simms and N. Chidlaw

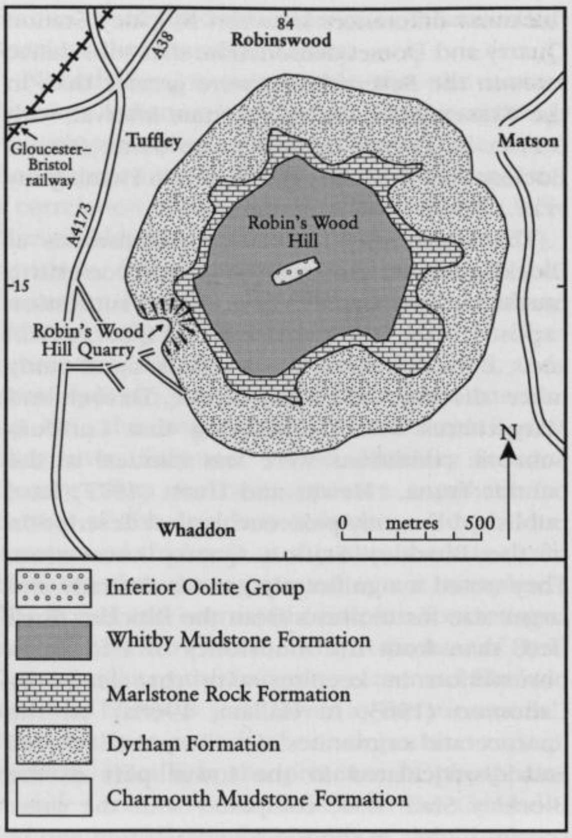

Figure 4.10 Geology and location map for the Robin's Wood Hill Quarry GCR site.

Introduction

The Robin's Wood Hill Quarry GCR site comprises a large quarry, disused for several decades, excavated into the south-western flank of Robin's Wood Hill overlooking Tuffley, a suburb of Gloucester (Figure 4.10). The section exposes a more than 60 m-thick succession of Pliensbachian mudstones and siltstones, with subordinate sandstone and bioclastic limestone units, and represents the finest inland section in Britain of the Upper Pliensbachian Substage (Middle Lias), here exposed almost in its entirety, as well as a considerable thickness of the underlying Lower Pliensbachian succession. This is represented by a good section through the Dyrham Formation, designated as its type locality by Sumbler *et al.* (1999), part of the overlying Marlstone Rock Formation, and underlain by the top of the Charmouth Mudstone Formation. It is one of a series of key sites revealing lateral facies and thickness changes both within the Severn Basin and across the whole of the Lower Jurassic outcrop. Excavations in 2000 have re-exposed a formerly obscured section through part of the Dyrham Formation, while a small track-side excavation nearby (at SO 8367 1468) exposes the upper part of the Marlstone Rock Formation and the base of the Whitby Mudstone Formation (Toarcian) above. The succession, and its rich and diverse fauna, has been well documented.

Despite his extensive research into the geology of this area, Robin's Wood Hill received only passing mention in Richardson's field guide to the geology of Cheltenham (1904). The site formed the subject of an excursion report (Watts, 1928), in which a general account of the fossil fauna and its palaeoecology was given, but the lithological succession otherwise remained undescribed until an excursion report by Ager (1955). In this he estimated the ammonite zone ranges for the section. A general account of the site was published by Dreghorn (1967). The site formed part of a major investigation by Palmer (1971, 1973) who described the stratigraphical succession in detail and attempted correlation with the succession in another disused pit, at

Stonehouse (SO 816 050), 10 km to the south, as well as with the successions recorded in the Stowell Park Borehole (Figure 4.1), and those on the Dorset coast. In the earlier paper, Palmer (1971) established the positions of the ammonite zonal and subzonal boundaries within the succession. He later (1973) listed the invertebrate fauna together with the lithostratigraphical distribution of each species and commented on the palaeoecology of parts of the succession on the basis of conclusions drawn from the diversity and composition of the invertebrate fauna. In the latter paper he described two new species of bivalve, *Hippopodium tuffleyensis* and *Hettangia aperta*: a third species, *Cardinia tuffleyensis*, was described in a subsequent paper (Palmer, 1975). A new species of crinoid, *Balanocrinus solenotis*, was based in part on fragmentary material from the upper part of the Dyrham Formation at this site (Simms, 1989). Elements of the microfauna have been investigated by Lord (1972, 1974).

Further details of the Lower Pliensbachian stratigraphy at this site were published by Phelps (1985), and well-preserved crinoid material from near the base of the Upper Pliensbachian succession was figured by Simms (1989). The Upper Pliensbachian succession at Robin's Wood Hill Quarry also formed part of a broader investigation into Upper Pliensbachian sedimentation patterns of the Severn Basin (Simms, 1990a) during which some revisions of the biostratigraphy established by Palmer (1971) were made. The most recent investigation of the site was by Chidlaw (1987) who logged the succession in more detail than that of earlier accounts.

Description

Robin's Wood Hill Quarry has been excavated at two levels, described as the 'upper quarry' and 'lower quarry' (Figure 4.11), and exposes almost 60 m of the Lower Jurassic succession (Figure 4.12). Ager (1955) and Palmer (1971) reported about another 8 m exposed below the lowest beds currently visible. The Pliensbachian–Toarcian boundary section, described below, was exposed in a nearby track-side excavation (SO 8367 1468) and recorded by Chidlaw in October 2001.

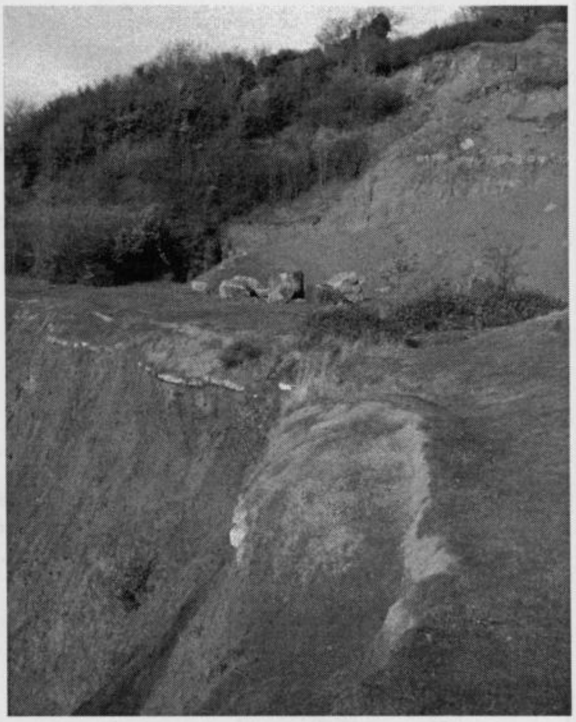

Figure 4.11 View of the upper part of Robin's Wood Hill Quarry. The conspicuous pale band near the top of the lower face is Bed 22; beds 28–30 are visible as a pale band about halfway up the face of the upper quarry; with Bed 35 at the top of the section. (Photo: M.J. Simms.)

		Thickness (m)
TOARCIAN STAGE		
Whitby Mudstone Formation		
Tenuicostatum Zone (presumed)		
D:	Clay, fawn-brown, soft, sticky.	0.90 (seen)
C:	Clay, mottled, pale-grey/orange, soft, sticky. This has a diffuse contact with Unit D above and infills, and overlies by a few cm, the irregular top of Unit B below.	0.30
UPPER PLIENSBACHIAN SUBSTAGE		
Marlstone Rock Formation		
Spinatum Zone (presumed)		
B:	Clay, mottled, pale-grey/orange/red-brown, soft, sticky, containing weathered clasts of Unit A; some are up to 0.35 m across, angular and only slightly iron-stained; others are reddish-brown and friable, 3–4 cm across, subangular and of high sphericity. The contact with units above and below is irregular, with mammilated limonite nodules 2–5 cm across locally present on the upper surface.	0.45
A:	Limestone, massive, well jointed, greenish-grey, bioclastic, with abundant ferruginous ooids. Belemnites and bivalves common, with some rhynchonellid brachiopods. This bed is lithologically identical to Bed 37 (= 16c of Palmer, 1971) of the main section reproduced below.	1.50 (seen)

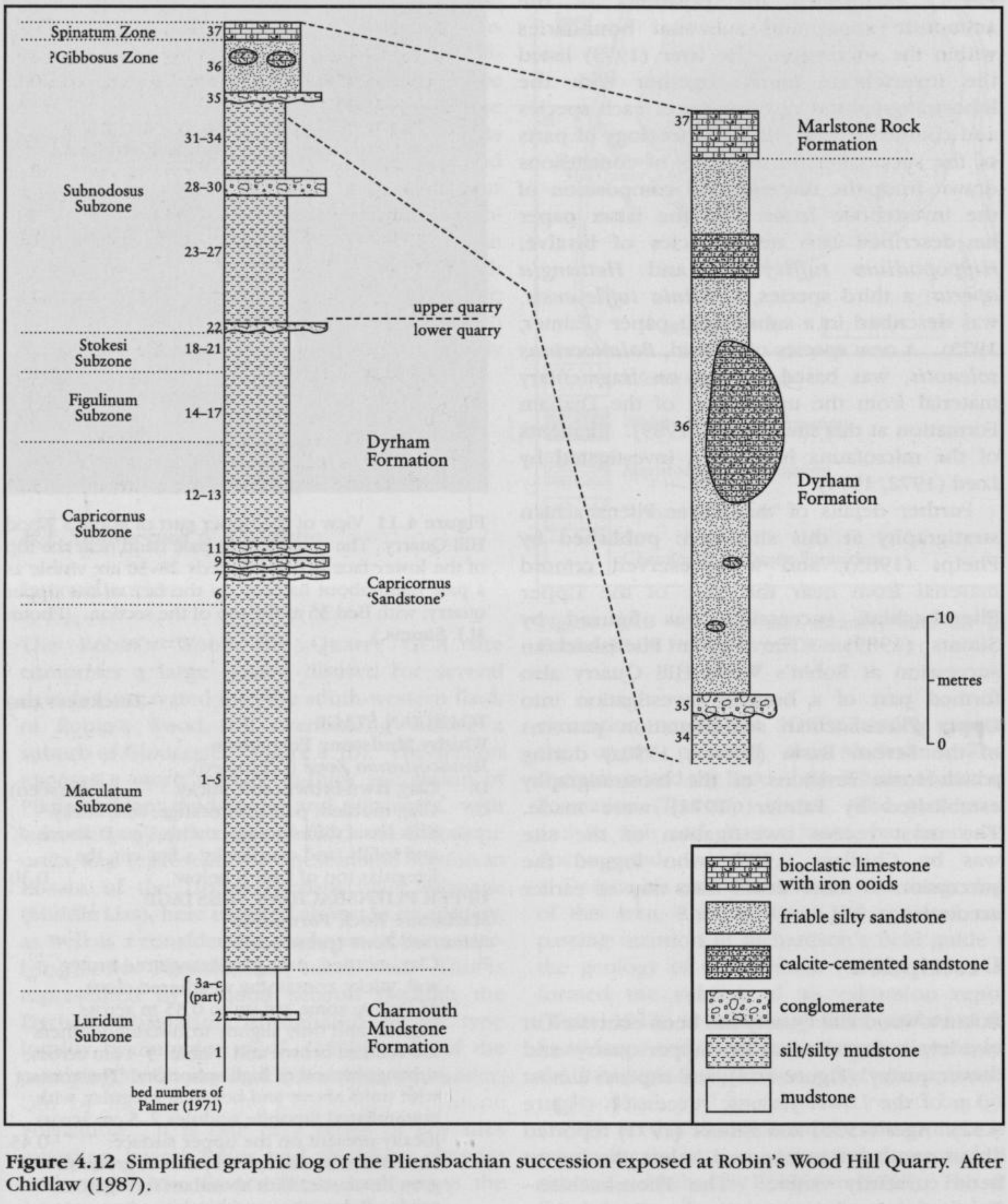

Figure 4.12 Simplified graphic log of the Pliensbachian succession exposed at Robin's Wood Hill Quarry. After Chidlaw (1987).

The descriptions and bed numbers of the units within the main quarry section, as shown below, and depicted in Figure 4.12, are based largely on the work of Chidlaw (1987), but follow the lithostratigraphical divisions of Cox *et al.* (1999). The bed numbers of Palmer (1971) are given in parentheses.

Thickness (m)

UPPER PLIENSBACHIAN SUBSTAGE
Marlstone Rock Formation
Spinatum Zone

37 (= 16c): Limestone, massive, rubbly weathering, brownish-grey, bioclastic, with abundant ferruginous ooids. Scattered shelly fauna including belemnites, rhynchonellids and bivalves. *Pleuroceras spinatum* and *Amaltheus* cf. *subnodosus* recorded by Palmer (1971). 0.33

Dyrham Formation
Margaritatus Zone, Subnodosus to *?Gibbosus subzones*

36 (= 16b): Sandstone, yellow-buff weathering, ferruginous, friable, micaceous, fine, silty. Locally between 1.8 m and 3.3 m above the base of the unit are hard, calcite-cemented, irregular 'doggers' up to about 1.5 m thick and 3 m across, with smaller ellipsoidal calcite concretions below the dogger horizon and more laterally extensive, though discontinuous, bands of calcite-cemented sand above the doggers. Abundant bioturbation, although trough cross-lamination and dish structures locally present. Fossils scattered and only well-preserved in cemented units, but including belemnites, bivalves and debris of the crinoid *Balanocrinus solenotis*. Simms (1990a) recorded *Amaltheus subnodosus* up to 2.6 m above the base of the unit. 4.87

35 (= 16a): Conglomerate, irregular, pebble- to cobble-grade. Clasts mostly flat-lying discoidal or ellipsoidal, of pale-grey siltstone. Matrix of yellow-brown mudstone within abundant fine bioclastic debris. Ager (1954) recorded *Gibbirhynchia micra* from the clasts. 0.18

34 (= 15 part): Siltstone, yellow-brown, sandy, micaceous. Local indistinct and bioturbated planar laminations. 0.20

33 (= 15 part): Silt, pale greenish-grey, sandy, micaceous. Mostly planar laminated with some cross-laminations near base. 1.80

32 (= 15 part): Silt, pale greenish-grey, micaceous. Planar laminated. Grades up into Bed 33 above. 3.33

31 (= 15 part): Mudstone, dark blue-grey, clayey, micaceous, silty. Grades up into Bed 32 above. 3.00

30 (= 14 part): Congomerate, flat pebble- to cobble-grade, with siltstone clasts set in a green-grey, sandy micaceous silt matrix. 0.12

29 (= 14 part): Limestone, hard, pale-grey, bioclastic, with occasional ferruginous ooids in top 0.02 m. Undulating base and top. 0.24

28 (= 14 part): Conglomerate, pebble- to cobble-grade. Discoidal clasts of hard blue-grey siltstone with ferruginous rind in a matrix of green-grey mudstone with abundant bioclastic debris. Irregular base. 0.22

Stokesi Subzone

27 (= 13 part): Silt, pale greenish-grey, locally cemented, sandy, micaceous. Bioturbated in top 0.25 m; cross-laminated below. 0.36

26 (= 13 part): Silt, pale greenish-grey, sandy, micaceous. Cross-laminated in top 0.04 m; planar laminated below. 1.64

25 (= 13 part): Silt, greenish-grey, clayey, micaceous, planar laminated in parts. Grades up into Bed 26 above. 4.33

24 (= 12): Siltstone, hard, shelly, micaceous. *Amaltheus stokesi* and *Lytoceras fimbriatum* recorded by Palmer (1971). 0.56

23 (= 11): Clay, blue-grey, silty, passing up into dark greenish-grey, planar-laminated, clayey micaceous silt. Floor of upper quarry lies 0.2 m above the base of this unit on the south side of the quarry. 3.27

22 (= 10): Conglomerate, pebble-grade, with hard, discoidal/ellipsoidal, blue-grey siltstone clasts in a matrix of grey-green mudstone with abundant coarse bioclastic debris and large thick-ribbed bivalves. The upper 0.15 m is deeply weathered, with friable clasts and a 0.05 m-thick reddish-orange layer at the top. Erosion surface contact with Bed 21. *Amaltheus wertheri* and *Tragophylloceras* recorded by Phelps (1985). 0.35

21 (= 9g part): Silt, blue-grey, sandy, micaceous. Planar laminated but streaked with fine yellow sand in places. Occasional scattered siderite nodules up to 0.25 m across and 0.06 m thick. 0.25

20 (= 9g part): Siltstone, blue-grey, sandy, micaceous, massive, with pea-sized siderite nodules. Broken thin-shelled bivalves. 0.04

19 (= 9g part): Silt, pale blue-grey, sandy, micaceous, with planar laminations locally disturbed by horizontal burrows. Occasional pea-sized siderite nodules and a discontinous row of larger siderite nodules at 1.7 m above the base. Small limonitic casts of amaltheid ammonites are common. *Amaltheus stokesi* and *A.* sp. recorded by Phelps (1985) from about this level. 3.52

18 (= 9f part): Siltstone, discontinuous, pale grey, commonly with abundant remains of *Balanocrinus gracilis*. Bivalves common and specimens of *Amaltheus bifurcus* and *A. wertheri*. 0–0.08

LOWER PLIENSBACHIAN SUBSTAGE
Davoei Zone, Figulinum Subzone

17 (= 9f part): Silt, green-grey, sandy, micaceous. Mostly planar laminated but cross-laminated towards base. 0.66

	Thickness (m)
16 (= 9e): Siltstone, pale blue-grey, indurated, planar- and cross-laminated, micaceous, with broken shell debris and small siderite concretions. *Oistoceras? angulatum* recorded by Phelps (1985).	0.10
15 (= 9d): Silt, blue-grey, micaceous, planar laminated and locally bioturbated.	5.49
14 (= 9c): Siltstone, blue-grey, indurated, wavy laminated, micaceous, with burrow mottling.	0.08
Capricornus Subzone	
13 (= 9b part): Silt, blue-grey, planar laminated, micaceous.	6.62
12 (= 9b part): Silt, dark blue-grey, indistinctly laminated, muddy, micaceous. *Aegoceras crescens* transitional to *Oistoceras angulatum* recorded by Phelps (1985).	1.14
11 (= ?): Iron-stained pebble conglomerate, with siltstone clasts in a siltstone matrix.	0.08
10 (= ?): Silt, blue-grey, indistinctly laminated, sandy, micaceous.	0.80
9 (= ?): Iron-stained pebble-grade conglomerate, with siltstone clasts in a siltstone matrix.	0.04
8 (= ?7): Silt, blue-grey, indistinctly laminated, sandy, micaceous, with bivalve moulds.	0.80
7 (= ?): Pebble conglomerate, with siltstone clasts in a siltstone matrix. *Aegoceras capricornus* recorded by Phelps (1985).	0.05
6 (= 6): Siltstone, pale grey, indurated, clayey, micaceous, forming prominent hard band. Together with beds 7 and 8 this represents the 'Capricornus Sandstone' of Palmer (1971).	1.65
Maculatum Subzone	
5 (= 5 part): Siltstone, pale grey, indistinctly laminated, clayey, micaceous.	1.14
4 (= 5 part): Silt, pale grey, planar laminated, clayey, micaceous. Moulds of small thin-ribbed bivalves near base.	5.37
3 (= 4): Siltstone, pale grey, planar laminated, clayey, micaceous.	0.19
2 (= 3c part): Silt, pale grey, planar laminated, clayey, micaceous. Siderite nodule bands at 8 m and 9.2 m above base.	10.5
1 (= 3c part): Silt, blue-grey, planar laminated, micaceous, with moulds of small thin-ribbed bivalves. Strata below this level were recorded by Palmer (1971, 1973) but are no longer visible (bed numbers are those of Palmer, 1971).	1 (seen)
Charmouth Mudstone Formation	
3c: (part): Shales, grey, silty, with ferruginous nodules.	*c.* 2
3b: Clay, blue, sticky, with ironstone nodules. *Androgynoceras sparsicosta* recorded by Phelps (1985) and *Aegoceras maculatum* recorded by Palmer (1971).	1.82
Ibex Zone, Luridum Subzone	
3a: Shales, grey, silty, grading up to dark-grey clay.	1.23
2: Shales, hard, grey, sandy. *?Beaniceras luridum* recorded by Phelps (1985) and Palmer (1971).	0.30
1: Shales, grey, with nodules.	*c.* 3

The floor of the lower quarry lies in a series of grey mudstones and silty mudstones of the Charmouth Mudstone Formation, which form beds 1 to 3 of Palmer (1971), corresponding to the Luridum Subzone and lower part of the Maculatum Subzone. This part of the succession is now rarely exposed. The mudstones of Palmer's Bed 2 contain thin shell beds that yield *Beaniceras* cf. *luridum* and are similar to shell beds in the correlative strata of the Charmouth Mudstone Formation at the **Blockley Station Quarry** GCR site that lies 40 km to the north-east.

Grey silty mudstones with several indurated units and siltstone clast conglomerate bands form the near-vertical face of the lower quarry, more than 20 m high. This encompasses Bed 2 to the lower part of Bed 23 of this account (Palmer's Bed 4 to the lower part of Bed 11), corresponding to much of the Dyrham Formation, in which the upper part of the Maculatum, the Capricornus, and the lower part of the Stokesi subzones were identified. Bed 6 forms the most prominent unit in the lower quarry and, together with beds 7 and 8 of Palmer (1971), was correlated with the 'Capricornus Sandstone', a fossiliferous flaggy, micaceous sandstone, in the Stonehouse section, 10 km to the south (Palmer, 1971, 1973). Bed 8 of Palmer (1971) has yielded the brachiopod *Tetrarhynchia dunrobinensis* (Palmer, 1973), a predominantly northern species (Ager, 1956–1967).

The lowest 8 m or so of the Stokesi Subzone is exposed at the top of the lower quarry, with the upper quarry exposing the remainder of the Dyrham Formation and the overlying Marlstone Rock Formation (Figure 4.11). Together the two formations attain a thickness of approximately 29 m at this site (Figure 4.12). The Upper Pliensbachian succession is dominated by grey silty mudstones but, like the Lower Pliensbachian succession immediately beneath, includes siltstone clast conglomerates. Palmer (1973) noted a general paucity of benthic fauna in the mudstones and muddy siltstones in contrast to the limestones and conglomerates, which often are abundantly fossiliferous with many large filter-feeding bivalves. In the mid-1970s an impersistent siltstone unit (Bed 18 of this account; about 1 m above the base of Bed 9f of Palmer, 1971) yielded abundant articulated specimens of the crinoid *Balanocrinus gracilis* together with large specimens of the ophiuroid *Palaeocoma milleri* and two intact examples of the small ophiuroid *Hemieuryale lunaris*, known previously only from dissociated ossicles (Hess, 1962). Some of the crinoid material was figured by Simms (1986, 1989).

The Marlstone Rock Formation forms the uppermost 0.5 m of the Upper Pliensbachian succession exposed in the upper quarry. It is a rather calcareous, flaggy, sometimes poorly oolitic, limestone, and has yielded *Pleuroceras spinatum*. Formerly (Palmer, 1971) the formation was taken to include the indurated, brown, micaceous sandstone of Bed 36 below, from which weather large spheroidal 'doggers', but Sumbler *et al.* (2000) have assigned these sandy beds to the Dyrham Formation. Specimens of *Amaltheus subnodosus* have been found up to 2.6 m above the base of this sandy unit, while a pebble bed at the base (Bed 35) yielded the brachiopod *Gibbirhynchia micra* (Ager, 1955; Palmer, 1971).

Interpretation

Palmer (1971) was the first to establish a detailed lithostratigraphy for the Robin's Wood Hill Quarry GCR site and succeeded in identifying the principal biostratigraphical boundaries. Where ammonites could not be found in the succession these boundaries were based partly on lithostratigraphical cross-correlation with the Stonehouse Brick and Tile Quarry, 10 km farther to the south (SO 816 050), and with the succession in the Stowell Park Borehole (Green and Melville, 1956).

Palmer (1971) assigned 7.7 m of silty mudstones of the Dyrham Formation in his beds 9b–c (beds 12–14 of this account) to the Figulinum Subzone on the basis of such correlation. Phelps (1985) recovered a specimen of *Aegoceras crescens* transitional to *Oistoceras angulatum* from Bed 12 (low in Bed 9b of Palmer, 1971) at Robin's Wood Hill Quarry, indicating the uppermost zonule of the Capricornus Subzone, and *Oistoceras*? *angulatum* from Bed 16 (Bed 9e of Palmer, 1971). Accordingly, he placed the two nodule bands of the Dyrham Formation, beds 9c and 9e (beds 14 and 16 of this account), and the intervening 2.74 m of silty mudstones, in the Figulinum Subzone. *Amaltheus bifurcus*, indicating the lowest zonule of the Stokesi Subzone (Phelps, 1985), has been found in Bed 18 (M.J. Simms, unpublished observations), and hence the Lower–Upper Pliensbachian boundary can be placed with some confidence below Bed 18.

Higher in the succession, Ager (1955) and Palmer (1971) interpreted the presence of *Gibbirhynchia micra* in Bed 35 as evidence for the Spinatum Zone. Palmer (1971) failed to find evidence for the Gibbosus Subzone below Bed 35 at Robin's Wood Hill Quarry. However, *Amaltheus subnodosus* occurs up to 2.6 m above the base of Bed 35 (Simms, 1990a) and hence the Gibbosus Subzone must lie above this level. Its presence has yet to be proven at this site, although it is known elsewhere in the northern Cotswolds. The Spinatum Zone is, therefore, probably confined to Bed 37 at the very top of the quarry, and Cox *et al.* (1999) included beds 35 and 36 within the Dyrham Formation. The most recent detailed log of the succession (Figure 4.12) can largely be correlated with the earlier accounts of Palmer (1971, 1973), but Chidlaw (1987, and this account) was unable to reconcile his own observations with part of the succession recorded by Palmer (beds 7, 8 and 9a of Palmer, 1971, broadly corresponding to beds 7–11 of this account).

As the most extensive inland exposure of the Pliensbachian Stage, incorporating the type section of the Dyrham Formation, the overlying Marlstone Rock Formation, and part of the underlying Charmouth Mudstone Formation, in the Severn Basin, the succession at Robin's Wood Hill Quarry has played an important role in inter- and intra-basinal correlation and interpretation. Palmer (1971) demonstrated a striking lithostratigraphical continuity between the quarries at Robin's Wood Hill and Stonehouse. He concluded, on lithostratigraphical and biostratigraphical grounds, that a sandy limestone and more than 6 m of silts immediately below the Marlstone Rock Formation at Stonehouse – since considered to represent the Subnodosus Sandstone Member – were absent from the section at Robin's Wood Hill Quarry. This he attributed to differential erosion prior to deposition of the highest part (beds 35–37) of the Robin's Wood Hill Quarry section.

Palmer (1971) also attempted correlation of the Robin's Wood Hill Quarry succession with those in the Stowell Park Borehole (Green and Melville, 1956). More recent work has helped to define formation boundaries within the succession. Sumbler *et al.* (1999) designated this as the type section of the Dyrham Formation and suggested its lower boundary, with the underlying Charmouth Mudstone Formation, be placed at the base of the Capricornus Sandstone (base of Bed 6 of this account) although we have placed it a little lower at the first appearance of silts. Palmer (1971, 1973) assigned all of his Bed 16 (beds 35–37 of this account), to the Marlstone Rock Formation, but here it is restricted only to Bed 37 at the top of the main quarry section, and beds A and B of the trackside section.

Overall similarities between the Robin's Wood Hill Quarry, Stowell Park Borehole and the Dorset coast successions, particularly in the general coarsening upwards through the sequence, reflect a regional (western Europe) shallowing that is evident in many Pliensbachian sequences (Hallam, 1981; Hesselbo and Jenkyns, 1998). More detailed lithostratigraphical correlation of marker bands between Robin's Wood Hill Quarry and the Dorset coast, located as they are in separate basins, must be regarded as tentative at best. For example, the Capricornus Sandstone, the most distinctive marker band in the Lower Pliensbachian successions of the Severn Basin has no lithostratigraphical correlative in the Green Ammonite Mudstone Member of the Wessex Basin (Hesselbo and Jenkyns, 1995), nor at Napton-on-the-Hill on the East Midlands Shelf (Callomon in Hallam, 1968a). The Subnodosus Sandstone Member (Simms, 1990a) in the upper part of the Dyrham Formation can be traced over an area similar to that of the Capricornus Sandstone in the Severn Basin. Limestone beds of comparable thickness and depth in the upper part of the Dyrham Formation, are known beyond the Severn Basin at both the **Neithrop Fields Cutting** and the **Napton Hill Quarry** GCR sites and, in the case of the latter at least, are of proven Subnodosus Subzone age. However, correlation of these widely separated occurrences must be considered highly tentative at best.

The succession exposed at Robin's Wood Hill Quarry has proven invaluable in understanding patterns and controls on sedimentation in the Severn Basin during early and mid-Jurassic times. The apparent absence of the Subnodosus Sandstone Member at Robin's Wood Hill Quarry (Palmer, 1971), was interpreted as a manifestation of uplift along a WNW–ESE axis, probably associated with movement on a basement fault close to Robin's Wood Hill late in Subnodosus Subzone times. Evidence of intermittent uplift on this axis imparting a gentle northward dip of the strata below the Marlstone Rock Formation has been recorded over an area extending at least 20 km to the north (Simms, 1990a). Although this pattern is fairly clear to the north of Cheltenham, extrapolation farther southwards to Robin's Wood Hill and Stonehouse is less certain. Simms (1990a) suggested that the Dyrham Formation at the Robins Wood Hill Quarry GCR site was deposited in a separate half-graben from that of sites farther north (Bredon Hill to Cleeve Hill).

Chidlaw (1987) disagreed with this interpretation, suggesting that lithological marker bands used by Palmer (1971) and Simms (1990a) for correlation within the Severn Basin were confined to individual sub-basins. Another possibility is that the Subnodosus Sandstone Member, far from being absent at Robin's Wood Hill Quarry, may in fact be represented in part by the thick silty sandstone of Bed 36. Sumbler *et al*. (2000) suggested that differential subsidence and intermittent truncation across sedimentary highs at times of eustatic lowstand, rather then any uplift, was the principal control on sedimentation erosion.

Conglomeratic horizons are developed at several levels throughout the succession at this site. Typically the clasts are of siltstone, evidently derived from the sediments beneath, and commonly are of a flattened discoidal shape. Palmer (1971) correlated some of these beds across the Severn Basin and possibly beyond, indicating widespread episodes of erosion and reduced sedimentation, which he (Palmer, 1973) attributed to periods of shallowing. The relative abundance of these episodes, represented by the conglomeratic horizons, at Robin's Wood Hill Quarry may indicate proximity to an area of uplift, and hence some may be of local distribution. Chidlaw (unpublished observations) has noted evidence for prolonged weathering, with leaching and concentration of iron oxide, at the top of Bed 22 in the Dyrham Formation and at the top of the Marlstone Rock Formation (Bed B) exposed in the track-side section. These horizons are developed at the top of upward-shallowing cycles and they may represent the lower horizons of lateritic palaeosols developed during brief periods of emergence.

Robin's Wood Hill Quarry has been the site of a number of significant palaeontological discoveries. The discovery of *Amaltheus subnodosus* up to 2.6 m above examples of *Gibbirhynchia micra* in Bed 35 extends the known range of this brachiopod, which formerly was recorded only from the uppermost Gibbosus Subzone and lower Spinatum Zone (Ager, 1954). The occurrence of *Tetrarhynchia* *dunrobinensis* in Bed 8 of Palmer (1971, 1973) extends its geographical range from its previously known distribution in Yorkshire and Scotland. Palmer (1973) interpreted the abundance of large filter-feeding bivalves in the coarser units of the Dyrham Formation and the Marlstone Rock Formation as evidence of well-oxygenated water and abundant 'plankton rain' and concluded, from the occurrence of trochid gastropods, that water depths did not exceed 100 m. The occurrence of articulated crinoids and ophiuroids in an impersistent siltstone in the Dyrham Formation in Bed 18 represents an example of an obrution deposit (Seilacher *et al.*, 1985) in which the crinoids and ophiuroids were killed and preserved as a result of catastrophic burial, perhaps associated with storm re-suspenion of sediment. Similar occurrences of *B. gracilis* and *P. milleri*, preserved in siltstone lenticles by obrution, are found at a comparable stratigraphical level in the Stokesi Subzone on the Dorset coast. Such deposits indicate that the sea floor was above storm wave-base at this time, and the sea was much shallower, perhaps as little as 20 m or less (Hallam, 1997). Still further support for this comes from the investigations of Lord (1972, 1974) and Malz and Lord (1976), who found a higher incidence of ornamented and heavily calcified ostracods in the Charmouth Mudstone and Dyrham formations at Robin's Wood Hill Quarry than in the broadly coeval beds at the **Blockley Station Quarry** GCR site, indicating a rather shallower, higher-energy palaeoenvironment at Robin's Wood Hill Quarry. Lord (1972, 1974) also noted a strong similarity between the ostracod faunas of Robin's Wood Hill and the Dorset coast and concluded that an open seaway connection existed between the two areas. In contrast, the connection with the East Midlands Shelf was much poorer. This equates broadly with the recognition by Ager (1956a) and Howarth (1958) of distinct faunal provinces for the south-west and the Midlands.

Conclusions

Robin's Wood Hill Quarry provides the finest section through the Pliensbachian Stage, in particular the Dyrham Formation for which it has been designated type locality, of any site between the Dorset and Yorkshire coasts. The succession exposed here has proven critical to understanding the underlying controls on facies distribution in the Severn Basin from the Upper Pliensbachian Substage into the Middle Jurassic Series. As one of only a small number of inland sites to still expose this part of the Lower Jurassic succession, Robin's Wood Hill Quarry is a key site for any investigations of early Jurassic palaeogeography, basin development and eustasy in southern Britain.

ALDERTON HILL QUARRY, GLOUCESTERSHIRE (SP 006 345)

Potential GCR site

M.J. Simms

Introduction

Alderton Hill Quarry is the westernmost of three small, long-abandoned quarries excavated into the Marlstone Rock Formation (Uppermost Pliensbachian) and Whitby Mudstone Formation (basal Toarcian) successions on the southern flank of Alderton Hill (Figure 4.13). There are few records or specimens specifically from the other two quarries, Dumbleton Quarry and Naunton Farm Quarry, and both are extensively overgrown. More than a century ago Alderton Hill Quarry was said by Woodward (1893) to have been abandoned for some time. Frequent reference to the site as 'Dumbleton' probably reflects the location of all three quarries within the Dumbleton Estate.

The section at Alderton Hill Quarry exemplifies the dramatic facies and faunal changes that occurred across the Pliensbachian–Toarcian boundary. The limestones of the Marlstone Rock Formation contain a rich benthic fauna while the succeeding argillaceous Whitby Mudstone Formation (Toarcian) is dominated by nektonic taxa. This is the type locality for the Dumbleton Member of the Whitby Mudstone Formation, a succession of paper shales and laminated limestone nodules, including the 'Fish Bed' nodules, which can be recognized over a large area of southern Britain and beyond. The Marlstone Rock Formation and the Fish Bed nodules at this site have been the source of many figured and type specimens, of both vertebrates and invertebrates, particularly insects.

The three quarries were already well-known for their unusual fossil fauna by the mid-19th century, with a fine collection amassed by Miss Holland of Dumbleton Hall (Wright, 1863). The succession was described or mentioned briefly

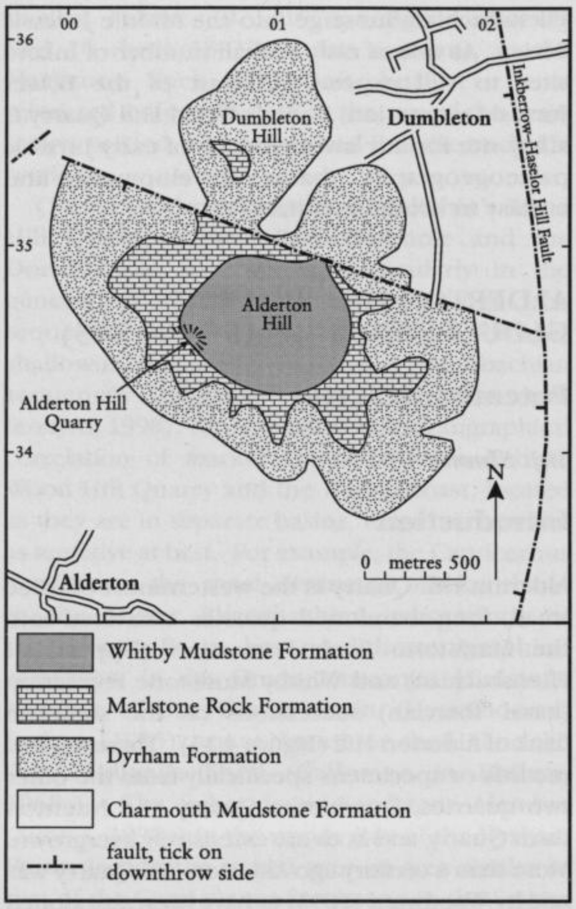

Figure 4.13 Geology and location map for the Alderton Hill Quarry GCR site.

in various papers in the second half of the 19th century and early 20th century (Brodie, 1845, 1858, 1860a; Murchison, 1845; Hull, 1857; Moore, 1867b; Guise, 1880; Tomes, 1886; Smithe and Lucy, 1892; Woodward, 1893; Richardson, 1904, 1929b; Buckman, 1922), with elements of the fauna listed or described in several additional publications (Brodie, 1849; Buckman, 1853; Wright, 1863; Tomes, 1886; Crick, 1896, 1922; A.S. Woodward, 1911; H. Woodward, 1911; Tillyard, 1925, 1933; Ager, 1956–1967, 1990; Howarth, 1958, 1992).

Description

Despite the numerous publications, the succession at Alderton Hill Quarry has never been documented in detail. Of the sections published (Murchison, 1845; Brodie, 1860a; Guise, 1880; Smithe and Lucy, 1892; Woodward, 1893) only those by Tomes (1886) and Richardson (1929b) provided more than the most general description. Tomes (1886) recorded a total thickness of 8.7 m (28 ft 3 in.), including 'surface soil': Richardson (1929b) recognized at least 12 distinct units within a total exposed thickness of 10.75 m (35 ft). The different total thicknesses probably arose from the advance of the quarry face into the hillside, but there are also significant differences between the two recorded sections. That reproduced below attempts to combine the detail from both accounts; beds 1–3 and 7–13 are based on Richardson's (1929b) description, while beds 4–6 are taken from Tomes (1886).

		Thickness (m)
TOARCIAN STAGE		
Whitby Mudstone Formation		
Dumbleton Member		
13:	Limestone, rubbly.	0.05 (2 in.)
12:	Clay, pale blue-grey.	1.5 (5 ft)
11:	Shales, light violet, interspersed with nodular limestone.	0.9 (3 ft)
10:	Limestone nodules, laminated – 'Fish Bed' (this was recorded as 1 ft (0.3 m) thick by Tomes and overlain by 4 ft (1.23 m) of 'surface soil').	0.15 (6 in.)
9:	Paper shales, bluish, with nodules.	0.25 (10 in.)
8:	Paper shales, violet (beds ?7, 8 and 9 were united by Tomes into a single 14 ft (4.3 m) unit of 'laminated blue shales').	3.9 (12 ft 9 in.)
7:	Clay, light grey, shaly.	0.9 (3 ft)
6:	Layer of intermittent nodules of hard stone containing 'fucoids' (described by Richardson as 'dark purple clay (?*Leptaena* Bed)').	0.08 (3 in.)
5:	Shales, blue, laminated (beds 4 and 5 were combined into a single unit by Richardson, who described them as a 'hard band with limestone nodules').	1.15 (3 ft)
4:	Clay, whitish-grey, hard, breaking up into angular lumps and weathering into a soft, light-coloured clay.	0.23 (9 in.)
3:	Shale, light blue, hard. In the lower part are many belemnites, and in the upper part numerous small pyrite crystals, small ammonites (?*Dactylioceras pseudocommune* = *Ammonites bolandrei*), gastropods and *Thecocyathus tuberculatus*.	0.38 (1 ft 3 in.)
UPPER PLIENSBACHIAN SUBSTAGE		
Marlstone Rock Formation		
2:	Marl, hard, containing *Tetrarhynchia tetrahedra*, *Pleuroceras spinatum*, belemnites and crinoid debris (Tomes described this as a 'friable shale, having the appearance of soft marlstone, brown or ferruginous in colour, and sometimes micaceous').	0.3 (1 ft)
1:	**Marlstone Rock Bed** (with two other bands not exposed).	1.02 (3 ft 4 in.)

At the time of writing, the section was largely obscured by vegetation, although slumping of the upper part of the face in the early 1980s exposed 2 m of paper shales and the Fish Bed.

The Marlstone Rock Formation forms a conspicuous shelf below the quarry although its exact thickness remains unclear. That part of the pit was flooded when visited by Smithe and Lucy (1892), but Woodward (1893) reported its thickness as 'about 14 feet' (4.3 m), commenting that the beds were not fully exposed. Richardson (1929b) referred to 'two other bands not exposed', but it is unclear as to whether these were in the lower part of the Marlstone Rock Formation or in the underlying Dyrham Formation.

The Marlstone Rock Formation appears to be predominantly a shelly, micritic limestone, in places pyritic. It has been a prolific source of well-preserved fossils, particularly molluscs. Richardson (1929) listed almost 50 nominal species. Amaltheid ammonites are a common and conspicuous element of this fauna. It is the type locality for *Pleuroceras spinatum* var. *buckmani* (Moxon, 1841) and *Amaltheus sedgwicki*, a synonym of *A. margaritatus* (Howarth, 1958). It has also yielded a rich and fairly diverse brachiopod fauna, including the holotype of *Tetrarhynchia dumbletonensis* (Ager, 1956–1967). Murchison (1845) referred to crustacean and plant remains, including a carbonized cone, and the humerus of a pterosaur from here.

The succeeding Toarcian Dumbleton Member of the Whitby Mudstone Formation comprises mudstones and paper shales with a few grey, nodular, argillaceous limestone bands. In the absence of any bed-by-bed collecting, many of the species recorded by Richardson (1929b) and others cannot be tied into the lithostratigraphy. Tomes (1886) recorded numerous specimens of the solitary coral *Thecocyathus tuberculatus*, and a few *Trochocyathus* sp., from weathered Whitby Mudstone Formation clays at disused workings on Stanley Hill (SP 010 298), Gretton, just 5 km to the south. He collected two specimens of *T. tuberculatus* from the upper part or top of Bed 3 at Alderton Hill Quarry. S.S. Buckman (1922) and Richardson (1929b) recorded abundant specimens of the minute brachiopods *Orthotoma globulina* (Ager, 1990) and *Nannirhynchia pygmaea* (Ager, 1956–1967) from beds 8 and 9, together with specimens of *Diademopsis* cf. *crinifera* with spines intact. Upton (1906) also noted that fish fragments, echinoid spines and *Pseudomytiloides dubius* were common in the paper shales, but ostracods and foraminifera were rare. More recent collecting from these shales in the 1970s and 1980s (M.J. Simms, unpublished observations) yielded disarticulated fish remains, a partial thorax of *Coleia richardsoni*, and ammonites with aptychi in place.

Only the Fish Bed of the Dumbleton Member is of a sufficiently distinctive lithology to ensure that loose blocks and nodules can be assigned with confidence to this bed. Individual nodules may be 1 m of more across, though commonly breaking into smaller blocks, but seldom are more than 0.2 m thick. Externally they are of creamy-yellow laminated limestone, though they are commonly 'blue-hearted' at the centre. A fairly rich fauna has been obtained from the Fish Bed nodules here and at other sites on adjacent hills. The most abundant vertebrate is the small early teleost fish *Leptolepis coryphaenoides*, occasionally found intact (Figure 4.14) and with traces of soft tissues but more usually as scattered bones; it was originally described from here as a new species, *Leptolepis concentricus* (Egerton in Brodie, 1849). Several other fish species occur more rarely, with this the type locality for the semionotid *Tetragonolepis discus* and the only British locality for the pachycormid *Euthynotus* (A.S. Woodward, 1895, 1911). Reptile remains have been found only rarely in the Fish Bed nodules in this area. Moore (1867b) referred to what would appear to be a fairly complete skeleton of an ichthyosaur in the Fish Bed nodules at Dumbleton, and Smithe (1865) noted a tooth of *Teleosaurus* and a

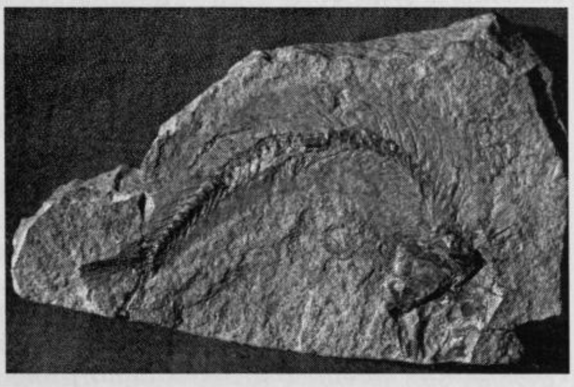

Figure 4.14 Large specimen (70 mm across) of the early teleost *Leptolepis coryphaenoides*, from the Fish Bed of the Dumbleton Member at Dumbleton Pit, just to the east of Alderton Hill Quarry. Specimen from the Simms Collection, in Bristol City Museum. (Photo: M.J. Simms.)

scapular arch or coracoid of a pterosaur from the Fish Bed nodules at Churchdown Hill (SO 880 190), near Gloucester.

The marine invertebrate fauna of the Fish Bed nodules are dominated by nektonic and planktonic species. Three species of ammonite, and isolated aptychi, have been recorded; *Hildaites murleyi* and *H. forte*, for both of which this is the type locality (Moxon, 1841; Howarth, 1992), and *Cleviceras elegans*, all indicating the Exaratum Subzone of the Serpentinum Zone. Of two species of belemnite, *Acrocoelites ilminsterensis* and *Chondroteuthis wunnenbergi*, both have been found in exceptional states of preservation with phragmocone and proostracum intact (Crick, 1896; Doyle, 1990–1992), while isolated groups of hooklets may also belong to one or other of these species (Doyle, 1990–1992). Crick (1922) figured specimens of the teuthids *Geoteuthis agassizi* and *Teuthopsis brunelii* from the Fish Bed nodules of Alderton Hill. Among the other molluscs *Pseudomytiloides dubius* occurs sporadically and *Goniomya tetragona* only very rarely. By far the most abundant mollusc, or indeed fossil of any type, in the Fish Bed nodules is the tiny gastropod *Coelodiscus minutus*. This can occur evenly scattered through some Fish Bed nodules, though it is absent from others; intact fish remains are rarely, if ever, encountered in those Fish Bed nodules in which the gastropod is abundant (M.J. Simms, unpublished observations). The only other invertebrates present are arthropods, represented by scarce benthic marine taxa, and a diverse and abundant fauna of insects, some of them extraordinarily well-preserved. The arthropods include the holotype of *Coleia richardsoni* (H. Woodward, 1911; Woods, 1925–1931), while examples of the insects have been figured by Buckman (in Murchison, 1845; Buckman, 1848, 1853), Brodie (1849) and Tillyard (1925, 1933). The Fish Bed nodules exposed in the quarries on the Dumbleton Estate were the source of numerous insect holotypes, including the dragonflies *Heterophlebia buckmani*, *H. angulata* and *Liassogomphus brodiei*, and the panorpoids *Actinophlebia anglicana*, *Orthophlebia brodiei*, *Protobittacus handlirschi*, *Necrotaulius pymgmaeus* and *Liassotipula anglicana*. More material was collected in the 1970s and 1980s (M.J. Simms, unpublished; now held in Bristol City Museum; Figure 4.15): the entire entomofauna is in need of further investigation.

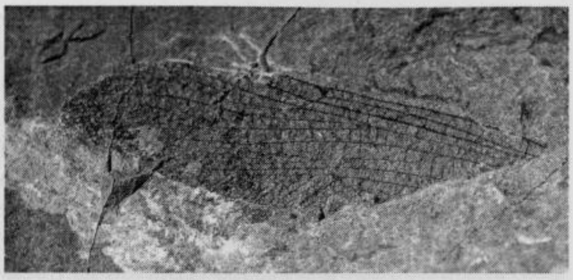

Figure 4.15 Incomplete wing (30 mm long) of the dragonfly *Heterophlebia buckmani*, from the Fish Bed of the Dumbleton Member at Alderton Hill Quarry. Specimen from the Simms Collection, in Bristol City Museum. (Photo: M.J. Simms.)

Interpretation

Although ammonites are common throughout the succession formerly exposed here, a detailed biostratigraphy cannot be established because few of the ammonites recorded were obtained *in situ*. Beds 1 and 2 contain abundant amaltheids, particularly species of *Pleuroceras*, and hence lie within the Spinatum Zone. The identification of the *Ammonites holandrei* from Bed 3 as *Dactylioceras pseudocommune* is, at best, questionable but may indicate an early Tenuicostum Zone (Paltus Subzone) age. The only other proven records are of *Cleviceras elegans*, *Hildaites murleyi* and *H. forte* from the Fish Bed, indicating a position within the Exaratum Subzone of the Serpentinum Zone.

The thickness of the Marlstone Rock Formation has not been ascertained at this site: cited thicknesses vary from 1.32 m (Richardson, 1929b) to 4.3 m (Woodward, 1893). Both are possible since the formation shows a dramatic southward thinning in this area from more than 6 m on Bredon Hill (SO 957 399) to 0.5 m on Cleeve Hill (SO 979 256), a distance of only 14 km (Simms, 1990a). Alderton Hill Quarry is approximately midway between the thick, sandy facies of the Marlstone Rock Formation of Bredon Hill and the ferruginous, oolitic and conglomeratic facies of Oxenton and Stanley hills. It shows greater lithological similarity to Bredon Hill than to the other sites. However, only excavation of the site can establish its lithological succession.

The overlying (Toarcian) Dumbleton Member succession is characterized by nektonic and planktonic fauna, with evidence of a significant benthic fauna at some levels. The most notable of these is the presence of corals at or near the top of Bed 3, suggesting well-oxygenated conditions and a pause in sedimentation. The presence of burrow systems (the 'fucoids' of Tomes, 1886) in Bed 6 also indicates at least dysaerobic conditions for a brief period within the anoxic environment represented by the paper shales.

The unusual fauna of the Fish Bed was noted by many early authors and comparisons were drawn with correlative sections elsewhere. Brodie (1860a) and Moore (1867b) noted similarities between the section at Alderton Hill Quarry and correlative strata in Somerset. Similar 'Fish Bed' facies are known from Northamptonshire and elsewhere in the East Midlands (Brodie, 1860a; Judd, 1875; Howarth, 1978), and from farther afield in Normandy (Smithe and Lucy, 1892; Dineley and Metcalf, 1999). In Germany and Switzerland the Exaratum Subzone is developed as bituminous paper shales with a laminated limestone band, the Unterer Stein, in which the most common fossil is *Leptolepis coryphaenoides* (Etter and Kuhn, 2000).

The mutual exclusion apparently shown by intact fish and the gastropod *Coelodiscus minutus* in the Fish Bed nodules, and the fact that the latter occur evenly scattered through some nodules but are absent from others, suggests that not all of the Fish Bed nodules occur at exactly the same level and that benthic oxygen levels were higher during deposition of the sediments containing abundant gastropods and only disarticulated fish. This is supported by the observations of Smithe (1865), and Simms (unpublished observations), who noted that Fish Bed nodules can be found throughout some 2.5 m (8 ft) of strata. The laminated nature of the Fish Bed nodules, the presence within them of uncrushed ammonites, and the similarity of the fauna in the surrounding paper shales, suggests that they represent early diagenetic carbonate segregations which developed within the shales. Those that grew at horizons representing the most anoxic periods during shale deposition contain the best-preserved insects and vertebrates. In contrast, those that formed at levels representing less anoxic conditions contain only poorly preserved vertebrates together with a greater or lesser abundance of benthic invertebrates, including an abundance of gastropods. A detailed account of the faunal distribution within the Fish Bed nodules and adjacent paper shales must await a more detailed investigation of the site.

The sudden lithological change exposed in the succession at Alderton Hill Quarry, from the shallow-water facies of the Marlstone Rock Formation with its abundant shelly benthic fauna, overlain by the laminated mudstones and limestones of the Dumbleton Member with its nektonic fauna and low-diversity benthos, marks a rapid eustatic rise in sea level in earliest Toarcian times (Hallam, 1981; Hesselbo and Jenkyns, 1998), which affected vast areas of northern Europe and beyond, and that produced dramatic changes in marine faunas (Hallam, 1987a; Vörös, 2002).

Conclusions

Alderton Hill Quarry exposes a section representative of the dramatic palaeoenvironmental changes that occurred in south-west England between the Marlstone Rock Formation and the Whitby Mudstone Formation. Sandstones with abundant shelly benthic faunas were replaced by mudstones with an overwhelmingly nektonic fauna that was preserved in the predominantly anoxic seabed conditions that prevailed during deposition of the Dumbleton Member. The site has long been a rich source of fossil material, particularly from the Marlstone Rock Formation and the Fish Bed, and has been an especially important source of fossil insect remains.

THE COTSWOLD CEPHALOPOD BED MEMBER AND THE BRIDPORT SAND FORMATION

N. Chidlaw and M.J. Simms

GENERAL DESCRIPTION

The upper part of the Toarcian Stage in the central and southern Cotswolds is developed in a predominantly arenaceous facies, which for many years was termed the 'Cotteswold Sands'. This was recognized as being lithologically and stratigraphically equivalent to similar sands in northern and southern Somerset (the Midford Sands and Yeovil Sands) and, still farther south, in Dorset (the Bridport Sands). Consequently it has now been subsumed within the Bridport Sand Formation (Sumbler *et al.*, 1999). The lithology and facies of the formation in the

Cotswolds does not differ significantly from that seen farther south, in the Wessex Basin. Typically it comprises friable, dull yellow silty sands with fairly regular bands of harder calcareous sandstone. Bioturbation commonly is intense and has largely destroyed any small-scale sedimentary structures, although cross-bedding, ripple cross-lamination, or individual burrows are evident in certain beds. Fossils generally are rather scarce, except at certain levels, while the friable nature of much of the formation leads to rapid weathering and degradation of exposures. Consequently it is rather poorly documented although some exposures are described in Cave (1977) and the formation as a whole was discussed by Davies (1969). The three GCR sites described here all expose the upper part of the formation. An aspect of the Bridport Sand Formation that has long intrigued geologists is the diachronous nature of its top and base between Gloucestershire (older) and Dorset (younger) (Buckman, 1889; Davies, 1969).

In the central Cotswolds the upper part of the Bridport Sand Formation is developed in a condensed, carbonate-rich facies commonly rich in ammonites and other fossils. The Cotswold Cephalopod Bed Member ('Cephalopod Bed' of earlier accounts) of the Bridport Sand Formation (formerly the 'Cotteswold Sands' in this area) was well documented by geologists in the late 19th and early 20th centuries, notably J. Buckman (1879) and his son S.S. Buckman (1887–1907, 1889), on account of its rich ammonite fauna. Important descriptive accounts published more recently are those of Davies (1969) and Cave (1977). Several of the classic sections exposed in quarries and sunken lanes are still accessible. Three sections, at **Wotton Hill**, **Haresfield Hill** and **Coaley Wood** (Figure 4.16), have been selected for inclusion in the GCR as representative of the member, and to demonstrate the nature of lateral variations within it (Figure 4.17).

The Cotswold Cephalopod Bed Member comprises a series of centimetre- to metre-scale units composed of highly bioclastic, extensively bioturbated, yellow and brown marls and marly limestones commonly rich in limonite ooids. These include abundant dark-brown ferruginous ooids, or occasionally pisoids, often marginally abraded and with a nucleus of limonite-coated, algal-bored, shell material. The member contains a rich and diverse shelly benthic and nektonic fauna. Ammonites, bivalves and belemnites are particularly conspicuous, with the ammonites documented by Buckman (1887–1907) and the belemnites by Doyle (1990–1992). Brachiopods are also present (Ager, 1956–1967) together with crinoid and echinoid debris. Much of the fossil material is fragmentary, extensively bored by algae and coated with limonite, though intact shells mostly are unbored and lack the limonite coating. Horizontal and U-shaped burrows occur in some of the units and bioturbation is ubiquitous. Lithologically, the several discrete units that together form the

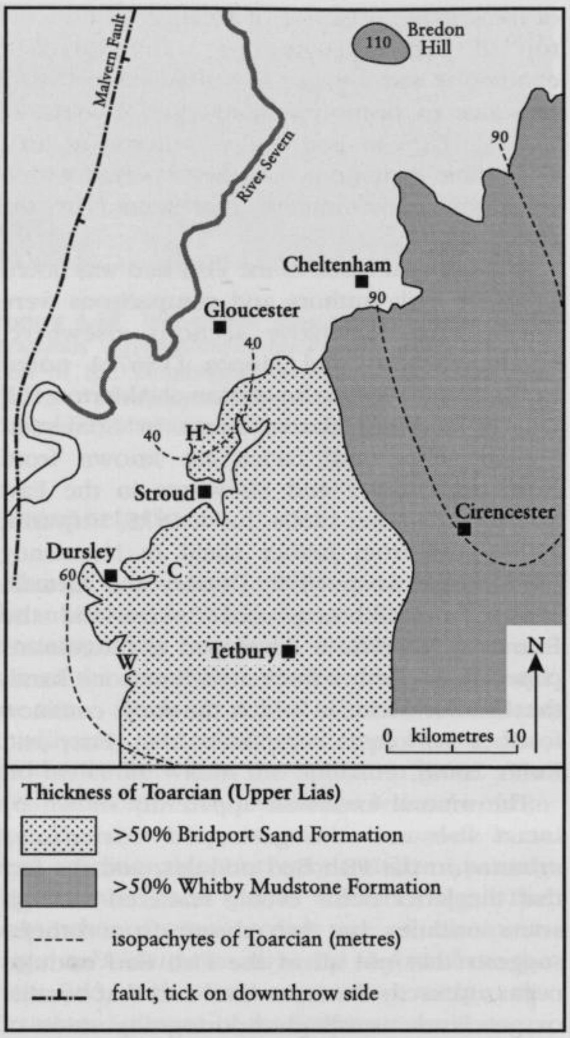

Figure 4.16 Outcrop/subcrop map of Toarcian strata in the Severn Basin, showing the geographical distribution of sand-dominated (Bridport Sand Formation > Whitby Mudstone Formation) and clay-dominated successions. The location of the three Cotswold Cephalopod Bed Member GCR sites is indicated: **W** – Wotton Hill; **C** – Coaley Wood; **H** – Haresfield Hill. After Green (1992).

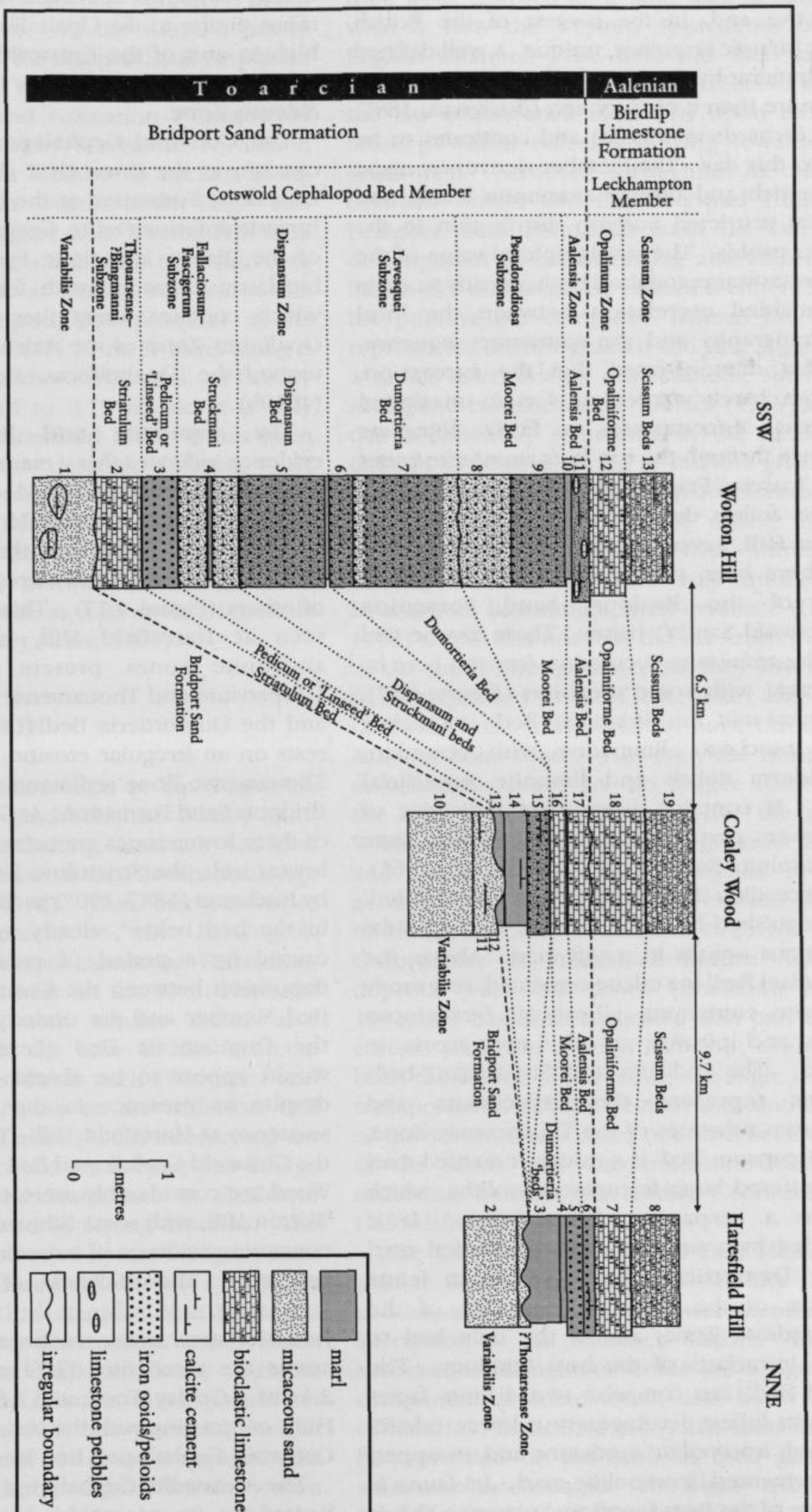

Figure 4.17 Lithostratigraphical and biostratigraphical correlation of named units within the Cotswold Cephalopod Bed Member (Bridport Sand Formation) at the GCR sites of Wotton Hill (from new observations by Chidlaw), Coaley Wood (after Richardson, 1910b) and Haresfield Hill (after Buckman, 1887–1907; and Richardson, 1904). Ammonite zonal stratigraphy revised by K.N. Page.

Cotswold Cephalopod Bed Member are distinctive and, in the context of the British Lower Jurassic sequence, unique. A well-defined lithostratigraphy was established for this succession more than a century ago (Buckman, 1887, 1889; Richardson, 1910b) and continues to be used to this day. The member derives its name from a rich and diverse ammonite fauna, and from its restricted outcrop distribution in the mid-Cotswolds. The stratigraphical value of the ammonites was recognized by these early workers and enabled correlation between the local lithostratigraphy and the ammonite sequence. This has demonstrated that the succession, although barely exceeding 4 m in maximum thickness, encompasses a fairly complete sequence through the top four ammonite zones of the Toarcian Stage (Figure 4.17).

In its fullest development, at sites such as **Wotton Hill**, seven named, lithostratigraphical units have been recognized above the typical facies of the Bridport Sand Formation ('Cotteswold Sands') below. These can be tied in to the ammonite succession (revised here by K.N. Page) with some precision (Figure 4.17). The lowest unit, the 'Striatulum Bed', is a slightly sandy, bioclastic limestone with abundant echinoderm debris and limonite superficial ooids. It contains ammonites indicative of the lower part of the Thouarsense Zone (= Striatulum Subzone of Dean *et al.*, 1961). The succeeding 'Pedicum Bed', or 'Linseed Bed' is distinguished by an abundance of ellipsoidal ferruginous ooliths in a soft marl. Above, the 'Struckmani Bed' is a calcite-cemented, very sandy biomicrite containing ellipsoidal ferruginous ooliths, and pisoids up to 4 mm across in its base. The Pedicum and Struckmani beds together represent the Fallaciosum and Fascigerum subzones of the Thouarsense Zone. The 'Dispansum Bed' is a calcite-cemented marl with scattered large ferruginous ooliths, which contains a Dispansum Zone fauna. It is succeeded by a sandier, calcite-cemented marl of the 'Dumortieria Bed', containing fauna indicative of the Levesquei Subzone of the Pseudoradiosa Zone, and is the only bed to contain intraclasts of the host lithology. The 'Moorei Bed' can comprise two distinct facies units in its fullest development; a lower, calcite-cemented, iron-oolitic sandstone and an upper, calcite-cemented, iron-oolitic marl. Its fauna is indicative of the Pseudoradiosa Subzone. This is overlain by the 'Aalensis Bed', a marl unit that locally contains reworked limestone pebbles more similar to the Opaliniforme Bed. It is the highest unit of the Cotswold Cephalopod Bed Member in this area and its fauna indicates the Aalensis Zone.

The Cotswold Cephalopod Bed Member is overlain at the three GCR sites by the Birdlip Limestone Formation at the base of the Middle Jurassic Inferior Oolite Group. The basal bed of the Birdlip Limestone Formation is a thin, bioclastic limestone with ferruginous peloids, which contains ammonites indicative of the Opalinum Zone of the Aalenian Stage. It was termed the 'Opaliniforme Bed' by Richardson (1910b).

The ammonite and lithostratigraphical evidence indicates that a marked thinning of the Cotswold Cephalopod Bed Member between **Wotton Hill** and **Haresfield Hill** is associated with the loss of some of the distinctive lithostratigraphical units and increased condensation of others (Figure 4.17). This is most strikingly seen at Haresfield Hill, where the lower ammonite zones present at Wotton Hill (Dispansum and Thouarsense zones) are absent and the Dumortieria Bed (Levesquei Subzone) rests on an irregular erosion surface, on lower Thouarsense Zone sediments of the underlying Bridport Sand Formation. At **Coaley Wood**, both of these lower zones are present. There too the lowest unit, the Striatulum Bed, was described by Buckman (1887–1907) as 'filling irregularities in the bed below', clearly indicating a hiatus caused by a period of erosion and/or non-deposition between the Cotswold Cephalopod Bed Member and the underlying sands. Only the Dumortieria Bed (Levesquei Subzone) would appear to be absent at Coaley Wood, despite its presence in the more attenuated sequence at Haresfield Hill. The other units of the Cotswold Cephalopod Bed Member at Coaley Wood are considerably more condensed than at Wotton Hill, with some lithostratigraphical units containing evidence of more than one ammonite subzone. The thickness of the succeeding Leckhampton Member, at the base of the Middle Jurassic succession, is broadly comparable across the three sites (2.74 m at Wotton Hill, 2.14 m at Coaley Wood, and 2.63 m at Haresfield Hill), contrasting with the variations seen in the Cotswold Cephalopod Bed Member beneath.

The Cotswold Cephalopod Bed Member is limited in its geographical extent along the Cotswold scarp, extending from the area north of Stroud southwards to Old Sodbury (18 km north-east of Bristol). To the south it passes laterally into sands of the Bridport Sand Formation ('Midford Sands'). Northwards it passes into typical Bridport Sand Formation ('Cotteswold Sands') or into Whitby Mudstone Formation (Green, 1992). The member is thickest along the scarp between Wotton-under-Edge and Nibley Knoll, (see Figure 4.18, **Wotton Hill** GCR site report) attaining a thickness of a little over 4 m. The GCR site at Wotton Hill shows the Cotswold Cephalopod Bed Member at its measurable thickest of 4.11 m: it thins along a NNE line linking the three GCR sites. At **Coaley Wood**, it is reduced to 0.79 m, and it is only 0.55 m thick on **Haresfield Hill**. It has been traced eastward from outcrop, thinning to as little as 0.08 m between Tetbury (ST 890 930) and Nailsworth (SO 000 850), where it contains representatives of the Striatulum and Pseudoradiosa subzones, before thickening north-eastwards to as much as 1.83 m in a borehole 10 km east of Tetbury (Cave, 1977).

INTERPRETATION

Early Toarcian sedimentation in the Cotswolds was dominated by mudrocks, the Whitby Mudstone Formation, reflecting a eustatic sea-level rise following the close of the Pliensbachian Age (Bradshaw *et al.*, 1992). Thin, marly, ironshot limestones, assignable to the Barrington Member of the Beacon Limestone Formation, occur to the south-west on the 'Avon Platform' (Chidlaw, 1987), with similar facies also developed towards the base of the Toarcian Stage in the Severn Basin itself (Whittaker and Ivimey-Cook, 1972), as at the Alderton Hill Quarry GCR site. Davies (1969) interpreted the mudrocks as deposited in deeper, low-energy conditions, and the limestones in shallower water often disrupted by strong currents. The mudstones are succeeded by the Bridport Sand Formation, considered by Davies (1969) to represent a sand-bar complex that advanced southwards from the Cheltenham area between mid-Toarcian times (Bifrons Zone, Crassum Subzone) and early Aalenian times (Opalinum Zone). Boswell's (1924) heavy-mineral analysis of the Bridport Sand Formation suggested that Armorican metamorphic rocks of Brittany were a likely source. Davies (1969) suggested that the sediment was eroded from rocks there when they were exposed as a land area situated in what is now the Western Approaches of the English Channel. The sand was then carried north-eastwards by longshore currents to where the bar commenced formation upon meeting more powerful currents flowing towards the south-west. However, throughout its outcrop between Dorset and the Cotswold Hills, the Bridport Sand Formation lacks the extensive development of cross-bedding and contrasting lithologies that might be expected either side of the putative bar complex. Instead the facies represented are fine grained and silty, suggesting a rather lower-energy environment, such as a shelf sand blanket facies. Davies (1969) noted that sedimentary structures in the sands are difficult to observe owing to the fine grain-size, lithological uniformity and extensive bioturbation, but when seen they include mainly ripple-formed cross-laminations, with infrequent development of large-scale cross-stratification. In addition, biostratigraphical evidence (Green, 1992) shows that not only did the sands migrate to the south through time, but they also began to be deposited in the Cheltenham and north Cotswold areas from Variabilis Zone through to Aalensis Zone times. However, the Armorican metamorphic rocks are no longer considered the only possible source area for the sands. While uplift of land or marine regression in west and south-west England is implied to have generated the sands, extensive erosion of post mid-Bifrons Zone sediments occurred from Oxfordshire to Yorkshire before Aalenian deposits were laid down (Bradshaw *et al.*, 1992). It has been suggested that part of this eastern area (the London Platform) could have been the source of the sands, although, if so, its transportation into the western and central parts of the Severn Basin could not have been direct, as the sands pass into mudstone-dominated sediments beneath the eastern Cotswolds and Oxfordshire (Green, 1992).

The Cotswold Cephalopod Bed Member is similar in several respects to the highly condensed Sinemurian and Lower Pliensbachian succession of the Radstock district. In both successions ferruginous ooids are a significant component at some levels, and both can be divided into distinctive individual units that can be correlated on the basis of their abundant ammonite assemblages. The highly condensed nature of the Cotswold Cephalopod Bed Member succession indicates that low subsidence rates played a significant role, and sedimentary breaks and the occasional presence of intraclasts at some sites indicates that erosion was important locally. Tectonic controls on sedimentation are well documented for the Severn Basin (Whittaker, 1972b, 1985; Simms 1990a) and clearly exerted a considerable influence on deposition of the Cotswold Cephalopod Bed Member. Chidlaw (1987) noted a similar pattern of lateral thickness variation for the Upper Pliensbachian succession (the Dyrham and Marlstone Rock formations) in the Severn Basin. He attributed this to syn-sedimentary extensional movement in a block-faulted basement, with deposition of the most condensed successions on sediment-starved highs. Farther north in the Severn Basin the succession is strikingly different, with mudstones dominating much of the Toarcian succession correlative with the Bridport Sand Formation farther south. Nonetheless, there does appear to be an increase in arenaceous sediments in the late Toarcian succession even on Bredon Hill, representing the deepest part of the basin (Whittaker and Ivimey-Cook, 1972). This suggests that there was at least a minor eustatic component to the development of the Cotswold Cephalopod Bed Member.

In the Cotswold Cephalopod Bed Member, the abundance of fragmentary shell material and presence of marginally abraded ooids suggests a fairly high-energy environment in which the lime-mud matrix may have been produced largely from the disintegration of skeletal material, including calcareous green algae. Despite predominantly high-energy conditions, this lime mud remained in the environment through its entrapment by algal mucilage and macrophytes, indicating an algal-rich environment. This developed in response to an abrupt termination of sand supply, perhaps associated with regional uplift rather in the manner suggested for the succession seen at the **Ham Hill** GCR site, creating improved conditions both for algae and for the shelly fauna, which rapidly colonized the sea floor. Remains of the abundant benthic and nektonic fauna were often fragmented and comminuted by strong currents, and extensively bio-eroded by endolithic algae. However, the typically unbored and unencrusted preservation of the intact ammonites indicates that they cannot have lain exposed on the sea floor for any length of time but must have been buried fairly rapidly. This suggests that the richness of the ammonite fauna here did not arise from a slow accumulation of ammonite conchs but more probably reflects a general abundance of this group in the living fauna, with periodic episodes of sediment re-suspension, perhaps due to storms, burying recently dead materials along with the bored and encrusted fragments of other shells. Early diagenetic cementation and subsequent erosion of the marly sediment produced intraclasts on at least one occasion.

In contrast, Davies (1969) concluded from the dominantly micritic matrix that the environment of deposition was essentially one of low energy, interrupted only occasionally by more powerful currents that produced the intraclasts and brought abraded ooliths, pisoliths and shell fragments into the area from dominantly higher energy conditions to the north-east. However, this appears unlikely, since that area is occupied by the Bridport Sand Formation ('Cotteswold Sands') and Whitby Mudstone Formation, both of which are relatively low-energy deposits.

An extensive facies belt broadly analogous to the Cotswold Cephalopod Bed Member, and similarly composed of shelly lime mudstones with limonitic ooids and intraclasts, is present on the 'Avon Platform' as the Marlstone Rock Formation (Chidlaw, 1987). Here too, ooid nuclei consist of shell fragments and siltstone and, like much of the thick-shelled macrofauna, are sometimes broken. Chidlaw discounted the possibility of the limonitic ooids here having been introduced from adjacent lithofacies belts, since ferruginous ooids from the latter are noticeably different in size and structure.

WOTTON HILL, GLOUCESTERSHIRE (ST 754 940)

N. Chidlaw

Introduction

The Wotton Hill GCR Site is located on the crest of the Cotswold escarpment, at about 180 m OD, overlooking the north-western outskirts of Wotton-under-Edge (Figure 4.18). It comprises two disused quarries, which together expose an almost continuous section through the uppermost formations of the Lias Group to within the highest formations of the Inferior Oolite Group. The larger of the two quarries, on the plateau crest, lies entirely within the Inferior Oolite

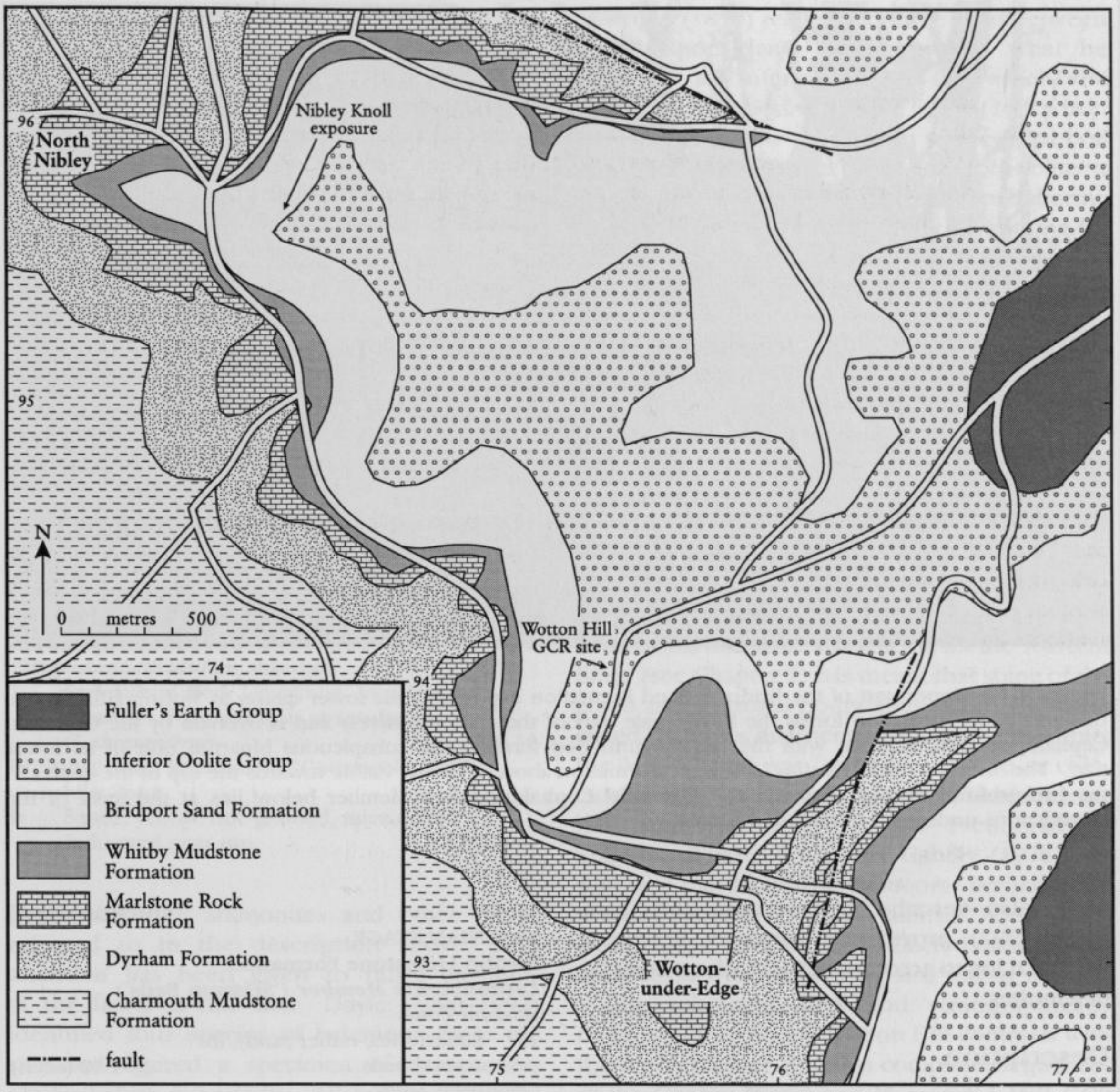

Figure 4.18 General geology and location map for the Wotton Hill GCR site and the Nibley Knoll exposure.

Group and is not discussed further here. The smaller, lower quarry exposes the boundary beds of the Lower and Middle Jurassic successions.

The section is well exposed (Figure 4.19), and contains the greatest measured thickness of the Cotswold Cephalopod Bed Member, a locally developed condensed sequence within the Bridport Sand Formation, which is one of the richest sources of late Toarcian ammonites in Britain, and has yielded a more complete Upper Toarcian ammonite sequence than any other in the Severn Basin. The regional dip of the strata is less than 1° to the south-east (Cave, 1977). The expanded development of the Cotswold Cephalopod Bed Member here contrasts with that seen at two adjacent GCR sites, **Coaley Wood** and **Haresfield Hill**; together these localities are of critical importance for understanding the late Toarcian history of the Severn Basin.

The site was first described by Wright (1856), who gave a short faunal list for each of the main units included on his log. The lower quarry was described in detail by Richardson (1910b), a summary of his section being reproduced by Reynolds (1921), Ager (1955) and Ager *et al.* (1973). Murray and Hancock (in Savage,

Figure 4.19 Upper part of the Bridport Sand Formation exposed in the lower quarry at Wotton Hill. Typical Bridport Sand Formation forms the lower, pale part of the central buttress and is overlain by the Cotswold Cephalopod Bed Member, with the Struckmanni Bed forming the conspicuous bipartite unit in its lower part. The Middle Jurassic Birdlip Limestone Formation above is clearly visible towards the top of the quarry in the background; its junction with the Cotswold Cephalopod Bed Member below lies at the level of the conspicuous undercut. (Photo: M.J. Simms.)

1977) also described the section, and Doyle (1990–1992) provided a summary lithostratigraphical log to accompany his work on Toarcian belemnites.

Description

The succession as recorded by Richardson (1910b) is described, with slight modifications, below. The section in the lower quarry was re-logged in August 1999 and is reproduced in graphic form in Figure 4.17. Biostratigraphical units are included to allow comparison between the description and Figure 4.17. There are no major differences in terms of unit thicknesses and succession between the description of Richardson (1910b) and Figure 4.17; the main discrepancies lie in details of facies identification and interpretation. In particular the 'limestone' of Richardson has been re-identified as calcite-cemented sandstone, while the terms 'ironshot' or 'iron speckled' refer to the presence of limonitic superficial ooids and peloids.

		Thickness (m)
AALENIAN STAGE		
Birdlip Limestone Formation		
Leckhampton Member **('Scissum Beds')**		
Scissum Zone		
13:	Limestones, rather sandy, in several beds.	1.40 (seen)
Opalinum Zone		
12:	**Opaliniforme Bed**: Limestone, hard, slightly iron-speckled.	0.30
UPPER TOARCIAN SUBSTAGE		
Bridport Sand Formation		
Cotswold Cephalopod Bed Member		Total 4.11
Aalensis Zone		
Aalensis Bed		
11:	Marl, ironshot, dirty-grey, indurated, with iron-peloidal limestone clasts lithologically similar to the overlying Opaliniforme Bed; very ferruginous at top.	0.15
10:	Clay, dark brown. *Homoeorhynchia cynocephala*.	0.05
Pseudoradiosa Zone, Pseudoradiosa Subzone		
Moorei Bed		
9:	Marl, ironshot, grey and brown. *Zeilleria*? sp. near top.	0.46
8:	Marl, ironshot, grey and brown, indurated. *Homoeorhynchia cynocephala*.	to 0.41

	Thickness (m)
Levesquei Subzone	
Dumortieria Bed	
7: Marl, ironshot, brown and grey-dappled, with thin and impersistent indurated bands. *Dumortieria novata, Dumortieria* sp., *Catulloceras leesbergi, Hudlestonia seriddens. Lobothyris haresfieldensis* in lower part.	0.91
6: Marl, sparsely ironshot, grey, indurated, very ferruginous in places.	0.20
Dispansum Zone	
5: **Dispansum Bed**: Limestone, coarsely but not richly ironshot, with marl parting. *Phlyseogrammoceras dispansum, Acrocoelites quenstedti, Brevibelus breviformis.*	0.76
Thouarsense Zone, ?Fascigerum–Fallaciosum subzones (part)	
4: **Struckmani Bed**: Limestone, coarsely but not richly ironshot, in two beds with marl parting.	0.51
3: **Pedicum Bed ('Linseed Bed')**: Marl, coarsely ironshot, dark. *Pseudogrammoceras saemanni, Acrocoelites tricissus.*	0.30
?Bingmanni–Stratulum subzones	
2: **Striatulum Bed**: Limestone, ironshot, massive. *Grammoceras striatulum, G. thouarsense.*	0.36
Bridport Sand Formation ('Cotteswold Sands')	
Variabilis Zone	
1: Sands, yellow, fine grained, micaceous; indurated near top.	5.83 (seen)

Other than the ammonites and other fossils referred to in the description above, little attention has been given to other elements of the fauna at this site. Doyle (1990–1992) identified four species of belemnite from the site and figured a specimen of *Acrocoelites* (*Toarcibelus*) *quenstedti*. All but one species, *Acrocoelites bobeti*, were confined to the Dispansum, Dumortieria and Moorei beds. Ager (1956–1967) referred to examples of *Homoeorhynchia cyanocephala* from this site.

A similar succession through the complete Cotswold Cephalopod Bed Member and a substantial thickness of the underlying Bridport Sand Formation is exposed in the side of a sunken lane at Nibley Knoll (ST 744 957) and was described in detail by Buckman (1887–1907, 1889). Richardson (1910b) stated that 'the sequence of the component layers of the Cephalopod Bed is so essentially the same as at Wotton Hill that it is unnecessary to detail it here'. The site was also mentioned by Cave (1977), but he did not provide any new information.

Wright (1856) recognized three units between the Bridport Sand Formation and what he regarded as Inferior Oolite for which the combined thickness was about 5.1 m (16 ft 6 in.). However, from his description of the basal bed of the Inferior Oolite as a 'loose rubbly oolite' it is probable that he included the Opaliniforme Bed within the Upper Lias, partly accounting for this exaggerated thickness. Nonetheless, he recognized that the affinities of this part of the succesion lay with the Upper Lias rather than the Inferior Oolite, contesting the earlier view of Strickland (1850) that the Cotswold Cephalopod Bed Member was the equivalent of the 'Dundry Ammonite Bed' of Bajocian age.

Interpretation

The ammonite fauna from this site is well documented and as a consequence the succession is stratigraphically well-constrained. Recent revision of the zonal and subzonal scheme for the Toarcian Stage (see Chapter 1) has meant that some of the zonal and subzonal boundaries at this and associated GCR sites may need revision. For example, the Moorei Bed was formerly regarded as coincident with the Moorei Subzone. This subzone has been superseded by the Pseudoradiosa Subzone (Figure 4.17), but Gabilly (1976) has reported that *Dumortieria moorei* occurs in the Mactra Subzone of the Aalensis Zone. Re-examination of accurately collected material will be necessary to resolve this, and similar issues.

The relatively thick and stratigraphically complete sucession at Wotton Hill contrasts with the much thinner, and less complete, sequences at the **Coaley Wood** and **Haresfield Hill** GCR sites (Figure 4.17). It indicates that subsidence was significantly greater here than farther east, in accordance with the site's putative position close to the hanging-wall of the half-graben fault. The succession is condensed, indicating that sedimentation rates in this mid-Cotswold region were very low towards the close of the Toarcian Stage. However, the biostratigraphical succession is relatively complete, suggesting that this area was less affected by the erosional events recorded by irregular boundaries at the other two sites. Deposition rates appear to have been reduced even further at the start of Middle Jurassic times, with the two ammonite zones of the Leckhampton Member represented by only 2.74 m of sediment compared with the 4.1 m for the Cotswold Cephalopod Bed Member beneath.

Conclusions

The lower quarry at the Wotton Hill GCR site is of exceptional importance because it exposes almost the fullest known development of the Cotswold Cephalopod Bed Member. It is a key site in any investigation of this local Upper Toarcian lithofacies and integral to interpreting the successions at the other two GCR sites of **Haresfield Hill** and **Coaley Wood**. Typical Bridport Sand Formation facies are exposed below the Cotteswold Cephalopod Bed Member, and most of the overlying Leckhampton Member (Scissum Beds) of the Birdlip Limestone Formation is exposed above. This provides an opportunity to examine the local lithostratigraphy at the boundary of the Early Jurassic Lias Group and Middle Jurassic Inferior Oolite Group. All the ammonite zones of this interval are represented, from the Variabilis Zone through to the Scissum Zone: they demonstrate extreme condensation of the upper part of the Toarcian Stage in this area. The quality of exposure is good, and this is maintained by a thick canopy of mature woodland, ensuring the limitation of undergrowth. The site makes a valuable contribution towards understanding early–middle Jurassic geological history, both locally and nationally.

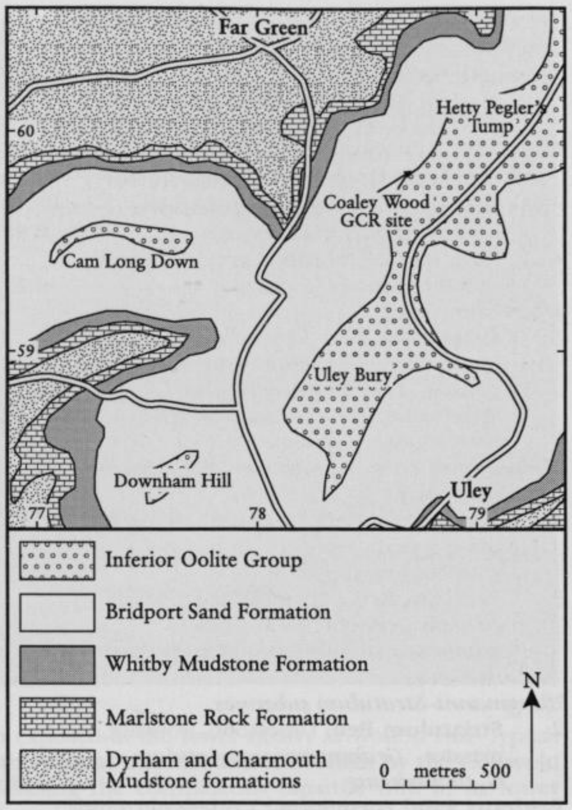

Figure 4.20 Geology and location map for the Coaley Wood GCR site.

COALEY WOOD, GLOUCESTERSHIRE (ST 786 996)

N. Chidlaw

Introduction

The Coaley Wood GCR site is located on the crest and upper face of the Cotswold escarpment at about 200 m OD, about 1.5 km north of the village of Uley (Figure 4.20). It comprises a disused quarry on the escarpment crest and two sunken lanes, which extend down the scarp face and beyond the limits of the site. The site is critical in the interpretation of the late Toarcian history of the Severn Basin, and an almost continuous section is provided through the uppermost beds of the Lias Group, consisting of the Bridport Sand Formation and the Cotswold Cephalopod Bed Member, to within the highest formations of the Inferior Oolite Group.

The exposure of the Cotswold Cephalopod Bed Member is more condensed than the equivalent succession at the Wotton Hill GCR site. This is inferred to have occurred through the non-deposition or 'merging' of lithostratigraphical units rather than any erosion or loss of biostratigraphical units. Although a normal fault, with a strike of 120° and a downthrow to the south, passes through the quarry, the strata are otherwise undisturbed and have a regional dip of less than 1° to the south-east.

The upper part of the sunken lanes and the quarry expose the Inferior Oolite Group, and hence are not discussed here. The remainder of the sunken lanes within the lower part of the GCR site expose the highest parts of the Lias Group and the boundary beds of the Lower and Middle Jurassic succession, and form the subject of this account. These sections were described by Buckman (1887–1907, 1889), Richardson (1910b) and most recently by Cave (1977).

Description

Richardson's (1910b) section through the Cotswold Cephalopod Bed Member was said to be located 'at the top of the bank below [Coaley Wood] quarry'; the latter is the conspicuous quarry in the Inferior Oolite Group immediately west of Crawley Barns (ST 7867 9950). Cave (1977) gave a grid reference of ST 7863 9947 for an exposure of the Cotswold Cephalopod Bed Member, which was at the approximate location of Richardson's section, but commented that there were 'minor differences' between the two. Richardson's (1910b) section is the more stratigraphically continuous of the two, although Cave's (1977) description employed more accurate lithological descriptions and mentioned additional fauna. Nonetheless, clear differences exist in the lithological descriptions of some units as recorded by the two authors. The log reproduced in this account, and in Figure 4.17, combines data from Richardson (1910b) and Cave (1977) to give as full an account as possible. However, where uncertainties occur, Richardson's descriptions have been adopted in preference to those of Cave. The Bridport Sand Formation was described most fully by Buckman (1889) and it is his recorded section that is reproduced here, with some additional stratigraphical and faunal information from Richardson (1910b).

	Thickness (m)
AALENIAN STAGE	
Birdlip Limestone Formation	
Leckhampton Member **('Scissum Beds')**	
Scissum Zone	
19: Limestones, somewhat sandy.	*c.* 1.68
Opalinum Zone	
18: **Opaliniforme Bed**: Limestone, oolitic, very hard, ooliths commonly replaced by limonite are contained in a matrix of sparry calcite. Base irregular and welded to bed below. *Pseudolioceras beyrichi*, *Canavarina* sp., rhynchonellid brachiopods, *Myophorella* aff. *formosa*, *Parallelodon hirsonensis*, *Tancredia*?, *Leioceras* sp..	0.46
UPPER TOARCIAN SUBSTAGE	
Bridport Sand Formation	
Cotswold Cephalopod Bed Member	Total 0.79
Aalensis Zone	
17: **Aalensis Bed**: Limestone, rubbly, conspicuously ironshot. Full of belemnites.	0.15
Pseudoradiosa and *?Aalensis zones*	
16: **?Aalensis Bed** and **Moorei Bed**: Limestone, rubbly. *Pleydellia leura*, *Astarte lurida*, *Opis carinata*, *Cypricardia brevis*, 'and in this bed or that below' *Hinnites objectus*, *Pleuromya* and *Gervillia fornicata*.	0.20
Dispansum Zone and *Thouarsense Zone*, *Fallaciosum Subzone* (part)	
15: **Dispansum** and **Struckmani beds**: Limestone, argillaceous, hard, with limonite pellets. Bivalves, belemnites, *Neocrassina*, *Pseudogrammoceras doerntense*, *P. placidum*, *P. bingmanni*, *P. quadratum*, *P. regale*, *P. struckmanni*, *P. compactile*, *Polyplectus discoides*, *Hammatoceras insigne* and *Phlyseogrammoceras dispansum*.	0.18
Fallaciosum Subzone (part)	
14: **Pedicum Bed** (**'Linseed Bed'**): Marlstone, brown, rubbly. *Esericeras eseri*, *Haugia* aff. *illustris*, *Pseudogrammoceras subfallaciosum*, *P. expeditum*, *P. thrasu*, *P. pedicum*.	0.18
Striatulum Subzone	
13: **Striatulum Bed**: Marl, filling irregularities in the bed below. *Grammoceras toarciense*, *G. audax*.	0.08
Bridport Sand Formation ('Cotteswold Sands')	
Variabilis Zone	
12: Very hard, bluish-grey sandy nodular bed.	0.08
11: Hard, blue-centred stone.	0.15
10: Sands, micaceous, fine grained, yellow.	*c.* 15.25
9: Brownish, concretionary rock, very slightly micaceous, containing dark oolitic grains and pieces of broken shells. Similar to Unit 15 of the Cotswold Cephalopod Bed Member, but harder. Some ammonites, but they are scarce.	0.84
8: Two bands of yellowish-blue, hard, somewhat sandy stone. *Phymatoceras pauper*, *Haugia* sp., large *Lima*.	0.61
7: Sands, yellow, becoming blue in the lower part.	3.05
6: Marl, concretionary, dark yellowish-brown, with ammonites.	0.08
5: Band of yellowish-blue, hard, sandy stone. Ammonites fairly abundant, especially on the top. *Haugia variabilis*, *H. grandis*, *Lytoceras sublineatum*, *Catacoeloceras* ? *dumortieri*, *Phymatoceras obtecta*.	0.23
Bifrons Zone, *Crassum Subzone*	
4: Sands, fine grained, yellow.	*c.* 7.6
3: Sandstone band, yellowish-blue, hard. *Hildoceras bifrons* abundant, *H. semi-politum*, *Pseudolioceras lythense*, *Plagiostoma* sp., *Hinnites objectus*.	0.30
2: Sands, yellow, visible for some metres, and conjectured to extend down to the spring.	12.2
Serpentinum and *Bifrons zones*	
Whitby Mudstone Formation	
1: Clay, blue. Exposures mostly obscured by vegetation.	

Buckman (1889) divided the Bridport Sand Formation into two main units. The 'Lilli Bed' corresponds to beds 2 to 4 of the above section, and the 'Variabilis Bed' encompasses beds 5 to 12 of the section. Only this latter part of the formation, from Bed 5 upwards, is included within the GCR site boundary. Buckman's estimated thickness for the Bridport Sand Formation here, as at Nibley Knoll, probably was under-estimated. Cave (1977) considered that the Bridport Sand Formation thickens northwards and reached a thickness of perhaps as much 76 m at Coaley Peak (1.8 km north of Coaley Wood). A further 30 m of the formation may, therefore, be present in the vicinity of this site.

Wright (1878–1886) figured, as *Harpoceras discoides*, a specimen of *Polyplectus* aff. *discoides* from the Dispansum and Struckmani beds (Donovan, 1954). Howarth (1992) described the type assemblage of *Hildoceras semipolitum*, originally described by Buckman, from a 0.3 m-thick hard sandstone band 12 m above the base of the Bridport Sand Formation; this is Bed 17 of Buckman (1887–1907, 1889) and Bed 3 of this section. It was said to be still exposed in the 1960s, in the bed of the track leading down the scarp through Coaley Wood.

Interpretation

Although the Cotswold Cephalopod Bed Member at Coaley Wood attains less than a fifth of the thickness seen at the **Wotton Hill** GCR site it appears to have an almost equally complete ammonite sequence, lacking only the Levesquei Subzone 'Dumortieria Bed'. The succession here is condensed to such an extent that only six distinct lithostratigraphical units can be recognized, as against ten at Wotton Hill, but the ammonite evidence shows that this has occurred through the apparent 'merging' of successive units towards the top of the sequence. However, some uncertainty surrounds the precise details of the ammonite sequence since several species listed in beds 14 and 15 by Richardson (1910b) and Cave (1977) are characteristic of horizons lower in the Toarcian Stage. Only re-determination of this material can resolve this issue (K.N. Page, pers. comm.).

The reduction in thickness from **Wotton Hill** to the Coaley Wood GCR site (Figure 4.17) can be ascribed to their relative positions within a half-graben. The stratigraphical condensation at Coaley Wood accords well with its inferred position towards a 'hingeline' structural high and contrasts with the succession at Wotton Hill, inferred to lie closer to the hanging-wall of the half-graben fault. The thickening of the main part of the Bridport Sand Formation towards Stroud, noted by Cave (1977), would appear to conflict with this, but the available evidence is insufficient to establish whether this thickening is at the expense of the Whitby Mudstone Formation or reflects local or temporary variations in basin subsidence. The more highly condensed nature of some of the lithostratigraphical units, and the absence of the Levesquei Subzone, suggests that the rate of subsidence slowed down dramatically towards the close of the Toarcian Stage. However, this contrasts with the situation at the third GCR site, **Haresfield Hill**. Here the Aalensis, Moorei and Dumortieria beds are well represented but the remainder of the Cotswold Cephalopod Bed Member seen at the other two sites is absent. These differences between Coaley Wood and Haresfield Hill indicate significant differences in the timing and rates of subsidence in different parts of the Severn Basin during the Toarcian Stage and perhaps account for the apparently anomalous thickening of the Bridport Sand Formation between Wotton Hill and this site.

The overlying Leckhampton Member is significantly thicker, at 2.14 m, than the Cotswold Cephalopod Bed Member but comparable with the other two sites. However, initially subsidence appears to have been rather greater than at the other two GCR sites, with the Opaliniforme Bed here being more than 50% thicker. Although the base of the Leckhampton Member is not conglomeratic here, an erosional hiatus may be indicated by its irregular base.

Conclusions

The sunken lane exposure of Upper Toarcian strata at the Coaley Wood GCR site provides an opportunity to examine the local lithostratigraphical units at the boundary of the Lower Jurassic Lias Group and the Middle Jurassic Inferior Oolite Group. All the ammonite zones are present, from the Variabilis Zone through to the Opalinum Zone, in a highly condensed succession. The site is well documented and provides a complete section through the Cotswold Cephalopod Bed Member, valuable for comparison with other exposures of the same beds in this area, and particularly the other GCR sites at **Wotton Hill** and **Haresfield Hill**. Together they demonstrate differences in rate and timing of subsidence across part of the Severn Basin during late Toarcian times. The upper part of the underlying Bridport Sand Formation ('Cotteswold Sands') is also exposed, containing bands of calcite-cemented sandstone with rare *Haugia* ammonites from the Variabilis Zone. The succession is capped by the Leckhampton Member (Scissum Beds) of the Birdlip Limestone Formation.

HARESFIELD HILL, GLOUCESTERSHIRE (SO 819 088)

N. Chidlaw and M.J. Simms

Introduction

The GCR site at Haresfield Hill, sometimes known as 'Haresfield Beacon' or 'Beacon Hill', lies on the crest of the Cotswold escarpment at 204 m OD, some 10 km south of Gloucester (Figures 4.16 and 4.21). The exposure consists of a line of crags that probably are largely natural and due to periglacial effects associated with the last (Devensian) glaciation. The uppermost beds of the Lias Group, consisting of the Bridport Sand Formation and the Cotswold Cephalopod Bed Member (Toarcian), and basal member of the Inferior oolite Group (Middle Jurassic) are well exposed (Figure 4.22).

The site contains an excellent section through a highly condensed representative of the Cotswold Cephalopod Bed Member underlain by sandy facies of the Bridport Sand Formation. In contrast to the other two equivalent GCR sites, at **Wotton Hill** and **Coaley Wood**, the Cotswold Cephalopod Bed Member and Bridport Sand Formation are incomplete both lithostratigraphically and in terms of the ammonite sequence, with several subzones not proved. This demonstrates the complexity of controls on condensed sedimentation in this area. The regional dip of the strata is low and to the south-east, though at the exposure itself some localized disturbance is evident.

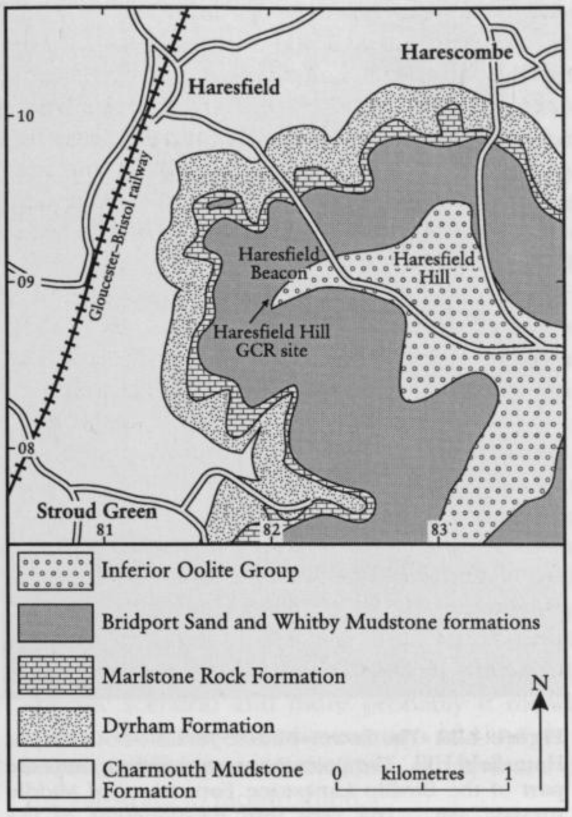

Figure 4.21 Geology and location map for the Haresfield Hill GCR site.

The exposure was first described by Wright (1856), subsequently by S.S. Buckman (1887–1907) and later by Richardson (1904). Brief mention of the site was made by J. Buckman (1879), Richardson (1910a), and by Ager *et al.* (1973), while Davies (1969) figured a 2.7 m graphic log through part of the Bridport Sand Formation. Material from the site was figured and described in three monographs on brachiopods (Davidson, 1851–1852; Ager, 1956–1967, 1990). A sketch of the exposure, somewhat inaccurately labelled, was published by Dreghorn (1967).

Description

The Toarcian and Aalenian succession as described by Buckman (1887–1907) and Richardson (1904) is described below. The GCR site itself encompasses only the top part of the Bridport Sand Formation ('Cotteswold Sands'). The lithostratigraphy and biostratigraphy is summarized in Figure 4.17.

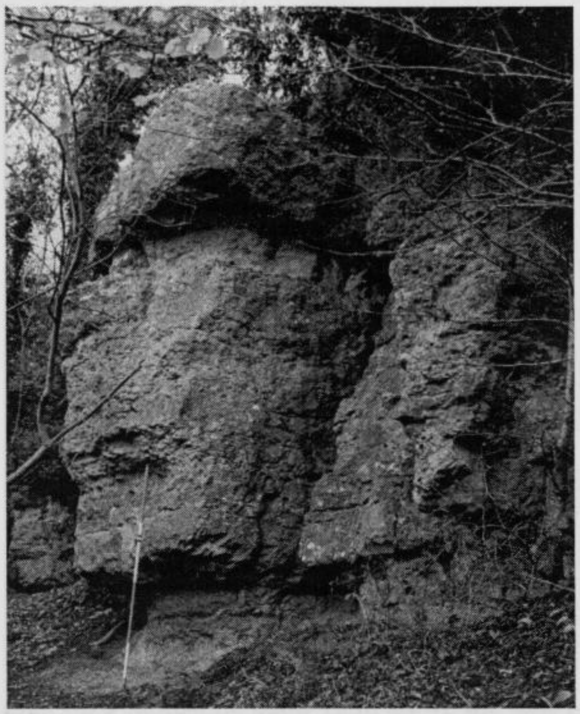

Figure 4.22 The Lower–Middle Jurassic boundary at Haresfield Hill. The prominent overhanging units are part of the Birdlip Limestone Formation, of Middle Jurassic age. The very thin development of the Cotswold Cephalopod Bed Member lies beneath the lower overhang and overlies an irregular erosion surface on the paler coloured sands of the Bridport Sand Formation. (Photo: K. Hitchings.)

Thickness (m)

AALENIAN STAGE
Birdlip Limestone Formation
Leckhampton Member
Scissum Zone

8: **Scissum Beds**: Limestone, grey, micaceous, sandy, in several beds; oolitic or ferruginous at some levels. Poorly preserved *Lioceras ambiguum*? at about 1.3 m above base. 2.33

Opalinum Zone

7: **Opaliniforme Bed**: Limestone, very hard, light greyish-yellow to dark-brown, containing very numerous very small dark-brown grains. *Lioceras opalinum* large and abundant, *Cypholioceras opaliniforme*, *Lioceras comptum*. 0.30

UPPER TOARCIAN SUBSTAGE
Cotswold Cephalopod Bed Member Total 0.55
Aalensis Zone

6: **Aalensis Bed**: Hardish yellow rock, softer in lower part, with ferruginous grains; very closely attached to Opaliniforme 'beds' above. *Grammoceras aalense*, *Pleydellia aalensis*, *Trigonia ramseyi*, *Lytoceras wrighti* in bottom of bed. 0.10

Thickness (m)

Pseudoradiosa Zone, Pseudoradiosa Subzone
Moorei Bed

5: Marl, yellow, somewhat soft, easily broken, with dark-brown grains. *Homoeorhynchia cyanocephala*, *Dumortieria moorei*, *Lytoceras wrighti*, belemnites. 0.15

4: Marl, dark brown, full of *Homeorhynchia cyanocephala*, *Furcirhynchia cotteswoldiae*, 'etc.' 0.05

Levesquei Subzone

3: **Dumortieria Bed**: Marl, yellowish-brown, containing at the base a line of nodules at regular intervals. These nodules are of bluish-grey, hard, sandy, micaceous stone, with no ferruginous grains and are similar to the stone occurring in the sands below. *Lobothyris haresfieldensis* abundant throughout unit and *Homoeorhynchia cyanocephala*. *Grammoceras striatulum* occurs in fragments. *Galeropygus dumortieri* recorded by Paris (1908). 0.25

Bridport Sand Formation ('Cotteswold Sands')
Bifrons and *Variabilis zones*

2: Sands, yellow, micaceous, showing rough alternation of ripple-laminated and bioturbated units at 0.2–0.3 m intervals. A sandstone band containing fragments of a variety of *Hildoceras bifrons* occurs about 21 m below the top of the formation. 57.9

Whitby Mudstone Formation
(No zonal data available)

1: Mudstone. 39.6

Wright (1856) published a short list of fossils from the Cotswold Cephalopod Bed Member at this site, though interpretation is hindered by the taxonomy used, which has now been superseded. Several fossil species have been described from the Upper Toarcian sequence here, with the site particularly noted for its brachiopod fauna. Specimens of *Furcirhynchia cotteswoldiae* were figured and described from here and it is also the type locality for *Lobothyris haresfieldensis* (Ager, 1956–1967, 1990). *Homoeorhynchia cynocephala* is common, particularly in the marl band of Bed 4. This was commented upon by Wright (1856) and led to Lycett (1857) proposing the term '*Cynocephala* Stage' for all the strata that later became the Bridport Sand Formation and the Cotswold Cephalopod Bed Member. Paris (1908) described, as *Galeropygus dumortieri*, an irregular echinoid collected from here by Linsdall Richardson, stating that 'it has the characteristic ironshot matrix of the *Dumortieria*-Bed attached to it'. Haresfield Hill is one of very few Lower Jurassic sites in Britain to have yielded irregular echinoids.

Interpretation

In one of the earliest references to the Cotswold Cephalopod Bed Member at this site, Strickland (1850) considered it equivalent to the 'ironshot oolite' of Dundry Hill, just south of Bristol, though this is actually of Lower Bajocian Sauzei Zone age (Parsons, 1979). Wright (1856) challenged this view, recognizing that the fossils in the Cotswold Cephalopod Bed Member indicated a position near the top of the Upper Lias rather than within the Inferior Oolite.

Wright's (1856) description of the Cotswold Cephalopod Bed Member at Haresfield Hill is more accurate than his description of the succession at Wotton Hill. He noted the marl band (beds 4 and 5 of this account), with its abundant brachiopod fauna, but, judging from his statement that 'the entire bed measures from 2 ft to 2 ft 6 in. [0.62–0.77 m]', he did not differentiate the Opaliniforme Bed at the base of the Aalenian succession from the Cotswold Cephalopod Bed Member below. This, and the finer subdivision of the succession, only really became possible with further refinement of the ammonite biostratigraphy.

The thickness of the Cotswold Cephalopod Bed Member at Haresfield Hill is little more than two-thirds that at **Coaley Wood** and barely an eighth of that at **Wotton Hill** (Figure 4.17). Much of this attenuation can be attributed to a hiatus in the lower part of the succession. Buckman (1887–1907) described 'a line of nodules at regular intervals', with *Grammoceras striatulum* at the base of the Dumortieria Bed. Re-examination of the exposure suggests that they represent the dissected remnants of a cemented band projecting above an erosion surface developed on the less indurated sands beneath. It suggests that in this area the lower part of the Thouarsense Zone (= Striatulum Subzone) was developed in typical Bridport Sand Formation facies. The Dumortieria Bed here accounts for almost half the total thickness of the Cotswold Cephalopod Bed Member. The site may have been tectonically isolated to some extent from events that affected the two nearby GCR sites at Wotton Hill and Coaley Wood, which perhaps were located in an adjacent half-graben. Differences in the rate and timing of subsidence across different parts of the Severn Basin are known to have exerted a significant influence on sedimentation and facies patterns at various times during early and middle Jurassic times (Chidlaw, 1987; Chidlaw and Campbell, 1988; Simms, 1990a).

Above the Cotswold Cephalopod Bed Member, the Leckhampton Member is of similar thickness at all three GCR sites. This suggests that subsidence patterns changed significantly between late Toarcian and early Aalenian times.

Davies (1969) considered the small-scale alternations within the Bridport Sand Formation at this site to indicate the early development of an emergent sand-bar in this region, with ripple-laminated sands, representing intertidal deposits, intercalated with bioturbated beach sands. There is little evidence to support this specific scenario and more probably it merely reflects variations in sedimentation rate and consequent differences in the time of exposure of the substrate to bioturbation.

Conclusions

The Haresfield Hill GCR site is the only well-documented exposure of the Cotswold Cephalopod Bed Member north of Stroud, and hence close to its northern limit. The site exposes the top of the arenaceous part of the Bridport Sand Formation ('Cotteswold Sands') and the overlying Leckhampton Member of the Birdlip Limestone Formation. It provides an opportunity to examine the local lithostratigraphical units at the boundary of the Lower Jurassic Lias Group and Middle Jurassic Inferior Oolite Group. The Cotswold Cephalopod Bed Member here is very thin, and the ammonite sequence incomplete, indicating a significantly different subsidence and depositional history from the nearby GCR sites at **Wotton Hill** and **Coaley Wood**.