British Lower Jurassic Stratigraphy

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

N. Chidlaw
Department of Earth Sciences,
University of Bristol

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

and

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

with contributions from

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

GCR Editor: R. Gallois

JOINT NATURE CONSERVATION COMMITTEE

Chapter 5

The East Midlands Shelf

INTRODUCTION

M.J. Simms

The East Midlands Shelf occupies an extensive area to the north-east of the Severn Basin, north-west of the London Platform and south of the Cleveland Basin (Figure 1.2, Chapter 1). The Lower Jurassic succession crops out as a strip, typically 10–15 km wide, extending from Warwickshire to the River Humber (Figure 5.1), with a narrow outcrop passing across the Market Weighton High before expanding once again into the Cleveland Basin. Major bounding basement faults, manifested in the Lower Jurassic succession as the asymmetric Vale of Moreton Anticline, define the western boundary between the Severn Basin and East Midlands Shelf (Figure 4.1, Chapter 4). To the south-east there is progressive onlap of Lower Jurassic strata onto the Palaeozoic basement of the London Platform (Donovan *et al.*, 1979). The northern boundary is defined by the Market Weighton High, across which there is a greatly attenuated Lower Jurassic sequence, separating the East Midlands Shelf from the Cleveland Basin. The eastern margin lies offshore in the southern North Sea and corresponds to the western bounding fault of the Sole Pit Trough (Bradshaw *et al.*, 1992) into which the Lower Jurassic strata thicken considerably (van Hoorn, 1987b). Across the East Midlands Shelf the Jurassic strata dip gently to the east or south-east and have experienced little disruption by faulting or folding. Some authors (e.g. Green *et al.*, 2001) have subdivided the region into two tectonic areas; the Midland Platform lying to the north and west of the London Platform and bounded to the west by faults on the eastern edge of the Severn Basin, passing gradually into the East Midlands Shelf *sensu stricto* that forms the western margin of the North Sea Basin.

The Lower Jurassic outcrop is of rather subdued relief and, in the absence of any coastal outcrop, there are very few natural exposures. Most significant exposures were associated with extraction of material for the production of building stone, bricks, cement or iron, but very few of these workings are still active today. Consequently documentation of the Lower Jurassic succession is biased towards those parts of economic value. All of the GCR sites on the East Midlands Shelf are associated with disused workings or with railway cuttings.

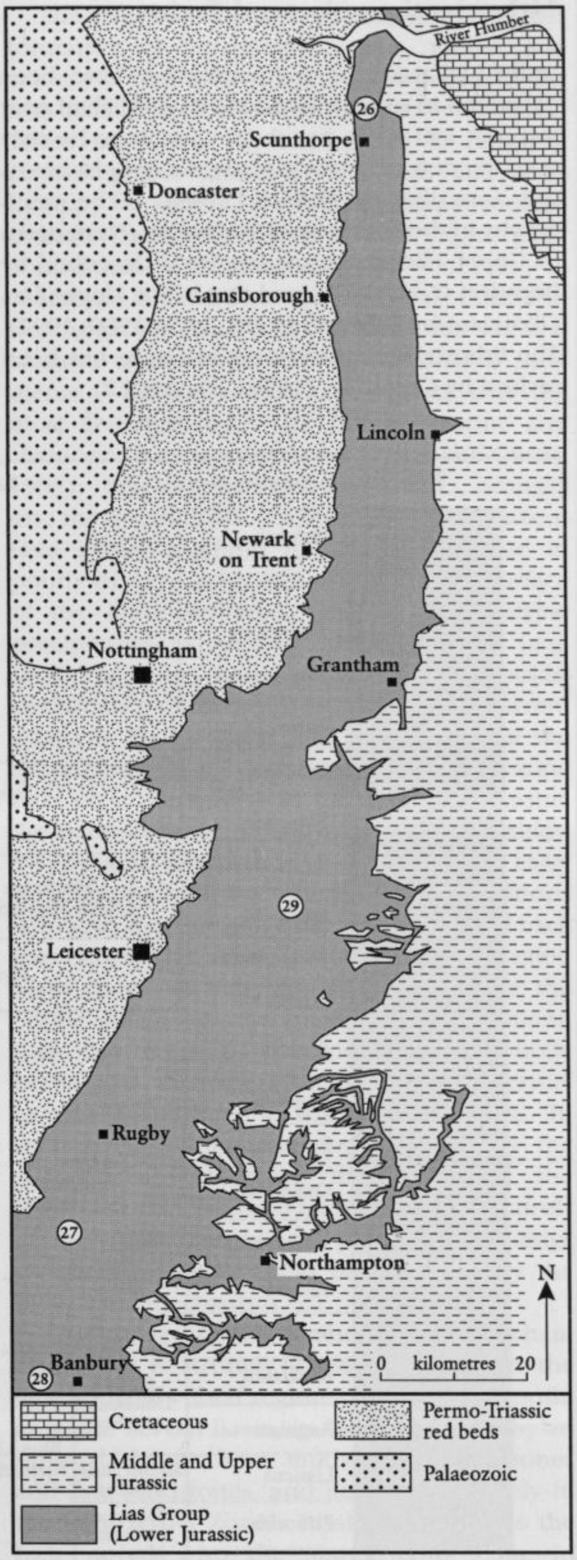

Figure 5.1 Generalized geology of the East Midlands Shelf. Numbers correspond to the locations of the GCR sites: 26 – Conesby Quarry; 27 – Napton Hill Quarry; 28 – Neithrop Fields Cutting; 29 – Tilton Railway Cutting.

Lithostratigraphy and facies

Individual parts of the succession have been described in numerous accounts published over the past 150 years, but there appears to be only one overview of Lower Jurassic stratigraphy across this area, that by Hallam (1968a). The stratigraphy of the Lower and Middle Lias (Hettangian to Upper Pliensbachian) has been described by Brandon *et al.* (1990) and that of the Upper Lias (Toarcian) by Howarth (1958, 1978, 1980, 1992). The lithostratigraphical nomenclature has been revised by Cox *et al.* (1999) (Figure 5.2).

Across the southern part of the shelf the lithostratigraphy is closely similar to that in the Severn Basin, but gradual changes are seen in passing northwards. The Blue Lias Formation comprises regular alternations of mudstone and argillaceous limestone little different from that seen elsewhere in southern England. In the south, the basal part of the formation, extending down into the 'Pre-Planorbis Beds', is exposed at the **Newnham (Wilmcote) Quarry** GCR site. Higher parts of the Blue Lias Formation, encompassing the (Hettangian and lower Sinemurian) Liasicus, Angulata, and Bucklandi zones, are spectacularly

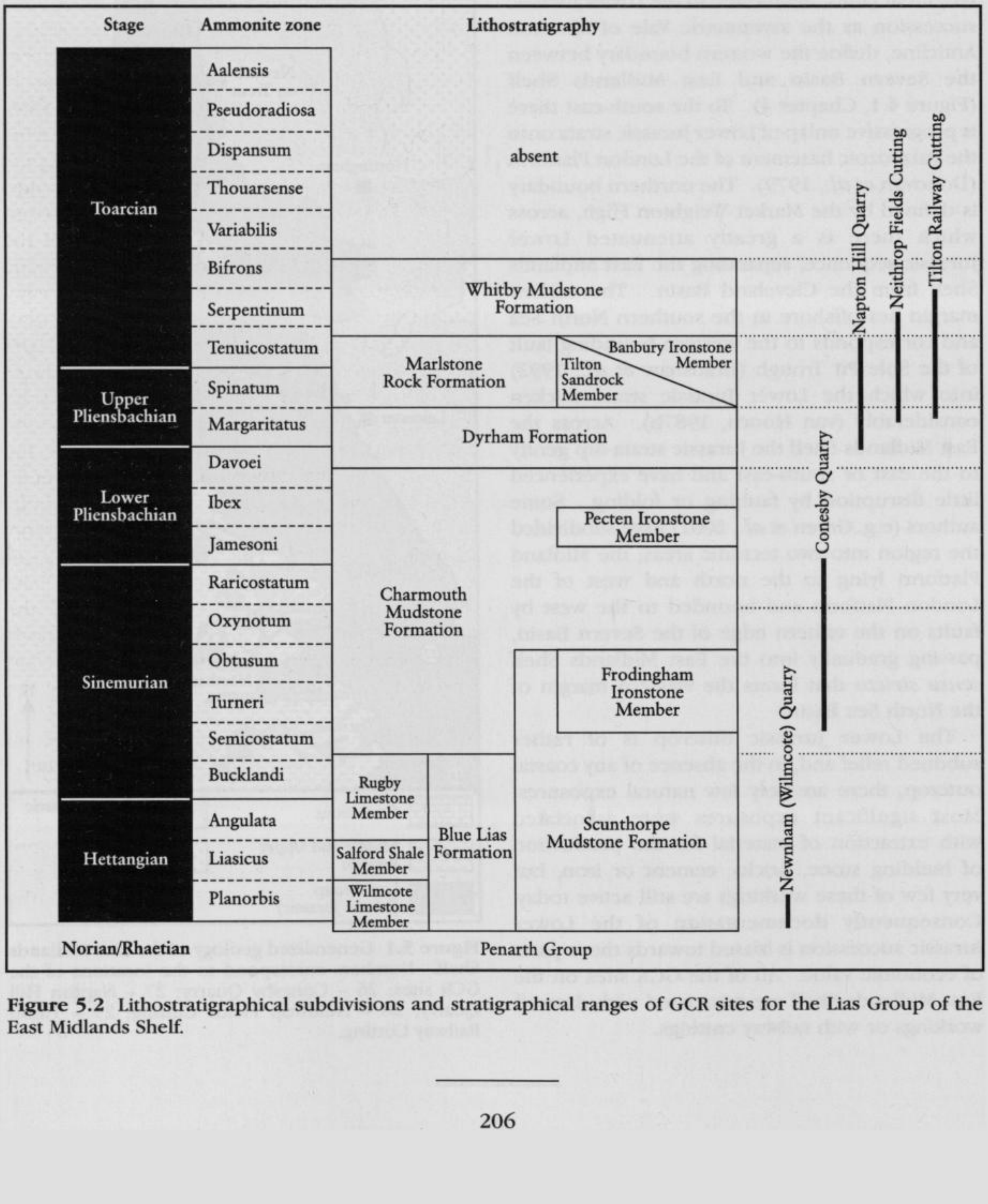

Figure 5.2 Lithostratigraphical subdivisions and stratigraphical ranges of GCR sites for the Lias Group of the East Midlands Shelf.

exposed in a working quarry at Southam (SP 419 629) (Clements, 1975) and a disused quarry at Rugby (SP 493 759) (Clements, 1977). Within the Blue Lias Formation Cox *et al.* (1999) recognized three members; the Wilmcote Limestone Member at the base, the Saltford Shale Member in the Liasicus Zone, and the Rugby Limestone Member for remaining strata up to the top of the formation. The succeeding Charmouth Mudstone Formation in the south is a mudstone-dominated sequence, which encompasses the (lower Sinemurian to late Lower Pliensbachian) Semicostatum to lower Davoei zones. It is not exposed at any of the GCR sites on the East Midlands Shelf.

Farther north and east on the East Midlands Shelf the Blue Lias Formation becomes a mudstone-dominated facies termed the 'Scunthorpe Mudstone Formation', which extends up to near the top of the Oxynotum Zone (upper Sinemurian). The succeeding Charmouth Mudstone Formation, which extends to the Davoei Zone (late Lower Pliensbachian), much like in the southern part of the shelf, is therefore of shorter duration in this area.

Local developments of ironstone and sandstone are a significant feature of the Scunthorpe Mudstone Formation on the more northern parts of the East Midlands Shelf (Brandon *et al.*, 1990). The most important of these economically is the Frodingham Ironstone Member of the Humberside region. The Frodingham Ironstone Member, and part of the succeeding Charmouth Mudstone Formation, are well exposed at the **Conesby Quarry** GCR site, located towards the north of the East Midlands Shelf.

The formation of iron-rich sediments, including iron oolites, at the present time, is very localized, and hence their origin in the geological record remains controversial (Taylor and Curtis, 1995; Sturesson *et al.*, 1999). It is likely that several different processes may produce them and suggestions for iron oolites range widely – for example ooid formation in tropical lateritic soils and subsequent incorporation into marine sediments (Madon, 1992); undercoatings of microbial films (Chidlaw, 1987; Burkhalter, 1995); or formed directly in the marine environment by lateral accretion in a similar way to calcareous ooids (Sturesson *et al.*, 1999). The source of the iron-rich sediment is widely thought to be tropical lateritic soils (Young, 1989) and recently this has been extended to include volcanic ash (e.g. Sturesson *et al.*, 1999).

The major difficulty with understanding the formation of ferruginous grains, matrix and cement is that often they are composed of the iron silicate minerals berthierine and chamosite. These are chemically stable only in reducing conditions yet faunal assemblages and sedimentary structures in the host sediments often indicate formation in well-aerated, high-energy conditions. Berthierine will convert to chamosite if heated to 120–160°C, or buried to depths greater than 3 km, so the latter mineral is more common in Palaeozoic iron-rich sediments. Recent consensus suggests that the most favoured origin for the berthierine and chamosite is a diagenetic one (Taylor and Curtis, 1995). Clay minerals and iron oxides, brought into the depositional environment from adjacent land areas, combine to form berthierine in poorly oxygenated conditions below the surface of the loose sediment, with the berthierine precipitated as laminae around nuclei (e.g. shell fragments, faecal pellets) to form ooids. Disturbance of the sediment, such as by current action or bioturbation, will move some of the berthierine ooids into the well-oxygenated zone near or at the surface of the sediment, causing the berthierine to be converted to iron oxides. Subsequent sediment disturbance could carry these grains back into the reducing conditions below, so that the iron oxides are converted back into berthierine. The process could be repeated many times, so that, depending on where the oolitic grains are transported in the sediment, they may range in composition from wholly berthierine through a mixture of berthierine/iron oxide laminae, to wholly iron oxides. In such circumstances the more frequently the sediment is disturbed, the greater is the likelihood that the ooid laminae will be entirely of iron oxide. Ferruginous pisoids and coatings on shell fragments could be produced by the same basic mechanism.

The base of the succeeding Dyrham Formation is strongly diachronous within the East Midlands Shelf region. Towards the south, as in the Severn Basin, its base is marked by an upward change from mudstones to siltstones and fine sandstones, and lies approximately in the mid-Davoei Zone. Passing northwards the base moves into the Margaritatus Zone in Nottinghamshire, and, still farther north, the entire formation passes into mudstones (Brandon *et al.*, 1990). The upper part of the Dyrham Formation is well exposed at three GCR sites on the East Midlands Shelf; **Napton Hill Quarry**, **Neithrop Fields Cutting** and **Tilton Railway Cutting**. The Marlstone Rock Formation is also exposed at these three sites in lithologies that are typical of the region. Sandy or oolitic ironstones commonly are the dominant facies and the formation may be divisable into the Tilton Sandrock and Banbury Ironstone members. The formation locally exceeds 10 m in thickness and encompasses the Spinatum Zone and part of the Tenuicostatum Zone (Howarth, 1980). In some parts of Lincolnshire and across the Market Weighton High, the formation is absent through intra-Jurassic erosion (Howarth, 1958).

The Whitby Mudstone Formation (Toarcian) shows consistency across the East Midlands Shelf. It is developed largely in dark mudstones with subordinate limestones (Howarth, 1978), lithologies similar to those in the Severn Basin. The youngest Whitby Mudstone Formation mudstones recorded on the shelf are of Bifrons Zone (late Lower Toarcian) age. Younger Lower Jurassic strata were removed by erosion prior to the deposition of the succeeding Middle Jurassic sediments. This erosive break increases in severity towards the Market Weighton High, where all later Jurassic strata were removed prior to the depostion of late Cretaceous strata.

Basin development

Compared with fault-bounded basins to the south-west, where the Lias Group may show substantial thickness changes over distances of only a few kilometres, the total thickness of the Lias Group remains remarkably constant across much of the East Midlands Shelf (Whittaker, 1985) at about 200–250 m. This is also substantially less than the maxima recorded for the major fault-bounded basins (Cleveland Basin > 400 m; Severn Basin > 500 m; Wessex Basin > 700 m). To the south-west and to the east there is a rapid thickening into the Severn Basin and Sole Pit Trough respectively, while to the south and to the north there is a relatively gentle thinning onto the London Platform and the Market Weighton High respectively. The onlap of progressively younger zones onto the London Platform during the Hettangian to Lower Pliensbachian interval has been described by Donovan *et al.* (1979); Brandon *et al.* (1990) have indicated that higher parts of the Lower Jurassic sequence were subsequently removed by erosion so that Lias Group strata are now absent from an extensive area of the London Platform. However, the palaeogeographical reconstructions of Bradshaw *et al.* (1992) imply that the London Platform remained an area of non-deposition throughout early Jurassic times. The effects of the Market Weighton High have also been discussed at some length (Kent, 1955) and there is a marked overall thinning and development of hiatuses within the Lias Group succession towards this positive structure. The Market Weighton High was attributed at one time (Sellwood and Jenkyns, 1975) to the effects of halokinesis associated with Permian evaporites, but there is little evidence to support this; more recent geophysical evidence suggests that it is due to the presence at depth of a granite body (Bott *et al.*, 1978). Much of the reduction in overall thickness of the Lias Group, however, can be attributed to post-Jurassic erosion and overstep by late Cretaceous strata.

Between these positive areas to north and south, and the rapidly subsiding basins to east and west, the East Midlands Shelf appears to have experienced a prolonged period of slow stable subsidence. The only major regional hiatus, evident also across much of the Cleveland Basin, is that which truncated the Toarcian succession above the Bifrons Zone. Whittaker (1985) observed that over much of eastern England, with the exception of the Cleveland Basin, subsidence was not directly associated with normal faulting but was primarily a peripheral effect of extension beneath contemporaneous North Sea basins. Similarly, the regional hiatus between the Toarcian and the Middle Jurassic successions may be due to events in the North Sea. The stability of the East Midlands Shelf may in part be linked to the presence of deeply buried granite batholiths (Donato, 1993; Donato and Megson, 1990) beneath the eastern part of the shelf. Within the East Midlands Shelf some facies and thickness variations may reflect syn-depositional fault movement and localized differences in subsidence rates, these being perhaps most evident in the Marlstone Rock Formation.

Comparison with other areas

The lithostratigraphical succession developed on the East Midlands Shelf shows an essentially gradual transition between that seen in the Severn and Wessex basins to the south-west and that in the Cleveland Basin to the north. The mudstones and limestones of the Blue Lias Formation, typical of basins to the south and west, pass northward across the shelf into the shell beds and ironstones of the Scunthorpe Mudstone Formation, marking a change from low-energy to higher-energy depositional environments. Higher in the succession the Marlstone Rock Formation and Whitby Mudstone Formation bear considerable similarity to correlative formations in the south-west. Unlike the Severn and Wessex basins to the south, though comparable to the situation across much of the Cleveland Basin, post-Bifrons Zone strata of the Whitby Mudstone Formation are absent, apparently removed by erosion prior to deposition of Middle Jurassic sediments.

For the most part Lias Group faunas across the East Midlands Shelf are not substantially different from those elsewhere in Britain, with any differences largely reflecting facies control. However, the late Upper Pliensbachian fauna shows a distinct provincialism and exemplifies the transition between the north-east and the south-west. *Pleuroceras* ammonite faunas documented by Howarth (1958) differ markedly between the Cleveland Basin and the Severn and Wessex basins, while specimens are rarely encountered at all on the East Midlands Shelf. Similar north-east/south-west distinction is evident among brachiopod faunas, as documented by Ager (1956a), although, unlike the ammonites, brachiopods form a major element of benthic faunas on the East Midlands Shelf and comprise a faunal province distinct either from that to the north-east or to the south-west.

NEWNHAM (WILMCOTE) QUARRY, WARWICKSHIRE (SP 151 594)

M.J. Simms

Introduction

The Newnham Quarry GCR overlooks the village of Astow Cantlow to the west and is less than 1 km south of the village of Newnham. The village of Wilmcote lies less than 1.5 km to the south-east and gives the site its alternative name, 'Wilmcote Quarry'. The site comprises a long-disused quarry excavated into the Blue Lias Formation (basal Lias Group), less than 500 m east of a prominent scarp formed by the underlying Penarth Group (Figure 5.3).

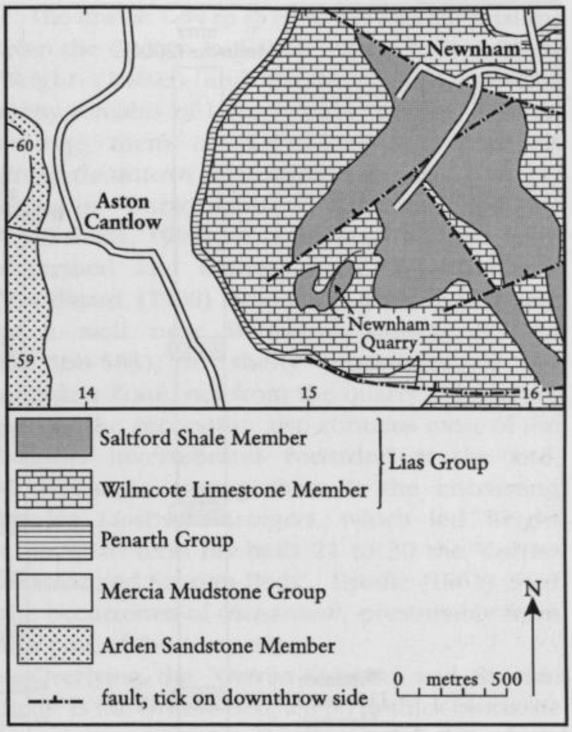

Figure 5.3 Geology and location map for the Newnham (Wilmcote) Quarry GCR site.

The quarry is one of the few remaining inland exposures of the Blue Lias Formation. It is the type locality for the lowest member of the Blue Lias Formation in this area, the Wilmcote Limestone Member, and exposes part of the overlying Saltford Shale Member. It also contains the best remaining section through the 'Insect Beds' of the basal Lias Group, once widely exposed in small quarries across Gloucestershire, Worcestershire and Warwickshire. The Wilmcote Limestone Member is well known for its insect fauna, as well as yielding plant material and important marine vertebrates. Consequently, this part of the succession often was referred to informally in 19th century publications as the 'Insect Beds', 'Insect Limestone' or 'Insect and Saurian Beds'. Material was obtained from many quarries and pits in Warwickshire, but Newnham Quarry is the only site remaining at which the succession can still be seen. The site has proven of outstanding importance for our understanding of terrestrial biotas in earliest Jurassic times.

The stratigraphical succession exposed at this site (Figure 5.4) was described by Wright

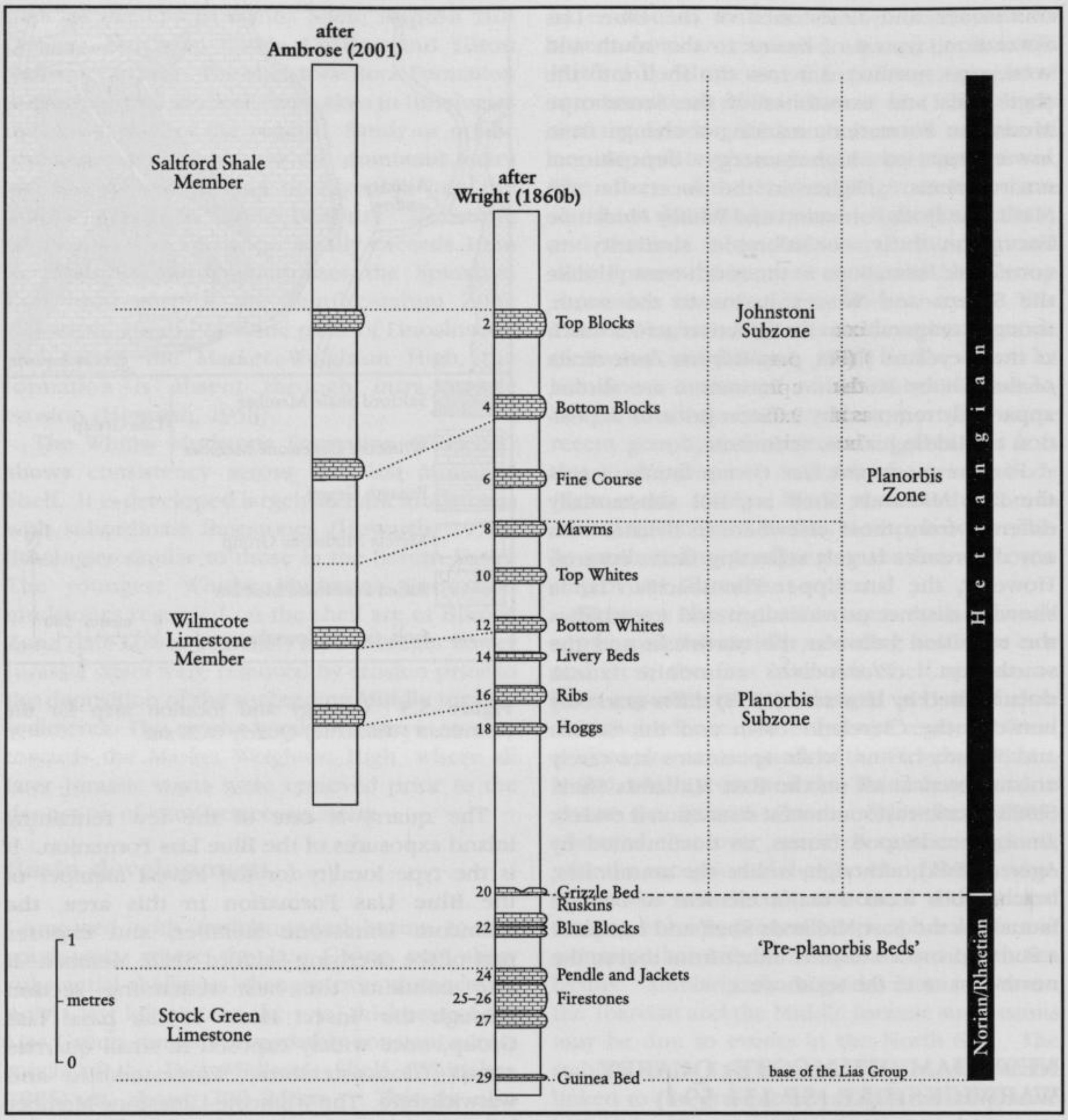

Figure 5.4 The section at Newnham (Wilmcote) Quarry as seen at the present day (Ambrose, 2001); and in the mid-19th century (Wright, 1860b).

(1857–1880, 1860a, 1878–1886), Brodie (1860b, 1868, 1887, 1897) and Woodward (1893). Similar successions were formerly exposed in several other quarries within a few kilometres radius, described in various publications (Brodie, 1845, 1868; Wright, 1860a; Williams and Whittaker, 1974). These are significant for the interpretation of the succession at Newnham Quarry, which can be considered representative of the basal part of the Lower Jurassic sequence in this area. Old *et al*. (1991) formally established the Wilmcote Limestone Member for the interbedded limestones and shales at the base of the Lias, and the lithostratigraphy of the site was discussed by Ambrose (2001). A faunal list for this part of the Lias, based on material in Warwick Museum, was included in Old *et al*. (1991, appendix 5) but they did not specify the horizon or, in many cases, the location of most of the species cited. Brodie (1868, 1897) also mentioned various elements of the fauna and flora while more specific accounts dealing with particular taxa were published by Jones (1862), Woods (1925–1931), Woodward (1866, 1888b) and Tomes (1878).

Description

The most extensive section at the Newnham Quarry site was recorded by Kirshaw and Tomes (in Wright, 1860a) (Figure 5.4). They described a section 16.32 m thick comprising 7.27 m (23 ft 8 in.) of Lower Lias above 9.05 m (29 ft 5 in.) of Penarth Group. The Penarth Group and lowest two beds of the Lias Group, beds 28 and 29 of Wright (1860a), were recorded in an excavation made specifically for the purpose of exposing this part of the succession. The same section was reproduced by Brodie (1868), though with minor differences in thickness quoted for some of the units. Brodie's (1857, 1860b) description noted that the section was broken by numerous faults and implied that it occupied a syncline, with 'several bands of limestone and shale in a basin formed by the outcrop of the Firestones, which dip at a considerable angle on the higher ground'. Many of the limestone bands within the succession were given names by the quarrymen.

The base of the Lias Group in this area is taken at the 'Guinea Bed', a thin (0.02–0.03 m thick) shelly limestone containing limestone intraclasts and a fairly diverse benthic fauna. From the Guinea Bed at Binton (SP 142 536), 7 km to the south, Wright (1860a, 1878–1886) recorded a range of encrusting, byssate and shallow-burrowing bivalves together with diademopsid echinoids and isastreid corals. Above the Guinea Bed, 0.3 m of rather indurated shale is succeeded by a limestone 0.42 m thick, comprising four distinct beds with mudstone partings. The lower three of these (beds 25–27 of Wright) which together were known as the 'Firestones', comprise fine-grained, recrystallized limestones with fine shell debris, micrite pellets and quartzose silt, and contain a fauna of encrusting, byssate and shallow-burrowing bivalves. These four limestone beds, the underlying shale unit and the basal Guinea Bed, were named the 'Stock Green Limestone' by Old *et al.* (1991).

The lowest 1.54 m (5 ft) of the Lias succession, from the Guinea Bed (Bed 29) up to Bed 21 of Wright (1860a) and Brodie (1868), yielded many remains of large marine reptiles, notable among them a 4.4 m-long skeleton of *Rhomaleosaurus megacephalus* from Bed 21, now in Warwickshire Museum (cited by Cruikshank, 1994). A megalosaurian limb bone described and figured from 'Wilmcote' by Woodward (1908) originated from the sinking of a well near Wilmcote Railway Station (SP 168 583), in shelly limestones of the Angulata Zone, not from the quarry. The lower part of the succession also contains most of the benthic invertebrates recorded at the site. Conspicuous among them is the encrusting bivalve *Liostrea hisingeri*, which led Wright (1860a) to term his beds 21 to 30 the '*Ostrea liassica* and Saurian Beds'. Brodie (1861) cited the occurrence of '*Isastraea*', presumably from this part of the succession.

Overlying the '*Ostrea liassica* and Saurian Beds' is the Grizzle Bed, a 0.08 m-thick bioclastic limestone containing vertebrate debris, a range of encrusting, byssate and shallow-burrowing bivalves, and abundant echinoid spines. This is overlain by a 1.28 m-thick dark laminated mudstone, the thickest unit of the entire section and currently the lowest unit exposed in the quarry. Above this Wright (1860a) and Brodie (1868) recognized nine limestone bands, from 0.05 m to 0.22 m thick, alternating with somewhat thicker (0.18–0.5 m) laminated mudstone units. The limestones are generally fine grained, argillaceous and, in the upper part of the succession, mostly laminated with thin dark organic partings. The mudstones also are well laminated with little evidence of bioturbation.

Ammonites are virtually the only fossils cited by Wright (1860a) from Newnham Quarry. However, Brodie (1868) also recorded marine reptiles, fish and crustacea, together with plant and insect remains, the latter apparently confined to the limestone bands. Brodie (1897) noted that the plants and insects were very fragmentary while the vertebrates and crustacea were more-or-less intact. Buckman (1850) described several fossil plants from what he termed the 'Insect Limestone' or 'Best Paving Slab' of sites in Warwickshire, Worcestershire and Gloucestershire, though not specifically from Newnham Quarry. Tillyard (1925, 1933) described several insect taxa from adjacent sites, notably Binton. Wright (1860a, 1878–1886) noted that certain beds at Binton appeared to be barren, but others yielded vertebrate and insect remains. One limestone bed at Binton was said by Wright (1860a, 1878–1886) to contain 'more insects than in all the other beds collectively', but it appears to be either unrepresented at Wilmcote or can be correlated with part of the laminated mudstone (Bed 19) immediately above the Grizzle Bed.

Greaves (1832) mentioned the discovery of an ichthyosaur at the quarry and figured a large intact specimen of the fish *Dapedium*. The same specimen was figured and described by Agassiz (1832) as *Tetragonolepis angulifer*. Benthic fossils appear to be very rare. They include several species of crustacea, among them forms described and figured by Woodward (1866, 1888b) as *Eryon wilmcotensis*, from the 'Bottom Blocks' (Bed 4), and *Aeger brodei*. Woods (1925–1931) also figured and described these types, together with examples of *Coleia barroviensis* for which he considered *Coleia* (= *Eryon*) *wilmcotensis* probably to be a synonym. There has been little recent work on the fossils for which this site is famous, and Whalley (1985) acknowledged the need for re-examination of the Midland fauna, which includes Newnham Quarry. Much of Brodie's fossil insect collection is held in the Natural History Museum in London, with further material in Warwickshire Museum. Cruickshank (1994) undertook a description and interpretation of the skull of *Rhomaleosaurus megacephalus* but other vertebrates have remained largely neglected.

Today a little over 7 m of the section can be seen on the western side of the quarry (Figures 5.4 and 5.5). However, this includes about

Figure 5.5 The basal Lias Group exposed at Newnham (Wilmcote) Quarry. (Photo: British Geological Survey, No. A10835, reproduced by permission of the British Geological Survey. © NERC. All rights reserved. IPR/51-14C.)

2.3 m of mudstones above the highest strata recorded by Wright (1860a) while nothing can be seen below the upper part of his Bed 19. Of the nine limestone bands recorded by Wright (1860a), only four could be identified by Old *et al.* (1991) and Ambrose (2001). Old *et al.* (1991) recorded *Psiloceras plicatulum*, *Psiloceras* sp., *Caloceras johnstoni*, *Caloceras* ? *intermedium*, *Caloceras* sp. and ?*Psilophyllites*, indicating the presence of both subzones of the Planorbis Zone, and placed the boundary between the Planorbis and Johnstoni subzones immediately above Bed 8 of Wright (1860a). Woodward (1893) claimed that a specimen of *Coroniceras rotiformis* (now *C. rotiforme*) was found at the site, although clearly this is erroneous.

The Blue Lias Formation at Newnham Quarry has been divided into two members, and the site has been designated the type locality for the lower of these, the Wilmcote Limestone Member (Old *et al.*, 1991; Ambrose, 2001). This unit encompasses strata from the Guinea Bed at the base of the Lias, including the Stock Green Limestone, to the highest limestone band, the 'Top Blocks' (Bed 2). Above this the succession is overwhelmingly dominated by the mudstone facies of the overlying member, the Saltford Shale Member (Ambrose, 2001) which persists through until the Angulata Zone (Figure 5.4).

Interpretation

Ammonites are the most common fossils in the upper two-thirds of the Wilmcote Limestone Member and have enabled biostratigraphical subdivision of the succession. The base of the Lower Jurassic succession and the Planorbis Zone was placed by Old *et al.* (1991) at the Grizzle Bed, which contains *Psiloceras*, with the top of the Planorbis Subzone 3.18 m higher, above Bed 8 of Wright (1860a), where species of *Caloceras* first appear. However, Wright (1860a, 1878–1886) and Brodie (1868) noted the occurrence of a single *Psiloceras planorbis* from the Firestones at Binton, 7 km to the south. Old *et al.* (1991) were unable to confirm this and suggested that the record had been assigned to the wrong bed.

According to Wright, (1860a) the lower Wilmcote Limestone Member of the Blue Lias Formation can be divided into two distinct facies assemblages. The lower of these he termed the '*Ostrea liassica* and Saurian Beds', corresponding to the Pre-Planorbis Beds, and contains a rich and diverse benthic fauna that demonstrates that benthic oxygen levels were high during deposition of both mudstones and limestones. The predominance of fine shell debris and micritic pellets in several of the limestones indicates that they are primary features of the succession. The presence of several distinct trophic groups of bivalves, including encrusters, epibyssate forms and shallow burrowers, is evidence for a significant diversity of habitat, while the presence of isastreid corals indicates clear warm water well within the photic zone. The base of this facies assemblage is sharply defined by the Guinea Bed, which shows clear evidence of a minor non-sequence originating from erosion between the Penarth Group and the succeeding Lias Group. Brodie (1887) noted that the Guinea Bed and Firestones were developed only where the 'White Lias' (= Langport Member) was absent. Arkell (1933) attributed the presence of limestone intraclasts in the Guinea Bed to early Hettangian erosion of the Langport Member although Old *et al.* (1991) regarded them as shoreline debris transported from farther east. The abundance of fossil material in this bed also suggests greatly reduced rates of sedimentation at this time. The top of the '*Ostrea liassica* and Saurian Beds' is marked by a bed rather similar to the basal Guinea Bed, the Grizzle Bed, which again indicates, by its abundance of shell debris, echinoid spines and vertebrate debris, that sedimentation rates were very low and perhaps accompanied by minor erosion.

Above the Grizzle Bed there is an abrupt change to laminated mudstones and limestones in which a benthic fauna is virtually absent. The almost complete lack of bioturbation, and the fine preservation of some of the vertebrates and insect remains, indicates prolonged benthic anoxia during the deposition of most of this part of the Wilmcote Limestone Member. However, Brodie's (1897) statement that most of the vertebrates are preserved more-or-less entire almost certainly reflects some degree of collecting bias, since disarticulated or fragmentary remains were often ignored by early collectors when more intact material was available. The presence, in these apparently anoxic sediments, of several species of crustacean is somewhat anomalous, though not atypical of laminated limestones in the Blue Lias Formation, suggesting either that they were not strictly benthic taxa, that they were tolerant of very low benthic oxygen levels, or that they were able to establish populations during transient benthic oxygenation events. The diversity of the insect and plant remains suggests that a landmass, perhaps the western margin of the London Platform, lay no great distance away, though Brodie (1897) noted that those from Newnham Quarry generally were more fragmentary than those from correlative strata at Strensham, farther west in the Severn Basin.

The laminated limestones lack the fine shell debris found in those near the base of the member, below the Grizzle Bed, and appear to be largely diagenetic in origin. The crushed nature of the ammonite shells indicates fairly late diagenetic cementation. Consequently Brodie's (1868, 1897) assertion that insect remains are confined to the limestones can be seen as merely a consequence of selective collecting; almost certainly insects must occur in the laminated shales but they have not been searched for there.

Lithostratigraphical correlation of individual limestones between the various described quarries in this area was attempted by Old *et al.* (1991), with moderate success. They noted that although quarry names were assigned to most of the limestones, these were not consistent between quarries. The only exceptions were the Guinea Bed, the Firestones, the Grizzle Bed and the Top Block. in addition, it appears that some limestones bands were not continuous and could not be correlated between quarries. In particular the insect-rich limestone at Binton appears to be represented by a thick mudstone with laminated horizons at Newnham. Brodie (1868, p. 16) noted that 'in one of the most westerly sections at Wilmcote ... the Insect Beds thin out and scarcely amount to three layers ... a thick mass of shale succeeds undivided as elsewhere by limestones'. The laminated nature of many of the limestones suggests that they developed through diagenetic modification of laminated mudstones. Their apparent absence or discontinuous nature may therefore reflect local variation in diagenetic factors.

In terms of larger-scale facies interpretations there are significant similarities between the succession at Newnham Quarry and that seen at other sites, notably the **Lavernock to St Mary's Well Bay** GCR site in south Wales. At the base of the succession comparison may be drawn between the limestone-dominated Bull Cliff Member at Lavernock and the similarly limestone-dominated Stock Green Limestone of the Wilmcote area, with both corresponding to the lower part of the Pre-Planorbis Beds of the Lias Group. At Lavernock this is succeeded by the limestone-rich St Mary's Well Bay Member, which gives way early in the Liasicus Zone to the mudstone-dominated Lavernock Shale Member. A similar transition occurs between the Wilmcote Limestone Member and the Saltford Shale Member (Ambrose, 2001), although it appears to occur rather earlier here, with mudstones becoming dominant towards the middle of the Johnstoni Subzone, and is presumed to relate to a eustatic rise in sea level. The laminated limestones that are such a significant element of the succession at Newnham Quarry are by no means unique and occur quite commonly in the Planorbis Zone elsewhere, such as at Lavernock in south Wales, Pinhay Bay in east Devon, and in temporary exposures near Gloucester (Simms, 2003a).

Conclusions

Newnham Quarry is the type locality for the Wilmcote Limestone Member at the base of the (Hettangian) Blue Lias Formation, which includes the so-called 'Insect Beds', laminated limestones that are a particularly characteristic feature of this part of the Lias Group across the Midlands. The site is the best extant inland exposure of the Blue Lias Formation and can be considered representative of this facies development both on the East Midlands Shelf and in the Severn Basin (Figure 4.1, Chapter 4). The sequence shows a sharp transition from the well-oxygenated '*Ostrea liassica* and Saurian Beds', with an abundant and diverse benthic fauna, to the predominantly anoxic 'Insect Beds', in which benthos is virtually absent and the fauna is dominated by vagile nekton and drifted terrestrial debris. In the 19th and early 20th centuries the site was an important source of fossil fish, marine reptiles, plants and especially insects, fine examples of which are now in the Natural History Museum in London and the Warwickshire Museum.

CONESBY QUARRY, NORTH LINCOLNSHIRE (TA 899 143)

K.N. Page

Introduction

The Conesby and Yorkshire East quarries complex (Figure 5.6) has provided the richest documented faunas of the Frodingham Ironstone Member of the Scunthorpe Mudstone Formation, of Sinemurian age, a deposit historically of great economic importance. Bivalves dominate the fossil assemblages, accompanied by ammonites, belemnites and rare intact echinoderms. Ammonite faunas from this site indicate the presence here of several biohorizons that, although rarely developed elswhere in Britain, are of key significance for Upper Sinemurian correlation across Europe. Sedimentologically and palaeoecologically this site is important for understanding the development of Lower Jurassic ironstone facies in Great Britain. Stratigraphically and taxonomically it is a key site for the study of mid-Sinemurian ammonite faunas.

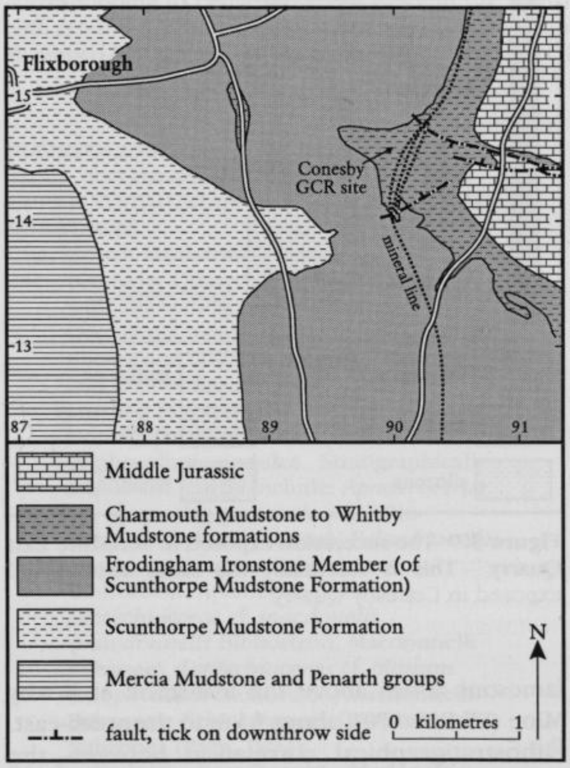

Figure 5.6 Geology and location map for the Conesby Quarry GCR site and Yorkshire East Quarry.

The Frodingham Ironstone Member has been mined around Scunthorpe for more than 130 years and was the basis for the town's former prosperity in steel-making. These links are so strong that the town's coat of arms incorporates three *Gryphaea*, one of the most conspicuous fossils in the surrounding quarries. The ironstone is no longer worked as an ore and, with the closing of the workings, most of the former exposures have been, or are in the process of being, lost to landfill or are flooded (Knell, 1990). The Lower Jurassic succession is overstepped by an early Cretaceous unconformity as the Market Weighton High is approached (Cope *et al.*, 1980a) and hence the Frodingham Ironstone Member does not extend far north of the River Humber. To the south it can be traced for some 17 km before passing into mudstones and less ferruginous limestones. Scunthorpe itself lies on the present outcrop of the Frodingham Ironstone Member, with its maximum preserved updip extent lying less than 5 km to the west. To the east it reaches a maximum thickness of about 10 m (32 ft according to Hallam, 1963) at Santon, about 5 km east of Scunthorpe, but has been traced at depth at least as far as Immingham, some 30 km east of Scunthorpe, and may well extend beyond the coast (Knell, 1990). The upper boundary of the Frodingham Ironstone Member is quite sharply defined, with an abrupt change from ironstone to mudstone. However, the lower boundary is more ill-defined and typically shows a progressive upward increase in the proportion of ironstone facies to mudstone (Hallam, 1963).

There is relatively little early work on the ironstone, the first account of the orefield being in Cross (1875), which , with the addition of a brief account in Ussher (1890), formed the basis of all subsequent reports up to the publication of Wilson (1948). Later work on the ironstone included that of Hallimond (1925), Davies and Dixie (1951), and Whitehead *et al.* (1952). The stratigraphical distribution of the ironstone has been discussed since some of the earliest publications, with more recent accounts including Hallam (1963), Cope *et al.*, (1980a), Gaunt *et al.* (1992) and Page (1992). Specifically palaeoenvironmental analyses are represented only by the work of Hallam (1963) and Young *et al.* (1990b). In the late 1980s and early 1990s intense activity associated with a landfill scheme at the Conesby Quarry site, north-east of

Scunthorpe, yielded a considerable fauna from the ironstone (Knell, 1988), though few specimens were associated with precise stratigraphical information. This is particularly significant for the ammonite faunas, making precise comparison with other sites difficult. Sole (2001) and Thompson (2001) have given accounts of the rescue-collecting operations at Conesby Quarry.

Yorkshire East Quarry is adjacent to the Conesby Quarry site and formerly was part of the same quarry complex, though excluded from the landfill schemes; the construction of a railway embankment partitioned the once continuous quarry face (Figure 5.6). Mechanical excavations at Yorkshire East Quarry, organized by British Steel in 1995, facilitated the first detailed stratigraphical recording of a section in the Frodingham Ironstone Member, which has now, in part, compensated for the lack of detailed information from the Conesby Quarry site. The new section showed the basal Charmouth Mudstone Formation, overlying the upper, fossil-rich, portion of the Frodingham Ironstone Member and was recorded and sampled in detail (Page, 1995).

Description

The section at Conesby Quarry has never been documented in detail but is closely similar to other sites nearby that have. Hallam (1963) stated that the section through the Frodingham Ironstone Member at Conesby was 'essentially similar' to that which he gave for the Crosby Mine (TA 907 133), only 1 km to the south-east. At the latter site he recorded a section through 8.54 m (27 ft 9 in.) of the Frodingham Ironstone Member, dividing it into eight distinct beds capped by dark shales. The section reproduced below (Figure 5.7) is based largely on that exposed at Yorkshire East Quarry, where excavations exposed more than 7 m of the Frodingham Ironstone Member (beds 0–23) and the lowest 3.5 m or so of the Charmouth Mudstone Formation (beds 24a–c) (Figure 5.8). At least 10 m of the mudstones were formerly seen in the adjacent Conesby Quarry site but have not been logged in any detail either for here or for the Yorkshire East Quarry, though records from Conesby Quarry have been incorporated into the section described below for Yorkshire East Quarry. Sellwood (1972) logged 34 m of the predominantly argillaceous Charmouth Mudstone Formation in the Raricostatum and

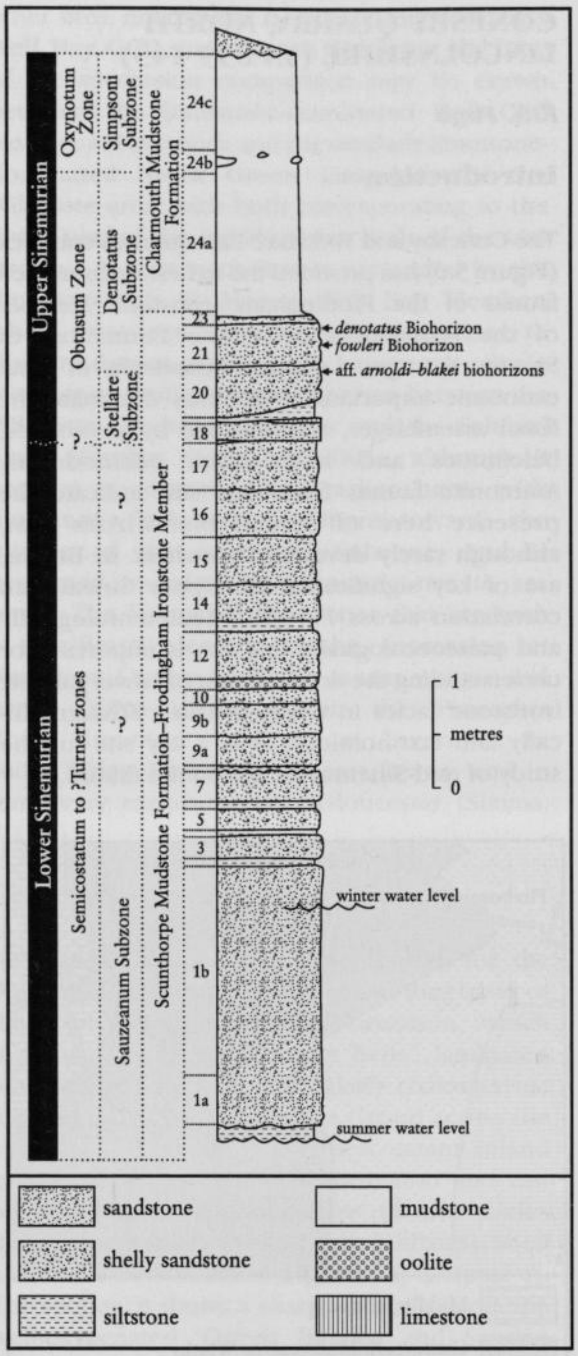

Figure 5.7 The succession exposed in Yorkshire East Quarry. This is essentially the same as that still exposed in Conesby Quarry.

Jamesoni zones above the ironstone at Roxby Mine (SE 910 170), about 3 km to the north-east. Lithostratigraphical correlation between the section recorded here and those recorded by Hallam (1963) at Crosby Mine and Sellwood (1972) has proven difficult or impossible.

Figure 5.8 Yorkshire East Quarry, Conesby; trial excavation in mid-1995, prior to SSSI notification. The lower face shows around 7 m of bedded Frodingham Ironstone Member above water level, with the top 1 m corresponding to beds 20–23 and yielding late Stellare to Denotatus subzone faunas. Above, and in the rear cliff, around 3.5 m of Charmouth Mudstone Formation can be seen, of Simpsoni Subzone age. The succession is capped by Quaternary 'Cover Sands'. (Photo: K.N. Page.)

Thickness (m)

PLEISTOCENE
Sands, unconsolidated, pale.

UPPER SINEMURIAN–LOWER PLIENSBACHIAN SUBSTAGES

Charmouth Mudstone Formation

24c: (Conesby Quarry). Mudstone, grey, with alternating paler, ?silty bands. Occasional bands of small pale-coloured phosphatic nodules present. Bivalves and ammonites frequent, usually crushed in the mudstones, but occasionally partly preserved uncrushed in phosphatic nodules. Stratigraphically important faunas include: *Apoderoceras* sp. (gr. *nodogigas/aculeatum* Biohorizon, Taylori Subzone), *Paltechioceras* ex grp. *aplanatum* (*aplanatum* Biohorizon, Aplanatum Subzone), *Leptechioceras* cf. *macdonelli* (*macdonnelli* Biohorizon, Macdonnelli Subzone), *Leptechioceras* cf. *planum* (*subplicatum* Biohorizon, Macdonnelli Subzone), *Echioceras* sp. (Raricostatum Subzone) (Page, 1992). > 6.0

24a–b: (Yorkshire East Quarry). Marl, pale greenish-grey weathering, with scattered small micritic nodules and a pale-grey, burrowed (*Chondrites*) soft calcareous lenticle at *c.* 1.45–1.60 m above base (= Bed 24b). Nodules yield small bivalves, including *Oxytoma*, and *Gagaticeras* sp.. *Gagaticeras* also occurs crushed in marl from around 0.55 m above the base of Bed 24a. *Oxynoticeras* cf. *simpsoni* is present at approximately this level in the former Conesby Quarry site, indicating the Simpsoni Subzone. *c.* 3.5

Scunthorpe Mudstone Formation

Frodingham Ironstone Member

23: Chamositic band, rusty-weathering, typically soft and sandy, with small (*c.* 3–4 cm) black, hollow-centred concretions in lower part. Rare dark olive-green unweathered patches. 0.01

22: Sandstone, silty, chamositic, soft, shelly; dark olive-green with small white-shelled bivalves when unweathered. Occasional *Gryphaea* present. Hardened dark, purplish-grey mudstone clast near top. Similar hard mudstone forms an impersistent band locally at base of bed. Calcareous shelly lenticles present locally. *Eparietites denotatus* present. Corresponds to the *denotatus* Biohorizon, Denotatus Subzone. 0.14

		Thickness (m)
21:	Sandstone, chamositic, greenish-grey, with small white shells (when unweathered). Flaggy bedded, typically splitting into 3 bands (beds 21a–c). Ammonite fauna includes *Eparietites fowleri* in upper 0.1 m (= 21c); corresponds to the *fowleri* Biohorizon, Denotatus Subzone. This is probably the level that has yielded very rare *Xipheroceras trimodum* and *Angulaticeras* sp. in Conesby Quarry. *Aegasteroceras* is also likely to be present.	0.28
20:	Sandstone, chamositic, with white calcareous shelly lenticles up to 1.5 cm thick full of small bivalves and occasional ammonites. The latter commonly with green chamosite-impregnated shells. Traces of cross-bedding present locally. Some hard mudstone clasts present. Ammonite fauna includes: ?*Eparietites* sp. (*c.* 0.05 m below top of bed; Denotatus Subzone); *Asteroceras* ex grp. *smithi* (transitional to *Aegasteroceras*); ?*Xipheroceras* sp. (in upper *c.* 0.12 m); *Asteroceras* ex grp. *smithi sensu stricto* (*c.* 0.15–0.3 m below top of bed; corresponds to the aff. *arnouldi–blakei s.s.* biohorizons, Stellare Subzone); *Asteroceras* ex grp. *stellare*, *Xipheroceras* sp. (*c.* 0.4–0.77 m below top of bed)	*c.* 0.5–0.8
19:	Sandstone, chamositic, silty, fine, sandstone, some shells (bivalves) present.	0.05–0.2
18:	Sandstone, calcareous with some shelly lenticles. Impersistent hard marl (up to 0.06 m thick) seen in upper part.	0.1–0.72
17:	Sandstone, ferruginous, soft, red-brown weathering, with some harder bands. Scattered *Gryphaea* present.	0.45
16:	Sandstone, chamosite oolite, hard, ferruginous, weathering a dark-brown colour. Shelly band with abundant *Gryphaea* in lower part.	0.45
15:	Sandstone, ferruginous, brown, soft.	0.45 m
14:	Sandstone, calcareous, shell rich, with abundant large bivalves (*Gryphaea* and *Cucullaea*).	0.3–0.35
13:	Seam, soft silty, fine, sandy.	0.1
12:	Sandstone, shelly, oolitic, with *Cucullaea*, etc.	0.45
11:	Pebble bed, intraclastic, full of small ferruginous clasts generally < 1 cm in diameter.	0.10
10:	Sandstone, calcareous and ferruginous, shelly, flaggy weathering in upper part, with large shells (*Gryphaea*, *Cucullaea*).	0.16
9:	Sandstone, calcareous, ferruginous, shelly. In two blocks separated by a parting. Upper block (9b) with common large shells (*Gryphaea*, *Cucullaea*). Lower block (9a) with fewer shells, but concentrated near top. Some small intraclastic pebbles present in lower part of 9a.	0.6
8:	Soft sandy parting.	0.05
7:	Sandstone, shelly, calcareous, ferruginous, with abundant *Cucullaea*, etc., and some pectinids.	0.28
6:	Soft sandy parting.	0.05
5:	Sandstone, calcareous, ferruginous, with large shells (*Cucullaea*, etc.) concentrated near top.	0.2
4:	Soft sandy parting.	0.05
3:	Sandstone, very shelly, calcareous, full of large shells, especially *Cucullaea*, with some *Gryphaea*.	0.22
2:	Soft sandy parting.	0.05
1:	Sandstone, massive, ferruginous, flaggy weathering near top, with some *Gryphaea*. Around 0.4 m present above water level on north side of access ramp to conservation exposure, below massive-bedded ferruginous sandstone seen (largely inaccessible on south side of ramp). Lower part in southern area of site more flaggy bedded.	*c.* 2.5
0:	Soft silty band seen just above water level on south side of site.	*c.* 0.15 (seen)

(Loose blocks of soft silty sandstone beside the flooded excavation in the southern area of the Yorkshire East Quarry site yielded abundant *Gryphaea* and common *Euagassiceras* ex grp. *resupinatum* with ?*Arnioceras* sp.. The lithology and location suggest an origin within or close to the base of Bed 2, Sauzeanum Subzone)

Within the ironstone itself, four basic lithologies have typically been recognized in the district (Davies and Dixie, 1951; Whitehead *et al*., 1952; Hallam, 1963; Gaunt *et al*., 1992), with a fifth described in Young *et al*. (1990b). Their basic characteristics, based largely on Young *et al*. (1990b) and Hallam (1963), are as follows:

Type A: Bioclastic ooidal grain-ironstone – calcitic bioclasts and goethite/berthierine ooids, more-or-less replaced by siderite, all covered with a thin berthierine grain coating and siderite cement. In hand specimen a spongy mass of berthierine-bearing shiny ooids. Hallam (1963) noted that types A and C often tend to grade into one another.

Type B: Sideritic mud-ironstone – small rhombs of siderite among parallel-orientated berthierine flakes. Ooids and bioclasts virtually absent. In hand specimen a tough indurated blue-grey mudstone. Hallam (1963) noted that this type is remarkably free of shells but, unlike the other types, it often contains minute shreds of organic matter parallel to bedding.

Type C: Goethite ooidal wacke-ironstone – goethite/berthierine ooids, more-or-less replaced by siderite, within a fine-grained berthierine/siderite matrix. The ooliths and pisoliths occur in a berthierine-rich mudstone with siderite crystals and quartz grains. Hallam (1963) noted that this is more argillaceous than Type A.

Type D: Ferruginous bioclastic limestone – goethite/berthierine ooids and calcareous bioclasts, more-or-less replaced by siderite, in a coarse sparry calcite cement (subdivided into D1, dominantly bioclastic, and D2, dominantly ooidal). Hallam (1963) noted that this often contains localized patches of mudstone with indeterminate boundaries, as well as obvious mudstone lithoclasts. Quartz silt is rarer in this type, while broken ooliths are somewhat commoner, than in the other types of ironstone. This type often exhibits cross-bedding.

Type E: Berthierine-bearing silty ooidal mudstone – siderite absent and clastic material prominent.

All five types of ironstone appear to be present in the Conesby district and lithologies are often relatively fresh and in part unweathered, particularly at the centre of large blocks. Types B and D are particularly distinct, with Type B often forming discontinuous or bifurcating seams within the more dominant Type D. The preservation of this material is ideally suited for further work on the formation, especially into the mineralogy and diagenesis, and as no contemporary published study exists, beyond the observations of Gaunt *et al.* (1992, pp. 35–6).

Fossils are frequently abundant in the ironstone, particularly in the topmost 1–2 m. Hallam (1963) listed more than 40 species whereas Young *et al.* (1990b) cited a figure of 42 species of bivalve alone, and provided data on the facies distribution and life habits of 35 of these. Individual shell bands typically are dominated by only one or two bivalve species, often *Cardinia* or *Gryphaea*. Shelly lenticles in the upper part of the ironstone may be rich in pectinids, including *Camptonectes*, *Entolium* and other bivalves, while the brachiopod *Piarorhynchia* (probably *Cuneirhynchia oxynoti*, although there is no mention of the Frodingham Ironstone Member in Ager's (1956–1967) monograph) was said by Hallam (1963) to be abundant in the top 1.25 m (4 ft) of all sections through the Frodingham Ironstone Member, though uncommon below this level. Cross (1875) also recorded *Spiriferina walcotti* from the ironstone. Hallam (1963) noted that moulds of thin-shelled bivalves occur in the types A and C ironstones and that other shells are at least partly replaced by chamosite. Calcitic preservation is found in Type D ironstones, where the bivalves are predominantly disarticulated, with valves convex-up and showing a higher degree of fragmentation than in other ironstone types and an abundance of algal borings. Deeper-burrowing bivalve species often are preserved in life position in types A and C but are absent from Type D.

Echinoderm debris is a common component of the more bioclastic units and intact echinoderm material has also been recovered. Knell (1988) figured large intact specimens of the asteroids *Solaster* and *Archastropecten*, while a specimen of *Isocrinus tuberculatus* (misidentified as *Isocrinus robustus*) was figured on the front cover of the July/August 1990 (vol. 6, no. 4) issue of *Geology Today*. These intact echinoderms invariably are associated with thin clay lenses within the ironstone.

Hallam (1963) observed numerous foraminifera in thin-sections of the ironstone facies and was able to extract representatives of six genera from the mudstone immediately overlying the Frodingham Ironstone Member at Crosby Quarry. He also described several types of ichnofossil from the member. Within the sediment itself he observed large, sub-horizontal, *Rhizocorallium* burrows and smaller, vertical U-tubes of *Diplocraterion*. Although many were filled with the same material as the surrounding sediment, some were seen to be filled with mudstone despite their position in exclusively ironstone parts of the succession. He also described and figured three types of microscopic or submicroscopic boring from the shells of *Gryphaea* and other bivalves at Crosby Mine. He attributed these to cirripedes, clionid sponges and algae, and noted that the algal borings were confined to shells in Type D ironstones.

Only Sellwood (1972) has investigated the palaeoecology of the overlying Charmouth Mudstone Formation, though at Roxby Mine some 3 km to the north-east rather than at this site. Above a winnowed shell bed at the top of the Frodingham Ironstone Member he identified seven minor cycles (Sellwood, 1970) up to the base of the Aplanatum Subzone, with each cycle coarsening upwards from dark mudstones to paler bioturbated siltstones before being abruptly succeeded by the mudstones at the base of the next cycle. The Aplanatum Subzone and Jamesoni Zone was developed in non-cyclic mudstones with a prominent shell bed, containing broken and encrusted material, at the Raricostatum–Jamesoni zonal boundary.

Interpretation

In the first geological account of the Frodingham Ironstone Member, Cross (1875) recorded a number of ammonite species that would now be assigned to the genera *Arnioceras*, *Agassiceras*, *Caenisites* and *Metophioceras*, together indicative of the Bucklandi, Semicostatum and Turneri zones. Ussher (1890) interpreted this assemblage as representing the Semicostatum Zone while Arkell (1933) assigned the ironstone to the Semicostatum and part of the Bucklandi zones. Hallam (1963) re-examined material in Scunthorpe Museum and collected new material, concluding that the Frodingham Ironstone Member spanned the interval from the Sauzeanum Subzone, near the top of the Semicostatum Zone, to the Denotatus Subzone, at the top of the Obtusum Zone. Earlier biostratigraphical mis-interpretations he attributed to the mis-identification of *Eparietites* and *Epophioceras* as *Agassiceras* and *Metophioceras* respectively.

More recent collecting (K.N. Page, unpublished observations) has refined the biostratigraphy still further, with the recognition of several discrete biohorizons (Page, 1992) in the upper part of the Frodingham Ironstone Member and the Charmouth Mudstone Formation of the Conesby Quarry area. Evidence for the presence of further biohorizons in the district is indicated by museum material, especially in the collections of Scunthorpe Museum that form the main repository of specimens from the ironstone. The biohorizons recognized in the upper part of the Frodingham Ironstone Member are particularly important. The lowest of these, the *blakei* (X) Biohorizon, is one of the most widespread in Europe, being recorded from North Yorkshire, Gloucestershire, possibly Somerset, Burgundy, the French Jura and Switzerland (Dommergues *et al.*, 1994; Blau and Meister, 2000). This fauna at Conesby Quarry is the best preserved in Britain and hence of primary importance for international correlation. Above the *blakei* Biohorizon fauna, the upper *c.* 0.12 m of Bed 20 in Yorkshire East Quarry yields coarsely ribbed *Asteroceras* ex grp. *smithi*, transitional to *Aegasteroceras* spp.. A similar fauna occurs with *Arnioceras* aff. *arnouldi* in Burgundy, suggesting a correlation with the aff. *arnouldi* (XI) Biohorizon of the Stellare Subzone. *Aegasteroceras* ex grp. *sagittarium* was formerly abundant in Conesby Quarry (Figure 5.9), indicating the succeeding *sagittarium* (XII) Biohorizon, while *Eparietites undaries*, representing the cf. *undaries* (XIII) Biohorizon, has also been found near the top of the Frodingham Ironstone Member (Joss, 1980). However, both biohorizons remain unproven at Yorkshire East Quarry, with the next fauna recovered from that site being typical *Eparietites fowleri* in the upper *c.* 0.1 m of Bed 21. The *fowleri* (XIV) Biohorizon is well documented in Britain only in the Conesby district, but has been recognized in Burgundy and in south-east France (Page, 1992; Blau and Meister, 2000). This fauna includes the rare eoderoceratid, *Xipheroceras trimodum* and an unusual species of extremely oxyconic *Angulaticeras*, apparently unlike anything recorded elsewhere in north-west Europe. Bed 22 yields well-preserved *Eparietites denotatus* indicating the *denotatus* (XV) Biohorizon. Records of *Oxynoticeras simpsoni* in the topmost Frodingham Ironstone Member (e.g. in Gaunt *et al.*, 1992) could, therefore, be late Denotatus Subzone *Eparietites*, including *E. denotatus* itself that has a body-chamber indistinguishable from true *O. simpsoni*.

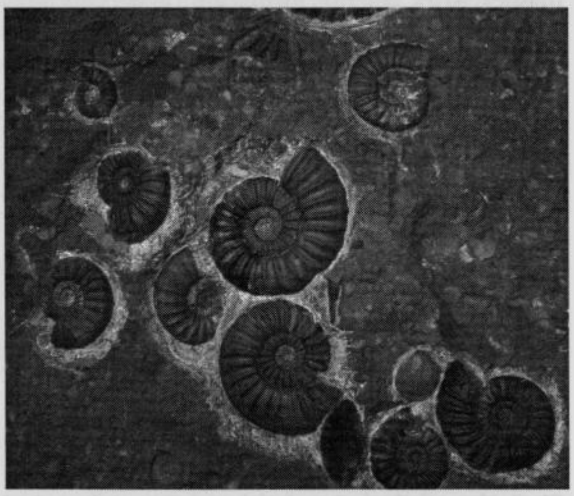

Figure 5.9 *Aegasteroceras* and other fossils from the Stellare Subzone or Denotatus Subzone of the Frodingham Ironstone Member at Conesby Quarry. Specimen in the collections of the National Museum of Wales. (Photo: M.J. Simms.)

The lower part of the Frodingham Ironstone Member has been less intensively collected in recent years, but Hallam (1963) cited examples of *Arnioceras* aff. *semicostatum*, *Pararnioceras* aff. *alcinoe*, *Caenisites* cf. *brooki* and *Microderoceras birchi* in addition to various Obtusum Zone taxa. Specimens of *Euagassiceras* from near the base of the section recorded here, together with Hallam's (1963) records, indicate the presence of the Sauzeanum, Brooki, Birchi, Stellare and Denotatus subzones within the Frodingham Ironstone Member. No conclusive evidence has been found for the presence of the Obtusum Subzone, an observation that was commented on by Hallam (1963).

In the overlying Charmouth Mudstone Formation Sellwood (1972) recognized a complete sequence of subzones through the Raricostatum and Jamesoni zones at Roxby Mine, but assigned the top of the Frodingham Ironstone Member and less than 1 m of the overlying mudstone to the Oxynotum Zone. However, specimens of *Eparietites* aff. *glaber* in Scunthorpe Museum indicate that the base of the Charmouth Mudstone Formation lies in the uppermost Denotatus Subzone. Furthermore, the lowest part of the formation in the Scunthorpe district has yielded a form, transitional between *Eparietites* and *Oxynoticeras*, referable to *Eparietites collenotii* (Dommergues *et al.*, 1994). This represents the aff. *glaber* Biohorizon previously recorded only from France and unknown elsewhere in Britain. Later faunas of Raricostatum Zone and basal Jamesoni Zone were recorded from the Conesby Quarry sites, though cut out at Yorkshire East Quarry by Quaternary deposits, but the Oxynotum and Densinodulum subzones were unproven.

The absence of any evidence for the Obtusum Subzone suggests a region-wide non-sequence at this level but the local absence of other biostratigraphically defined faunas probably indicates no more than the sporadic occurrence of fossil-rich lenses within the Frodingham Ironstone Member. Similarly, the apparent absence of the Oxynotum and Densinodulum subzones at Conesby, despite their supposed presence at Roxby (Sellwood, 1972), probably reflects collection failure. Nonetheless, it is clear that sedimentation during deposition of the Frodingham Ironstone Member was discontinuous. Hallam's (1963) observation of mudstone-filled *Diplocraterion* burrows within an entirely ironstone part of the succession implies modest periods of erosion during deposition. Similarly the presence of intensively bio-eroded *Gryphaea* shells suggests that shell material was exhumed or remained exposed on the sea floor for significant periods of time. Sellwood's (1972) comment, that subzonal boundaries within the Raricostatum Zone correlate with the tops of minor sedimentary cycles, also implies that there may have been significant pauses during deposition of this part of the Charmouth Mudstone Formation.

The palaeoecology of the ironstone has been discussed by Hallam (1963) and typical fossils illustrated in a booklet by Knell (1990). Young *et al.* (1990b) provided a contemporary review and suggested that grading, bioturbation, sedimentary structure and shell-rich coquinoid biofabrics indicated alternating storm and fair-weather conditions. These features are displayed in tripartite pseudo-cycles, comprising a storm couplet overlain by background sediments, although they have been modified to varying degrees by subsequent lower-energy events. Young *et al.* (1990b) suggested that the major storm events represented in the Frodingham Ironstone Member might occur as infrequently as once in 150 000 years yet they noted that the depth of scouring was of similar magnitude to the bed thickness. From this they inferred that sediment remained in the mobile superficial layer for a similar length of time, perhaps accounting for the apparent mixing of some of the ammonite faunas.

These storm events, infrequent though they might have been, inevitably had a significant effect on the taphonomy of the ironstone faunas, with shells being reworked, transported, and in some cases destroyed, although storm-produced units contain essentially the same species as interstratified fair-weather deposits. As discussed by Young *et al.* (1990b), Type C ironstones represent background fair-weather deposits with fossil-rich fabrics showing an interplay between physical and biological depositional processes, including intense bioturbation. In contrast the types D1 and D2 ironstones represent tempestites, with sorting (both size and taxonomic), fragmentation and convex-up orientatation of bivalve shells. Coquinas of *Cardinia* and pectinids characterize the base of many of these tempestite pseudo-cycles. Hallam (1963) concluded that the organic material and lack of bioturbation in the Type B ironstones suggested deposition in anoxic bottom waters.

There is evidence within the Frodingham Ironstone Member of both high-energy shoal conditions and lower-energy periods with deposition of more muddy suspended sediment, which was then intensely bioturbated (Gaunt *et al.*, 1992). This environmental instability, with rapid deposition following storms, was a major factor in the obrution mechanism that caused preservation of articulated asteroids and crinoids beneath thin mudstone lenses. The prevalence of tempestite facies within the member indicates that the sea floor was well above storm wave-base whereas the presence of abundant endolithic algal borings in bivalves in Type D ironstones indicates a position well within the photic zone, with deposition perhaps occurring in no more than 20–25 m of water (Hallam, 1963).

As with so many sedimentary ironstones, the precise reasons for the geographical and stratigraphical location of the Frodingham Ironstone Member remain uncertain. However, it is perhaps significant that the Pecten Ironstone Member within the Charmouth Mudstone Formation, of upper Jamesoni to lower Ibex zone age, is confined to the same geographical area as the older Frodingham Ironstone Member, suggesting a common underlying control. The somewhat condensed nature of the Frodingham Ironstone Member, with barely 10 m of ironstone correlating with almost three times this thickness of clastic sediments in Robin Hood's Bay, to the north, and five times this thickness on the Dorset coast, suggests slow rates of deposition. The often low proportion of clastic material in these ironstones also indicates deposition in an area of sediment starvation, perhaps on a local high. In this respect the proximity of the Frodingham Ironstone Member to the southern margin of the Market Weighton High may be significant (Figure 5.10), with periodic movement on this structure perhaps exerting a major influence on facies development in the Lower Jurassic Series of the area. The absence of similar ironstones at this level in adjacent basins, and their development instead at other levels, suggests that eustatic changes exerted only a minimal influence, if any at all, on the development of these facies.

Young *et al.* (1990b) considered that the primary iron mineral in the ironstone was berthierine. The formation of this mineral requires low-oxygen, low-salinity conditions, which conflicts with the apparent palaeoecological evidence for well-oxygenated conditions. It has been suggested that the berthierine was formed elsewhere, perhaps in brackish-water lagoons protected from the sea by some form of barrier, perhaps shell banks, and received dissolved and particulate iron from an adjacent low-lying

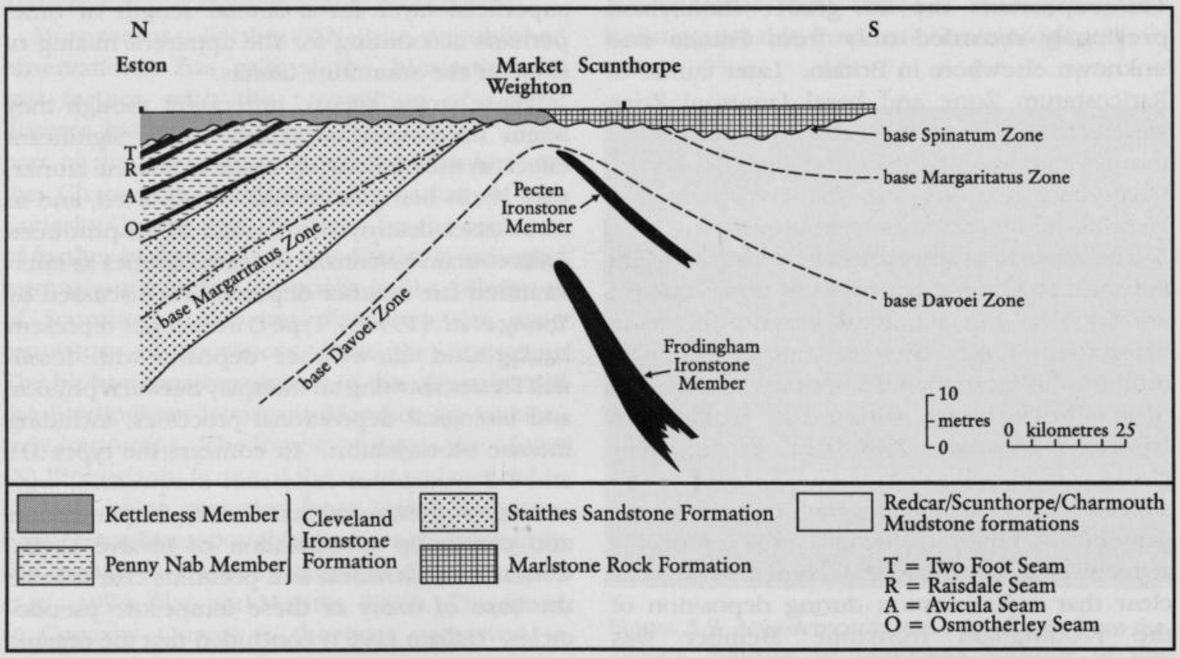

Figure 5.10 Schematic section across the Cleveland Basin, Market Weighton High and northern end of the East Midlands Shelf showing the relationship of the Liassic ironstones to the underlying structure. After Howard (1985).

and well-vegetated landmass with lateritic soil formation (Gaunt *et al.*, 1992). Subsequently these berthierine-rich muds were washed into a fully marine, shallow-water environment, perhaps during storms. Nonetheless, the frequent low-diversity but high-abundance characteristics of the benthic fauna does tend to suggest some form of restricted conditions at times, though this may have taken the form more of physical factors associated with these facies rather than any chemical properties of the seawater at this time.

Conclusions

Yorkshire East Quarry is one of the last remaining exposures of the Frodingham Ironstone Member, adjacent to the former Conesby Quarry, which has yielded the richest-known faunas from this unit. The well-preserved ammonite faunas indicate the presence of several biohorizons within the Obtusum Zone, including the ***blakei*** Biohorizon, a key reference level for correlating Upper Sinemurian sequences across Europe, and the aff. ***glaber*** Biohorizon, otherwise unknown in Britain. Other elements of the fauna include intact specimens of several species of asteroid, an extreme rarity in the British Lower Jurassic Series, and of *Isocrinus tuberculatus*.

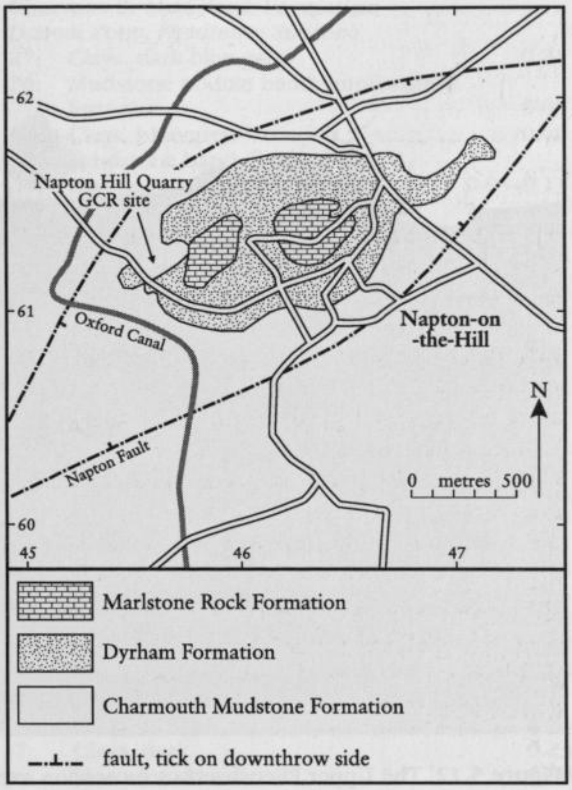

Figure 5.11 Geology and location map for the Napton Hill Quarry GCR site.

NAPTON HILL QUARRY, WARWICKSHIRE (SP 457 613)

M.J. Simms

Introduction

The Napton Hill Quarry GCR site is a disused brickpit at Napton-on-the-Hill. It is one of the few remaining inland exposures of the Upper Pliensbachian (Middle Lias) succession in Britain, comprising the top of the Dyrham Formation and the base of the Marlstone Rock Formation. Napton Hill Quarry forms an outlier of Upper Pliensbachian strata within a small fault-bounded block (Figure 5.11) west of the main outcrop in east Warwickshire. The quarry formerly exposed the entire Upper Pliensbachian (Middle Lias) succession, and the upper part of the underlying Lower Pliensbachian (Lower Lias) succession, consisting of the base of the Dyrham Formation and the top of the Charmouth Mudstone Formation, which was worked for brick-making. Today only the Upper Pliensbachian succession remains exposed (Figure 5.12), and the lower part of the quarry has been back-filled. This is one of a series of key sites that together reveal lateral facies changes across the Upper Pliensbachian outcrop. Strata formerly exposed here yielded rich Lower Pliensbachian ammonite assemblages, which contributed to the development of ideas on ammonite evolution and biostratigraphy.

The biostratigraphical succession was summarized by Trueman (1918) although his description lacked lithological detail or bed thicknesses. Howarth (1958) described the Upper Pliensbachian succession; a fuller section, extending down into the top of the Lower Pliensbachian succession, was described by Callomon (in Hallam, 1968a). It was described again briefly in Lord's (1974) study of Upper Pliensbachian (= Domerian) and Toarcian ostracods. The section, as currently exposed, was described by Old *et al.* (1987). In the past the site was an important source of liparoceratid ammonites that formed the basis of phylogenetic and taxonomic research undertaken by Trueman (1918) and Spath (1938).

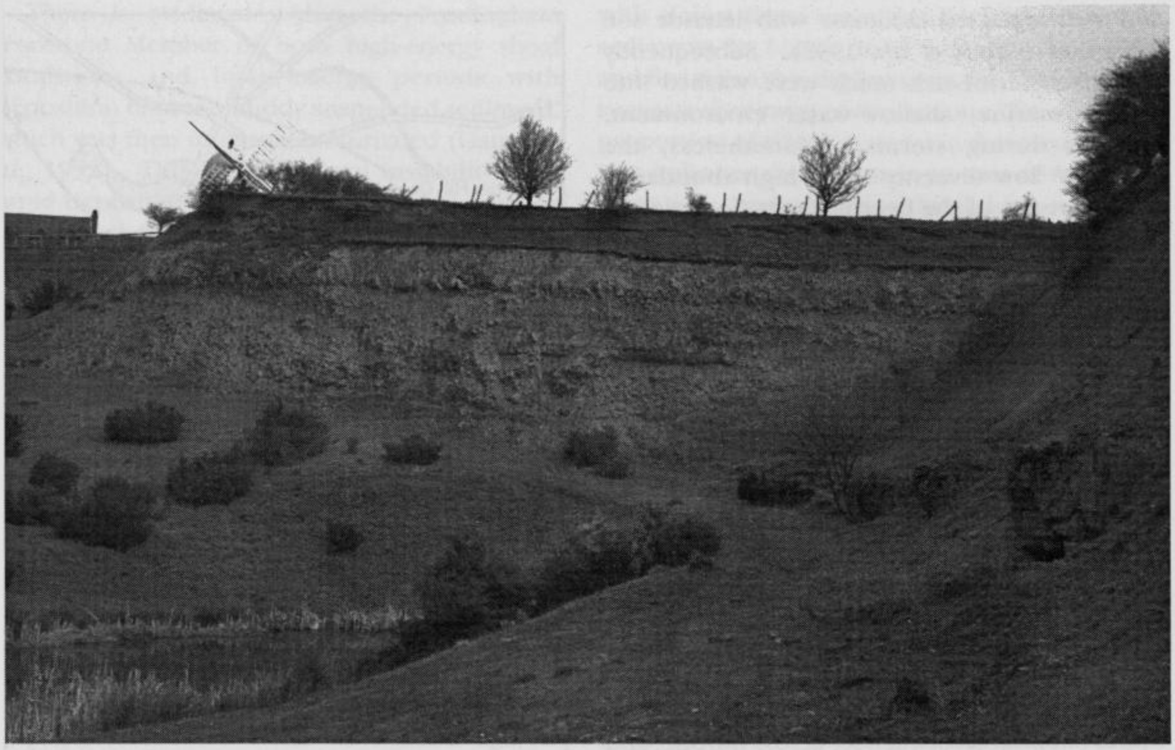

Figure 5.12 The Upper Pliensbachian succession exposed at the Napton Hill Quarry GCR site. The Marlstone Rock Formation lies at the top of the section, with the sandstone of Bed 33 visible a little lower in the face. The large blocks projecting from the lower part of the right-hand face are some of the doggers that occur in Bed 29. (Photo: M.J. Simms.)

Description

The most complete section of the site was published by Callomon (in Hallam, 1968a). The biostratigraphical succession published by Trueman (1918) implies that older parts of the succession may have been exposed at one time. However, it has been suggested (J.H. Callomon, pers. comm.) that the lower parts of Trueman's section may have been based on material from the immediate neighbourhood rather than from the pit itself. The section described by Callomon was almost 53 m thick and divided almost equally between the Lower and Upper Pliensbachian substages. The former comprised 26 m of grey and blue-grey silty clays and shales with bands of nodules, 0.05–0.2 m thick, at irregular intervals. The Lower and Upper Pliensbachian (= Lower and Middle Lias) junction was identified by Howarth (1958) at a level 26.5 m (86 ft 2 in.) below the top of the Marlstone Rock Formation. Much of the Upper Pliensbachian comprises typical Dyrham Formation facies, mostly siltstones and silty mudstones together with several horizons of large sandstone 'doggers' and a 0.5 m-thick fossiliferous sandstone. The Upper Pliensbachian succession is capped by the Marlstone Rock Formation, here divisible into a lower sandstone unit and an upper limestone unit, with a basal pebble bed. Old *et al.* (1987) report that in this area the Lower Pliensbachian becomes more silty and micaceous upwards towards the Upper Pliensbachian, and is a paler grey than the clays lower in the succession. The upper part of the Lower Pliensbachian also is more ferruginous in parts, with mudstone and ferruginous nodules forming a significant component of this part of the succession.

The following Upper Pliensbachian section is based largely on the description of Old *et al.* (1987), with some additional data from Howarth (1958). The Lower Pliensbachian succession is that of Callomon (in Hallam, 1968a).

Bed	Description	Thickness (m)
	Marlstone Rock Formation	
37:	Limestone, bioclastic, rubbly and flaggy, ferruginous, orange-brown, sandy; green when fresh. *Camptonectes mundus*, *Modiolus scalprum*, *Protocardia truncata*, *Pseudolimea* sp., crinoid debris.	3.00
36:	Sandstone; fine grained and micaceous, soft and poorly cemented. Small rounded pebbles of sandstone and siltstone at the base.	0.50
	Dyrham Formation	
35:	Siltstone; sandy and ferruginous, with shell debris. Belemnites near base.	0.64
34:	Siltstone; grey, ochreous and micaceous. Poorly cemented, with iron-stained fractures and surfaces.	2.20
33:	Sandstone; orange, poorly cemented and calcareous, with iron-stained fractures. Many bivalves and other fossils; *Modiolus scalprum*, *Protocardia truncata*, *Unicardium cardioides*, *Camptonectes* sp., *Ceratomya* sp., *Pseudolimea* sp., *Pseudopecten* sp., *Amaltheus subnodosus*, *A. margaritatus* and *A. striatus*.	0.54
32:	Mudstone; pale grey, silty with sandy wisps and ferruginous doggers up to 1 m across.	2.20
31:	Limestone; grey-green, weathering reddish-orange. Sandy and ferruginous with shelly cementstone doggers. *Protocardia truncata*, *Pholadomya* sp., ?*Pleuromya*, *Amaltheus* cf. *subnodosus*.	0–0.88
30:	Mudstone; pale grey to brown, increasingly silty towards top with shell debris and ironstone nodules. A row of scattered doggers 3.1 m from the top. *Liparoceras* (*Becheiceras*) *bechei* in lowest 1.5 m.	4.8
29:	Sandstone; poorly cemented, with patches of silt and abundant doggers up to 1.5 m thick and 5 m across, of medium-grained calcareous sandstone, blue-hearted but weathering green-brown or orange. Abundant fossils, particularly pectinids and other bivalves, crinoid debris and large specimens of *Amaltheus stokesi* and *Protogrammoceras nitescens*. Scattered grey phosphatic nodules weathering red-brown. Very sharp boundary with underlying mudstones.	1.5
28:	Mudstone; pale grey, weathering brown, with a little silt towards the top and more towards the base. Ferruginous bands and small doggers are common in the top 1.0 m and a row of scattered doggers occur 9.2 m from the top. Junction with Charmouth Mudstone Formation at base (Howarth, 1958). The top 4.0 m of this unit form the lowest part of the succession now seen in the quarry (Figure 5.12).	9.62
	Charmouth Mudstone Formation	
	Davoei Zone, Figulinum Subzone	
27:	Clays, dark blue-grey.	0.23
26:	Mudstone nodule band, impersistent, ferruginous.	0.05
25:	Clays, blue-grey.	0.40
24:	Sandstone band, ferruginous, nodular.	0.05–0.13
23:	Clays, shaly, dark blue-grey.	1.70
22:	Line of brown, ferruginous mudstone nodules with ammonites.	0.10–0.20
21:	Clays, shaly, blue-grey.	0.45
20:	Brown ferruginous sandy mudstone nodule band.	0.13
19:	Clays, shaly, blue-grey.	0.45
18:	Mudstone nodule band, ferruginous.	0.15
	Capricornus Subzone	
17:	Clays with median nodule band; ammonites.	0.92
16:	Nodules.	0.15
15:	Clays, grey.	0.77
14:	Mudstone nodules.	0.15
13:	Clays.	1.08
12:	Nodule band.	0.15
11:	Clays and shales.	5.38
10:	Seam of nodules.	0.08
9:	Clays.	0.45
	Maculatum Subzone	
8:	Nodules.	0.08
7:	Clays, dark.	0.23
6:	Line of nodules.	0.08
5:	Clays, grey.	1.54
4:	Mudstone nodules.	0.10
3:	Clays.	0.69
2:	Nodules.	0.15
1:	Clays below.	seen to 10.15

Considerably less than half of this total thickness is visible today. The Lower Pliensbachian succession, consisting predominantly of the Charmouth Mudstone Formation has long since been obscured by back-filled material as has the base of the Upper Pliensbachian Dyrham Formation. The top 4 m of Bed 28 are the lowest part of the succession that can be seen clearly at present: the Marlstone Rock Formation is still well-exposed at the top of the face (Figure 5.12).

Ammonites have figured prominently in all descriptions of the site, either for their biostratigraphical value (Howarth, 1958; Callomon in Hallam, 1968a) or for their significance in interpreting the phylogeny of the liparoceratids (Trueman, 1918; Spath, 1938; Callomon, 1963). Spath (1938) cited examples of nine species of liparoceratid from here, including the holotype of *Liparoceras naptonense*. Other macrofossils have received little attention. Palmer (1975) cited the bivalve *Cardinia attenuata* as occurring in the Ibex Zone, while Woods (1925–1931) figured a chela of the crustacean *Eryma* sp. from the Marlstone Rock Formation here, but otherwise there appear to be no published accounts of other elements of the macrofauna. Lord (1974) recovered a limited microfauna of ostracods and foraminifera from only one of 17 samples; the productive level was a shelly sandstone (Bed 29) 13 m below the Marlstone Rock Formation.

Interpretation

The biostratigraphy of the main part of the recorded section is fairly well-established through the investigations of Howarth (1958) and Callomon (in Hallam, 1968), but is not fully resolved at some levels.

Uncertainty surrounds the age of the Marlstone Rock Formation since it has not yielded any ammonites at this site. Howarth (1980) demonstrated the presence of Tenuicostatum Zone ammonites in the upper part of the formation at numerous sites, from Dorset to the East Midlands Shelf, but no such evidence has been found here although this zone is proven in the top of the Marlstone Rock Formation at Byfield, less than 10 km to the south-east (Howarth, 1978). The lower part of the Marlstone Rock Formation is assumed to be at least partly of Spinatum Zone age, although again no ammonites have been found here. Within the underlying Dyrham Formation the Stokesi Subzone (beds 28–29) and the Subnodosus Subzone (beds 30–33) are proven by the presence of the index species, although Howarth (1958) and Old *et al.* (1987) failed to find any age-diagnostic fauna between the base of the Marlstone Rock Formation, and the highest occurrence of *Amaltheus subnodosus* little more than 2 m below. The lower, sandy part of the Marlstone Rock Formation at Napton Hill draws comparison with the Tilton Sandrock Member of Leicestershire, and similar facies below the Marlstone Rock Formation at the **Robin's Wood Hill Quarry** GCR site in Gloucestershire. At both sites these are at least partly of Subnodosus Subzone age. The Gibbosus Subzone is present elsewhere on the margins of the London Platform (Hallam, 1968) and in the Severn Basin (Simms, 1990a) but remains unproven here.

The Lower Pliensbachian succession at Napton Hill Quarry was famed for its ammonites, and Trueman (1919) recorded a series of distinct faunas. The lowest of these, described as 'Beds with *Tragophylloceras ibex*' succeeded by 'Beds with *Acanthopleuroceras valdani*', correspond to the Valdani Subzone of the Ibex Zone. Above this a succession of 'capricorn' and 'involute' liparoceratids suggests the presence of higher parts of the Valdani Subzone and the succeeding Luridum Subzone. No thickness or lithological information was cited in Trueman's (1919) account of the ammonite succession, while Callomon (in Hallam, 1968) did not recover any ammonites from more than 12 m of clay below Bed 6. Hence it remains unclear if the Ibex Zone faunas described by Trueman (1919) came from beds 1–5 of the Charmouth Mudstone Formation, described by Callomon (in Hallam, 1968), or were from a lower stratigraphical level that was no longer exposed when Callomon visited the site. It is even possible that Trueman's Ibex Zone material came from other localities in the area.

The succession at Napton Hill Quarry presents interesting comparisons with other inland sites at a similar stratigraphical level. For example, the calcareous sandstone of Bed 33 within the Dyrham Formation at Napton Hill Quarry, of proven Subnodosus Subzone age, may represent a correlative of the Subnodosus Sandstone Bed of the Severn Basin (Simms, 1990a), which occurs at a similar depth below the Marlstone Rock Formation. The Marlstone Rock Formation itself is markedly less oolitic at Napton Hill Quarry than at the **Neithrop Fields Cutting** GCR site, 20 km to the south. The ooliths at Napton Hill occur only in patches suggesting that the site lay outside of the main chamositic oolite shoals and that ooliths were transported to the area only during storm events.

The Upper Pliensbachian at Napton Hill Quarry is 25.88 m thick (Old *et al.*, 1987), similar to that at Robin's Wood Hill Quarry where it is 28.42 m thick. This is in marked contrast to the Lower Pliensbachian, where correlative units at Napton Hill appear to be much thinner. The Figulinum Subzone is estimated to be 6.33 m thick at Robin's Wood Hill and 3.81 m thick at Napton Hill Quarry, with corresponding figures for the Capricornus Subzone being 11.18 m and 9.13 m respectively. However, it has been suggested that more than 11 m of the Upper Pliensbachian Dyrham Formation may have been removed by erosion at Robin's Wood Hill Quarry prior to deposition of the Marlstone Rock Formation (Palmer, 1971; Simms, 1990a). Hence the original thickness of the Upper Pliensbachian succession at Robin's Wood Hill Quarry may have been close to 40 m, a figure broadly in line with that for other sites in the Severn Basin, such as Bredon Hill where it reaches 41.2 m in thickness (Whittaker and Ivimey Cook, 1972). The Upper Pliensbachian succession at Napton Hill may also contain hiatuses, with the sharp contact between beds 28 and 29 perhaps being the best indication of this (J.C. Callomon, pers. comm.). The current evidence indicates only that the thickness of the Upper Pliensbachian, as for the Lower Pliensbachian, is significantly greater in the Severn Basin that at Napton Hill Quarry.

Within the Lower Pliensbachian succession nodule bands are frequent both at Napton Hill Quarry and at the Robin's Wood Hill Quarry GCR site. However, the 'Capricornus Sandstone Bed', a prominent maker band at Robin's Wood Hill and elsewhere in the Severn Basin, appears to be absent at Napton Hill. Temporary exposures at SP 455 616, just below the site of the old pit, exposed several metres of silty clay, with *Liparoceras cheltiense*, *Tragophylloceras ibex* and *Acanthopleuroceras valdani*, capped by a coarsely bioclastic *Gyrphaea*-rich muddy limestone. This limestone may be the '85' Marker Member of Horton and Poole (1977) (J. Radley, pers. comm.), which is known to crop out only a few kilometres to the east, although there is no evidence from published accounts for the presence higher in the succession at Napton Hill of the '100' Marker Member.

Although the limestone and sandstone bands in the Dyrham Formation are sometimes richly fossiliferous, the intervening silty mudstones are poorly fossiliferous. Lord (1974) ascribed the scarcity of fossils at most levels to secondary decalcification but correlative strata at the Robin's Wood Hill Quarry and Dorset coast GCR sites, which have an overall lithological similarity, have equally sparse faunas and it is probable that this is due to primary environmental factors rather than post-diagenetic destruction of fossil material.

Conclusions

Napton Hill Quarry is one of very few exposures of the Upper Pliensbachian Middle Lias remaining in inland Britain. It provides a stratigraphical succession invaluable for investigating facies changes, and their implications for palaeogeographical reconstructions, across the Middle Lias outcrop of southern Britain. Lower Pliensbachian sediments formerly exposed at the site yielded a sequence of ammonites that played a critical role in the changing interpretations of the evolution of the Liparoceratidae.

NEITHROP FIELDS CUTTING, OXFORDSHIRE (SP 439 419)

M.J. Simms

Introduction

The Neithrop Fields Cutting GCR site is a former mineral railway cutting (Figure 5.13), which is now a tarmacked path through a residential housing estate. It is the only site on the western edge of the East Midlands Shelf at which parts of the Upper Pliensbachian and Toarcian Middle and Upper Lias are exposed. It provides an outstanding section through the two, allowing the transition between them to be examined.

Although the Marlstone Rock Formation formerly was worked extensively in the Banbury district, either for low-grade ironstone or for building stone, the workings rarely penetrated the base of the formation and the succeeding Whitby Mudstone Formation often was absent through recent erosion. The cutting at Neithrop Fields exposes the full thickness of the Marlstone Rock Formation, almost 10 m of the underlying Dyrham Formation and the lowest 2 m of the overlying Whitby Mudstone Formation (Figure 5.14).

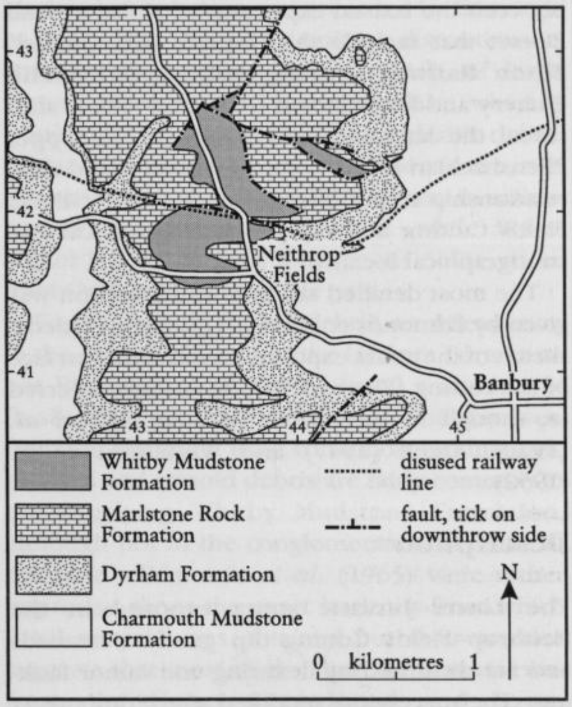

Figure 5.13 Geology and location map for the Neithrop Fields Cutting GCR site.

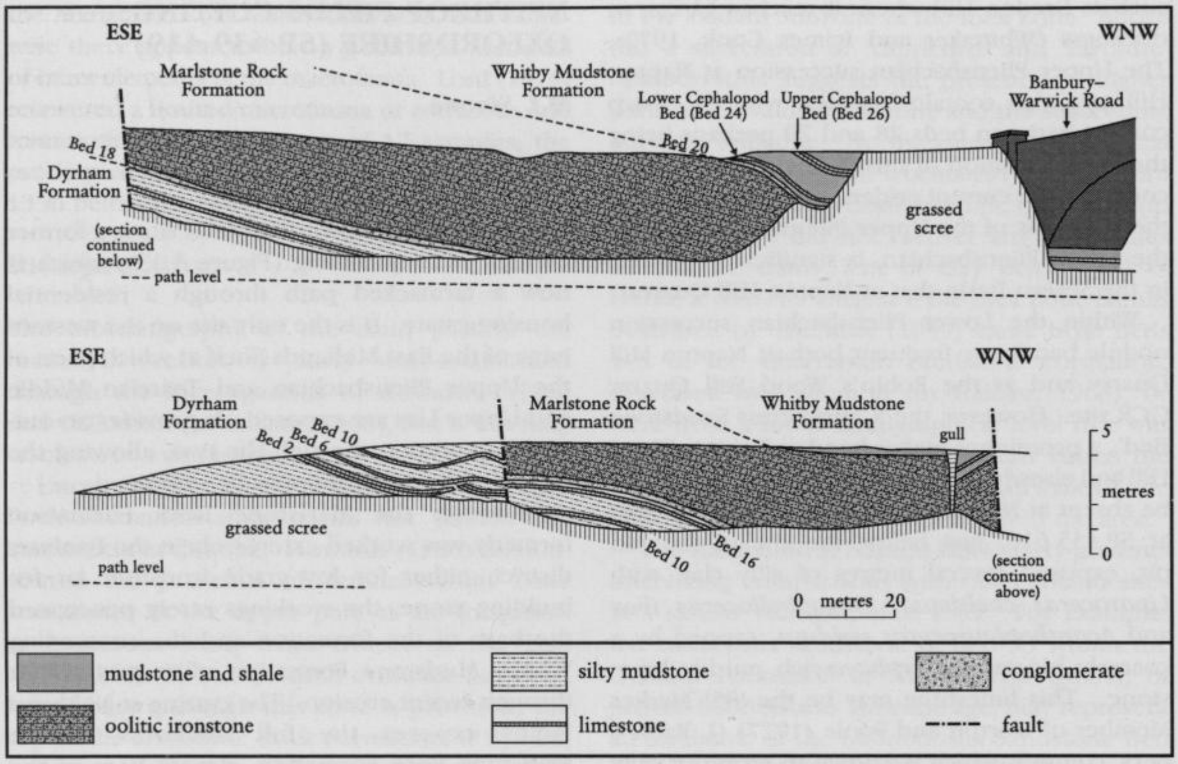

Figure 5.14 The section at Neithrop Fields Cutting. After Edmonds et *al.* (1965).

This GCR site is one of a series of inland sites between the coastal exposures of Yorkshire and Dorset that include the **Napton Hill Quarry**, **Tilton Railway Cutting**, **Robin's Wood Hill Quarry** and **Maes Down** GCR sites. These sites reveal the lateral facies changes in the Upper Pliensbachian and Toarcian succession and their relationship to underlying structures. Neithrop Fields Cutting is a key palaeogeographical and stratigraphical locality.

The most detailed account of the section was given by Edmonds *et al.* (1965), who provided a sketch of the strata exposed on the southern face of the cutting (Figure 5.14). It was also referred to, though in less detail, by Lamplugh *et al.* (1920), Arkell (1947) and Whitehead *et al.* (1952).

Description

The Lower Jurassic strata exposed in the Neithrop Fields Cutting dip gently westwards and are disturbed by flexuring and minor faulting. The succession, modified after Edmonds *et al.* (1965), is as follows.

		Thickness (m)
Whitby Mudstone Formation		
28:	Shale, grey.	0.30
27:	Oolite, thinly bedded, ferruginous.	0.20
26:	**Upper Cephalopod Bed**: Oolite, greyish-blue, often ferruginous, ammonites; *Harpoceras* cf. *falciferum* and *Zugodactylites* cf. *braunianus* recorded by Arkell (1947).	0.30
25:	Clay, calcareous, shaly, with ammonites near top.	0.60
24:	**Lower Cephalopod Bed**: Limestone, fine grained, with ammonites and calcite veining; *Harpoceras falciferum*, *Dactylioceras athleticum*, *D. gracile*, *Hildoceras* sp. and *Trachylytoceras* sp.	0.20
23:	Clay.	0.23
22:	Clay, oxidized, ferruginous.	0.02
21:	Limestone, pale, discontinuous, sideritic.	to 0.08
20:	Conglomerate, discontinuous, with large flattened and rounded limestone clasts.	to 0.05
Marlstone Rock Formation		
19:	Oolite, calcitic and sideritic or chamositic, in discontinuous beds, alternating with weathered limonitic horizons. Abundant bioclastic debris. *Lobothyris punctata*, *L. edwardsi*, *Tetrarhynchia tetrahedra*, *Rudirhynchia* cf. *huntcliffensis*, *Gibbirhynchia* sp., *Zeilleria* sp., ?*Spiriferina*,	

		Thickness (m)
	Camptonectes cf. *mundus*, *Chlamys* cf. *julianus*, *Oxytoma inequivalvis*, *Pleuromya costata*, *Pseudopecten* sp., *Liostrea* sp., *Balanocrinus donovani* and belemnites.	4.3
18:	Conglomerate, ferruginous, with oysters above.	0.22
Dyrham Formation		
17:	Mudstone, silty, micaceous.	0.15
16:	Limestone, thinly bedded, shelly, ferruginous, with ironstone nodules.	0.15
15:	Shell band, ferruginous, earthy.	0.10
14:	Mudstone, limonitic, silty.	0.25
13:	Mudstone, rather ferruginous, silty, micaceous.	0.13
12:	Mudstone, silty, micaceous, with ferruginous layers and nodules.	0.93
11:	Clay, grey, silty.	0.15
10:	Limestone, bluish-grey, coarsely bioclastic.	0.15
9:	Mudstone, sandy and silty, calcareous, micaceous.	0.72
8:	Mudstone, micaceous, silty.	0.08
7:	Shelly ferruginous band with ironstone nodules.	0.20
6:	Limestone, bluish-grey, locally ferruginous.	0.15
5:	Mudstone, ferruginous, shelly, micaceous, with ironstone nodules at top.	0.20
4:	Limestone, shelly, ferruginous. *Amaltheus* sp..	0.08
3:	Clay, discontinous, micaceous, silty.	0.01
2:	Limestone, fine, massive, with calcite veins.	0.82
1:	Shale and mudstone, micaceous, with ferruginous bands and limestone and ironstone nodules.	5.5

The Dyrham Formation comprises about 10 m of micaceous, silty, and sometimes sandy, mudstone. Limestone and ferruginous bands, often rich in shell debris, occur at several horizons, particularly in the upper part of the section. Most are no more than 0.15 m thick but a finer, more massive limestone (Bed 2) reaches 0.8 m in thickness and is a useful marker horizon. Elsewhere, limestone and ironstone nodules occur scattered through the section or are concentrated at particular levels. Eastwards from the main cutting, discontinuous exposures of brownish, silty, micaceous shale were reported by Edmonds *et al*. (1965) to pass into grey micaceous Lower Lias clays. Lamplugh *et al*. (1920) stated that only 40 feet (12.3 m) of Middle Lias was present below the Marlstone Rock Formation.

The Marlstone Rock Formation here is 4.75 m thick and is dominated by calcareous chamositic and sideritic oolite, in places deeply weathered to limonite. The ooliths may be scattered or concentrated in patches or clusters. Other elements of the Marlstone Rock Formation include shell fragments, crystals of chamosite and siderite, and ferruginous mud pellets similar in size to the ooliths. In unweathered samples the whole may be set in a matrix of sideritic ferruginous mud or calcite cement. Weathering leaches out the carbonate component of the Marlstone Rock Formation, concentrating the iron as the hydrated oxide limonite. Although Edmonds *et al*. (1965) divided the Marlstone Rock Formation into 13 distinct units, these show great lateral variation and few can be traced any distance. Cross-bedding is common throughout the formation and impersistent lenses of shelly calcareous limestone commonly replace the dominant ferruginous oolite facies. The basal unit here comprises a 0.22 m-thick ferruginous conglomerate that can be traced over much of the Banbury area. Clasts within the conglomerate are well-rounded fragments of ironstone and phosphatic mudstone together with eroded belemnites and other fossil debris. The clasts are embedded in an ironstone matrix rich in quartz grains. Encrusting bivalves are recorded from immediately above the conglomerate (Edmonds *et al*., 1965).

Only about 2 m of the succeeding Whitby Mudstone Formation was recorded by Edmonds *et al*. (1965). The lowest unit is a discontinuous conglomerate, up to 0.05 m thick, of large flattened and rounded limestone clasts, which is overlain by up to 0.08 m of pale sideritic oolite. Within the overlying grey mudstones are two further limestone units. The lower is a fine-grained limestone 0.2 m thick while 0.6 m higher is a 0.5 m-thick ferruginous oolite, more thinly bedded in the upper part.

Fossils, other than shell debris, are uncommon in the silty mudstones of the Dyrham Formation but Edmonds *et al*. (1965) listed a number of fossil taxa, mainly brachiopods and bivalves, from the Marlstone Rock Formation. Ammonites, bivalves and crinoid debris are fairly common in the overlying Whitby Mudstone Formation, although not in the conglomerate and oolite at the base. Edmonds *et al*. (1965) were rather imprecise about the exact horizons from which fossil material was obtained but their account suggests that most of the Toarcian material was from the Upper Cephalopod and Lower Cephalopod beds.

Interpretation

Only one ammonite, *Amaltheus* sp., was recorded from the Dyrham Formation (Bed 4) by Edmonds *et al.* (1965). Although not sufficient to confirm a Margaritatus Zone age for the formation, this age is supported by litho-stratigraphical correlation with other sites in the general area, such as the **Napton Hill Quarry** GCR site 20 km to the north.

Amaltheid ammonites are extremely rare in the Marlstone Rock Formation of the Midlands (Howarth, 1958), and none have been found at the Neithrop Fields Cutting. Other fossils listed by Edmonds *et al.* (1965), particularly some of the brachiopods, indicate a Spinatum Zone age for most, if not all, of this formation (Ager, 1956–1967). Edmonds *et al.* (1965) noted the apparent absence of the so-called 'Transition Bed' (Walford, 1878) from this site despite its wide-spread occurrence at the top of the Marlstone Rock Formation throughout the Banbury region and farther afield in Oxfordshire, Northamptonshire and Leicestershire. Howarth (1980) subsequently demonstrated that the 'Transition Bed' had no stratigraphical significance and was the weathered top of the Marlstone Rock Formation. He also showed that at least the uppermost few centimetres of the Marlstone Rock Formation in the Banbury district lie within the Tenuicostatum Zone of the Toarcian Stage. Since no ammonites have been recorded either from the main body of the Marl-stone Rock Formation or from the conglomerate (Bed 20) and limestone (Bed 21) that immediately succeed it, the placing of the Pliensbachian–Toarcian boundary at the base of the conglomerate (Bed 20) is, essentially, arbitrary.

Edmonds *et al.* (1965) recorded stratigraphically diagnostic ammonites from the Lower and Upper cephalopod beds in the Whitby Mudstone Formation, two prominent limestone marker bands recorded elsewhere in Northamptonshire. The Lower Cephalopod Bed is of Falciferum Subzone age, as are the clays beneath (beds 22 and 23) (Howarth, 1978). The Upper Cephalopod Bed, and the beds above (beds 27 and 28) and immediately below (Bed 25), can be assigned to the Commune Subzone at the base of the Bifrons Zone. The entire Tenuicostatum Zone and the succeeding Exaratum Subzone of the Serpentinum Zone, if present, must lie within the upper part of the Marlstone Rock Formation and the discontinuous conglomerate and limestone units immediately above.

The Dyrham Formation can be compared with the similar sections at the **Napton Hill Quarry** and **Robin's Wood Hill Quarry** GCR sites. The 0.8 m-thick limestone (Bed 2) below the Marlstone Rock Formation at Neithrop may correlate with an impersistent 0.88 m-thick limestone 5.54 m below the Marlstone Rock Formation at Napton Hill Quarry but this is far from certain. The correlative beds at Robin's Wood Hill Quarry, which lies towards the centre of the Severn Basin, are siltstone-dominated in contrast to the slightly sandier sequences seen at Neithrop Fields Cutting and Napton Hill Quarry. The slightly coarser sediments in the Banbury district have been attributed to greater uplift of the London Platform in the Banbury district (Hallam, 1968a).

The Neithrop Fields Cutting GCR site is of importance in exposing a complete section through the Marlstone Rock Formation in fairly typical 'Banbury Ironstone' facies of chamositic oolite with minimal detrital clastics. Hallam (1967a) attributed the accumulation of the oolitic ironstones in this area to deposition in fairly shallow-water on a submarine 'high' separated from terrigenous input by a deeper 'clastic trap'. However, it is equally important as one of a series of inland sites which together demonstrate lateral facies changes along the outcrop in this part of the Lower Jurassic sequence. The Marlstone Rock Formation shows considerable variation in facies and thickness both to the south-west and north-east of the Banbury region. In the Cotswold Hills to the south-west it is typically a relatively thin oolitic, often ferruginous, bioclastic limestone. In its thicker development towards the centre of the Severn Basin it may contain a significant sandstone component as on Bredon Hill (Whittaker and Ivimey-Cook, 1972). To the north of the Banbury region the ironstone facies thins and becomes less chamositic while the lower part of the Marlstone Rock Formation is developed as a sandstone. Both units are well exposed at the **Napton Hill Quarry** GCR site. The Marlstone Rock Formation thickens again into an oolitic ironstone as it passes onto the East Midlands Shelf in north-east Leicestershire and southern Lincolnshire, but thins once more to the north and disappears entirely near Lincoln as the Market Weighton Block is approached.

The development of the thick ironstone facies in both the Neithrop Fields Cutting and **Tilton**

Railway Cutting areas may reflect the presence of local structurally controlled highs during this interval, leading to clastic starvation and the accumulation of ironstones. The main difference between the Marlstone Rock Formation exposed at Neithrop Fields Cutting and that at Tilton Railway Cutting, in the Leicestershire Ironstone Field, is that the Tilton Sandrock Member underlies the main oolitic ironstone facies, the Banbury Ironstone Member, at the latter locality (Howarth, 1980). However, there is no firm basis for assuming a direct correlation between the Tilton Sandrock Member and the lower part of the Banbury Ironstone Member and correlation instead with the sandy, upper part of the Dyrham Formation beneath the Marlstone Rock Formation at Neithrop Fields Cutting may be more appropriate.

The Whitby Mudstone Formation exposed at Neithrop Fields Cutting provides an important comparative section to that at Tilton Railway Cutting, more than 60 km to the north-east. At the latter site, Exaratum Subzone strata are at least 1.5 m thick and the preceding Tenuicostatum Zone is represented in at least the upper 0.9 m of the Marlstone Rock Formation. These two zones are unproven at Neithrop Fields Cutting, but Howarth (1978) showed that a few kilometres north-east of Neithrop the Exaratum Subzone is represented by 1 m of sediment and the Tenuicostatum Zone occupies almost the top 1 m of the Marlstone Rock Formation. As with the sandy facies of the Dyrham Formation near the base of the section, the localized condensation of the basal part of the Whitby Mudstone Formation at Neithrop Fields Cutting may also reflect slightly greater uplift in this area of the London Platform.

Conclusions

The importance of the Neithrop Fields Cutting lies primarily in exposing a complete section through the thick, oolitic ironstone facies of the Marlstone Rock Formation. This is developed over a considerable area around Banbury on the north-western margin of the London Platform but, although widely exploited as an ore of iron, the quarries rarely exposed the base and none are now working. It is one of a series of inland sites that together demonstrate the substantial facies changes shown by the Upper Pliensbachian succession in passing along the Jurassic outcrop between the Dorset and Yorkshire coasts. As such, it is of critical importance for any interpretation of early Jurassic palaeogeography and basin development. The Whitby Mudstone Formation above the Marlstone Rock Formation provides one of the only exposures of this part of the Lias succession in this area.

TILTON RAILWAY CUTTING, LEICESTERSHIRE (SK 763 053)

M.J. Simms

Introduction

The Tilton Railway Cutting GCR site is a key geological site of national importance. The section here goes through the Pliensbachian–Toarcian boundary, and the site exposes a section through the full thickness of the Marlstone Rock Formation and parts of the underlying Dyrham Formation and overlying Whitby Mudstone Formation (Figures 5.15 and 5.16). It encompasses the only remaining exposure of the 'Transition Bed' at the top of

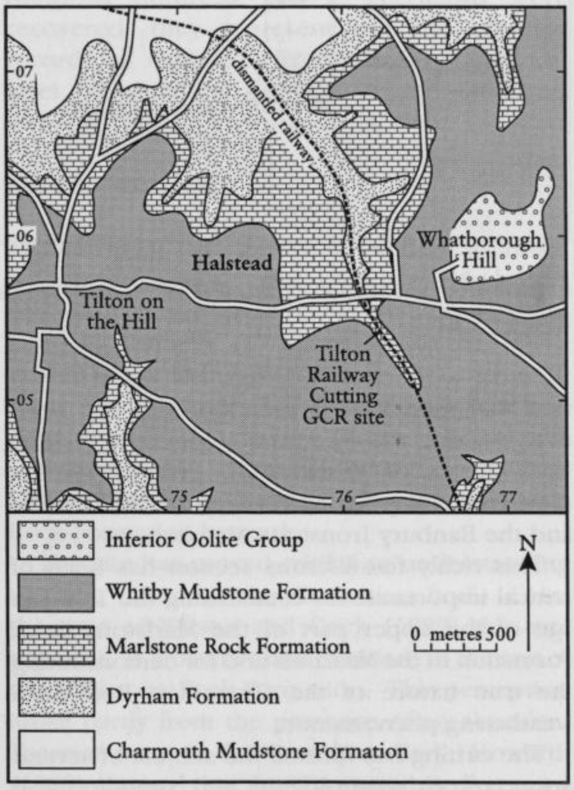

Figure 5.15 Geology and location map of the Tilton Railway Cutting GCR site.

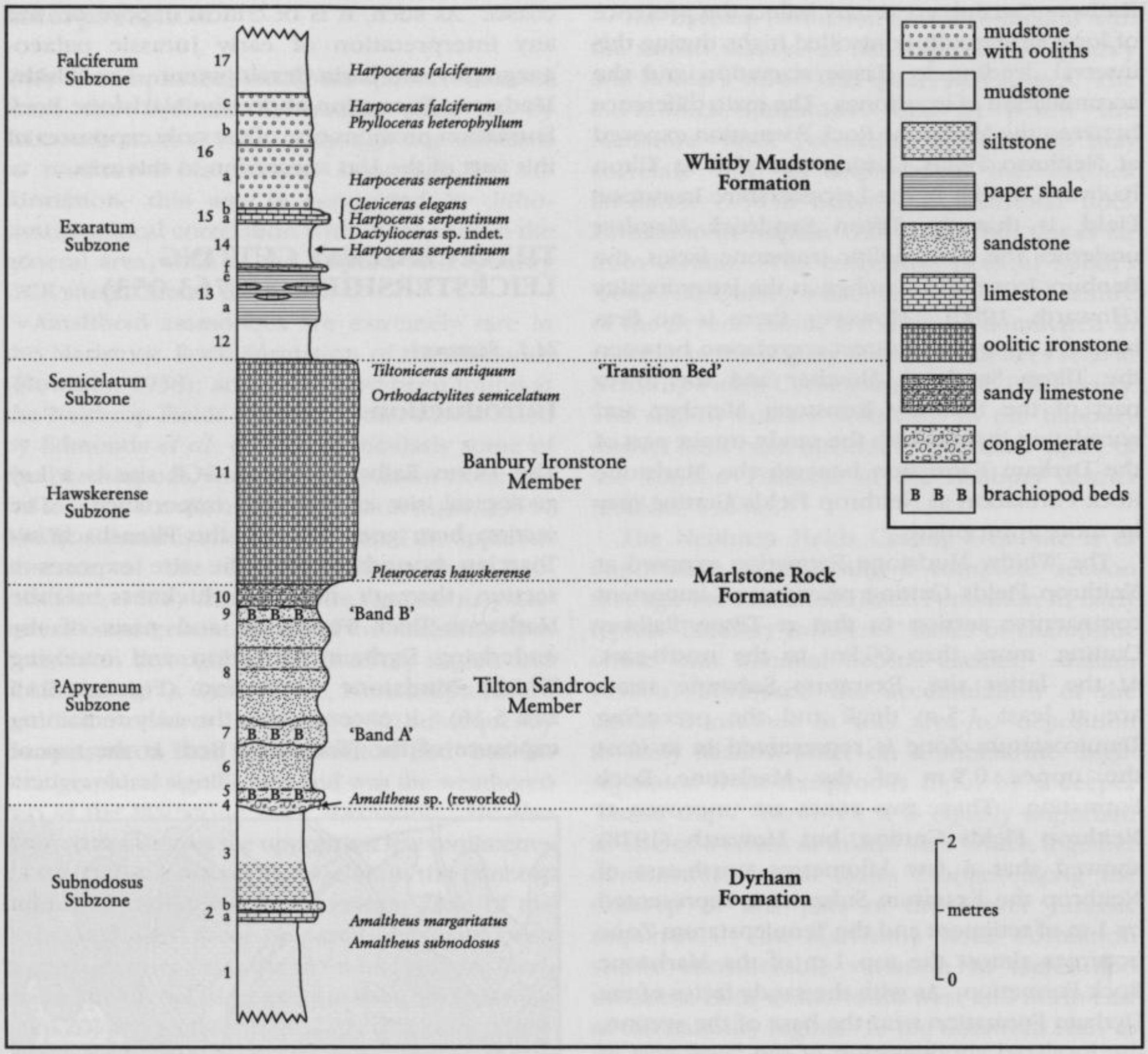

Figure 5.16 The section exposed at Tilton Railway Cutting. After Roy Clements, unpublished, reproduced with permission.

the Marlstone Rock Formation, and has been designated as the type locality for the Marlstone Rock Formation (Cox *et al*, 1999), which is represented here by the Tilton Sandrock Member and the Banbury Ironstone Member.

This richly fossiliferous section has been of critical importance for establishing the Toarcian age of the upper part of the Marlstone Rock Formation in the Midlands and for demonstrating the true nature of the 'Transition Bed' as a weathering phenomenon.

The cutting has formed the subject of several important palaeontological and stratigraphical publications. It was described by Wilson and Crick (1889) soon after it had been excavated; their description included two new species from the site. Fox-Strangways (1903) published a photograph of the section taken at about the same time. It was mentioned briefly by Woodward (1893) and Whitehead *et al.* (1952). The section was described in detail by Hallam (1955), who discussed the succession and the palaeoecology of various brachiopod species within it (Hallam, 1962b, 1968a). The site also figured significantly in Hallam's (1967a) analysis of the Pliensbachian–Toarcian boundary beds, while observations of the Whitby Mudstone Formation here were incorporated in Wignall's (1991) model for the environment of deposition of transgressive black shales. The site has yield a rich and diverse invertebrate fauna. A new species of brachiopod, *Gibbirhynchia tiltonensis*, was described from the site by Ager (1954), who also discussed the palaeogeographical significance of the Tilton brachiopod fauna (Ager, 1956a). Lord (1974) investigated the site's microfauna, but recovered only a few poorly preserved ostracods from the Tilton Sandrock Member. The ammonite fauna and its stratigraphical significance has been the focus of the most recent publications, by Howarth (1980, 1992). The site gives its name to the Toarcian ammonite genus *Tiltoniceras*, which occurs abundantly in the top of the Marlstone Rock Formation, although the lectotype itself is from the Yorkshire coast (Howarth, 1992).

Description

The lowest part of the succession is exposed at the northern end of the cutting, with higher beds descending with the gentle southerly dip of the strata and the southward rise of the cutting floor. Beds 1 to 3, assigned to the Dyrham Formation, comprise about 2 m of silty mudstones with a 0.25 m-thick bipartite sandstone and limestone bed. This part of the succession has yielded *Amaltheus subnodosus* and *A. margaritatus*.

There is a clear contact characterized by erosion between the Dyrham Formation and the overlying Marlstone Rock Formation, with reworked pebbles, containing *Amaltheus* sp. (R.G. Clements, pers. comm.) incorporated into the lowest unit (Bed 4) of the latter formation.

A broad two-fold division of the Marlstone Rock Formation can be recognized in the East Midlands, into an upper ironstone unit, here termed the 'Banbury Ironstone Member', and a lower sandstone unit, often referred to as the 'Sandrock' and here termed the 'Tilton Sandrock Member'. Hallam (1955) identified two biofacies within the Banbury Ironstone Member itself, each characterized by a distinctive brachiopod fauna. The lower of these, Hallam's 'Band B', is dominated by *Tetrarhynchia tetrahedra* and *Lobothyris punctata*. These taxa become rare in the upper biofacies in the top 0.9 m of the Marlstone Rock Formation, which instead is dominated by *Gibbirhynchia northamptonensis* and *Zeilleria subdigona*. Both are also present in smaller numbers in the lower biofacies unit but the upper unit is distinguished by the first appearance of *Gibbirhynchia tiltonensis*.

The 'Transition Bed' at the top of the Marlstone Rock Formation has been described as a pale-brown or cream, finely oolitic limestone, sometimes flaggy and sometimes passing up into sandy marl. It varies from 0.01 m to 0.25 m in thickness and gives the impression of resting non-sequentially on an irregular surface developed on the dark-green oolitic ironstone beneath, with the boundary often marked by an undulating thin sheet of limonite. Specimens of *Tiltoniceras antiquum*, *Dactylioceras semicelatum* and *Gibbirhynchia tiltonensis* are common in the top 0.2 m, together with many small gastropods and other fossils. A full list of fossils found in the Marlstone Rock Formation was published by Wilson and Crick (1889) and included two new species; the bivalve *Pinna tiltonensis* and the echinoid *Eodiadema granulata*.

Lord's (1974) investigation of the microfauna proved the lowest paper shales of the Whitby Mudstone Formation exposed nearby to be barren, though ostracods were recovered from the Tilton Sandrock Member. Most were heavily encrusted with quartz grains and many were unidentifiable, though examples of *Trachycythere tubulosa tubulosa* and *T. verrucosa* were recovered; they represent one of very few records of ostracods from this stratigraphical level (assumed by Lord to be the Spinatum Zone, but see 'Interpretation' below).

Interpretation

At the top of the succession exposed at Tilton Railway Cutting, the Whitby Mudstone Formation lies entirely within the Serpentinum Zone. Howarth (1980) assigned the lower 2.80 m to the Exaratum Subzone but concluded, from the absence of *Cleviceras exaratum* itself, that the lower part of the subzone was represented by a non-sequence between the Whitby Mudstone Formation and the Marlstone Rock Formation beneath.

The site has proved critical to understanding the true nature of the 'Transition Bed'. From the time of Wilson and Crick (1889) this was regarded as a distinct unit 'welded' to the top of the Marlstone Rock Formation. This perception arose partly from the presence of an abundant Toarcian fauna in the 'Transition Bed'. Howarth (1980) showed that the 'Transition Bed' is not a separate unit but is merely the weathered top of the Marlstone Rock Formation, in which the chamosite and siderite of the oolitic ironstone have been weathered to limonite. Where it has been partly decalcified it assumes a friable granular texture. The Toarcian fauna is not confined to the 'Transition Bed' but extends into the unweathered ironstone beneath. Howarth (1980) even observed vertically embedded ammonites that cross the boundary between the 'Transition Bed' and the ironstone beneath, establishing unequivocally that the supposed non-sequence is no more than a weathering front.

Howarth's (1980) observations at Tilton, and at other locations along the outcrop of the Marlstone Rock Formation, showed that the upper part of the formation was of Toarcian age. At Tilton only the Semicelatum Subzone, the uppermost subzone of the Tenuicostatum Zone, has been proven for the top 0.9 m. No evidence has been found for the lower three subzones. *Pleuroceras* cf. *hawskerense*, indicative of the underlying Hawskerense Zone, has been found 3.0 m below the top of the Marlstone Rock Formation and hence it is possible that part or all of the remainder of the Tenuicostatum Zone is represented in the intervening 2.1 m. However, amaltheid ammonites are rare in the Marlstone Rock Formation of the Midlands (Howarth, 1958) and hence it can only be assumed that the lower part of the formation here may lie entirely within the Spinatum Zone. Howarth (1958) concluded that the Banbury Ironstone Member corresponded broadly with the Hawskerense Subzone and the Tilton Sandrock Member could be assigned to the Apyrenum Subzone.

The presence of *Amaltheus subnodosus* and *A. margaritatus* indicates that the top of the underlying Dyrham Formation can be assigned to the Subnodosus Subzone (R.G. Clements, pers. comm.). The erosion surface and the presence of pebbles and derived specimens of *Amaltheus* at the top of this unit implies the existence of a non-sequence that cuts out at least the overlying Gibbosus Subzone.

The rich brachiopod and mollusc fauna of the Marlstone Rock Formation at Tilton has been the subject of several palaeoecological and biogeographical publications (Ager, 1956a; Hallam, 1955, 1962b). Hallam (1955) noted that fossil material occurred in two distinct taphonomic settings. In one of these, exemplified by his 'Band A', the brachiopods occur as small densely packed clusters of *Tetrarhynchia tetrahedra* and *Lobothyris punctata* showing little evidence of disarticulation and with many of the shells filled with calcite rather than sediment. They exhibit a wide size-range, suggesting a natural population; Hallam (1962b) considered them to represent life assemblages that grew during periods of reduced current activity. Individual clusters of brachiopods appear to have spread and coalesced, perhaps indicating a longer period of relative quiescence. The other type of shell accumulation, a thanatocoenosis, is exemplified by Hallam's 'Band B' and contains broken and disarticulated shells of bivalves, brachiopods and belemnites. Ager (1956a) recognized a distinctive brachiopod fauna in the Marlstone Rock Formation of the Tilton area and proposed a separate Tilton Subprovince within the wider Midland Province. Like other parts of the Midland Province the fauna is dominated by a super-abundance of *Tetrarhynchia tetrahedra* and *Lobothyris punctata* and an abundance of *Gibbirhynchia northamptonensis* but is distinguished by abundant *Zeilleria subdigona* near the top of the Marlstone Rock Formation. This last species it shares in common with the Spinatum Zone in Yorkshire but it lacks characteristic south-western taxa, such as *Quadratirhynchia* spp. and *Homoeorhynchia acuta*, and hence is distinct from the Banbury Subprovince to the south. Howarth (1958) commented on the remarkable correlation between Ager's brachiopod provinces and the biogeography of the various species of the ammonite *Pleuroceras*. For this group the Midland Province appears to have represented a significant barrier between the faunas of the South-western and Yorkshire provinces, with only a few individuals of *Pleuroceras spinatum* and *P. hawskerense* appearing to have strayed into the region. Ager (1956a) commented on the relatively low diversity of the Tilton brachiopod fauna, despite the abunance of the four species mentioned. This suggests generally adverse conditions for brachiopod colonization and growth, perhaps associated with a mobile and unstable substrate. The life assemblages indicate periods of relatively calm conditions punctuated by episodes of stronger current activity and sediment movement that brought about the death and burial of the brachiopod clusters as well as transporting and breaking up fossil material and creating the prominent cross-bedded units. The same factors that restricted brachiopod diversity in this area may also have prevented the successful establishment of the amaltheid ammonites during ironstone deposition.

As one of only a small number of inland exposures of the Marlstone Rock Formation and contiguous strata, Tilton Railway Cutting provides an important comparative section for other sites to north and south. The Marlstone Rock Formation at the **Neithrop Fields Cutting** GCR site, some 65 km to the south-west, differs from that seen here in being developed entirely in ironstone facies. The succession at the **Napton Hill Quarry** GCR site, 45 km to the south-west, shows greater affinities with that at Tilton since, although the ironstone facies is weakly developed, a 0.5 m-thick sandstone unit occurs in the lower part of the Marlstone Rock Formation. The occurrence of ironstone accumulations at Tilton, as elsewhere in the East Midlands Ironstone Field, indicates the presence of a mechanism for clastic sediment starvation during deposition. The development of ironstone facies may have been associated with local highs on the sea floor, separated from sources of terrigenous sediment by local depocentres. These putative features perhaps reflect the configuration of en-echelon fault-bounded blocks in the underlying basement, with ironstones accumulating on the upthrown crests of these fault blocks and clastics deposited in the downdip troughs. Support for this comes from the general coincidence of the south-western margin of the Midlands Ironstone Field with the Vale of Moreton Anticline, which was known to have been active in Lower Jurassic times (Whittaker, 1972b). Intra-Liassic movement on some of these basement faults may have shifted the location of local depocentres over time and perhaps accounts for the upward transition from sandstone to ironstone facies in parts of the ironstone field.

Conclusions

The exposure of the Marlstone Rock Formation and contiguous strata at Tilton Railway Cutting is the finest remaining in the Leicestershire Ironstone Field, exposing both the ironstone and sandstone facies. It is a vital link in a small series of inland sites that establish the distribution and nature of regional variations in Upper Pliensbachian times between the coastal exposures of Dorset and Yorkshire. Observations made here have proved critical to understanding the true nature of the 'Transition Bed' and in establishing the Toarcian age of the upper part of the Marlstone Rock Formation in the Midlands. The rich brachiopod fauna has formed the subject of important palaeoecological and biogeographical investigations. Several invertebrate species were first described from this site, which also lends its name to the basal Toarcian ammonite *Tiltoniceras*.