British Lower Jurassic Stratigraphy

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Chapter 6

The Cleveland Basin

INTRODUCTION

M.J. Simms

The Cleveland Basin is a relatively small sedimentary basin located in the north-east of England. Separated from the East Midlands Shelf by the Market Weighton High, it lies on the western edge of the extensive (Anglo–Dutch) North Sea Basin complex that underlies much of the southern North Sea (Gatcliff *et al.*, 1994). The Lower Jurassic part of the succession attains a thickness of more than 450 m in the north-east of the onshore part of the basin and is variously exposed in cliffs and foreshore along some 50 km of coast between Redcar in the north-west and Ravenscar in the south-east (Figure 6.1). In the offshore area, the Lower Jurassic successsion thickens dramatically to twice its onshore thickness (Kent, 1980).

With such magnificent and fossiliferous exposures of Lower Jurassic rocks, it is not surprising that the Cleveland Basin was visited and written about by many geologists in the 19th century. However, by comparison with the equivalent succession on the Dorset coast, it was relatively neglected through much of the following century. The first half of the 19th century saw the publication of two important general works on the geology of the Yorkshire coast, by Young and Bird (1822, 2nd edition 1828) and by Phillips (1829, later editions 1835 and 1875). These were followed by similar works by Simpson (1868), by the [British] Geological Survey (Fox-Strangways, 1892) and, most significantly, Tate and Blake's (1876) ***The Yorkshire Lias***. Despite the number of books published on the geology of this stretch of coast, few papers were published in academic journals. Notable among these was the description by Hunton (1836) of the Pliensbachian and Toarcian succession at Boulby Cliff, in which he recorded the bed-by-bed distribution of particular ammonites and effectively pre-empted the work of Oppel (1856–1858) more than 20 years later in recognizing ammonite 'zones'.

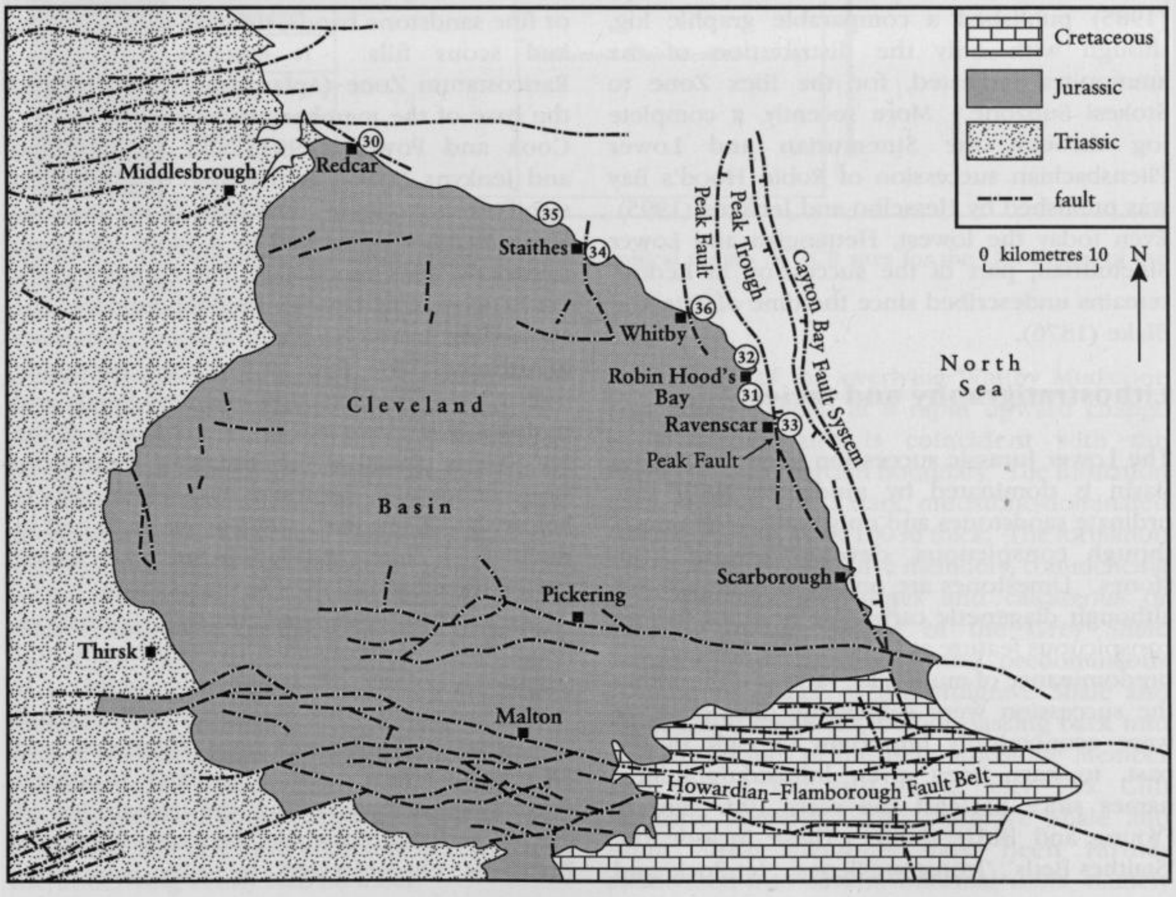

Figure 6.1 Sketch map and structure of the Cleveland Basin. After Rawson and Wright (1992).

The first half of the 20th century saw little published on the Yorkshire Lias, other than a brief summary in Arkell (1933). The Upper Pliensbachian and Toarcian successions were re-described for the first time in some 80 years by Dean (1954) and Howarth (1955, 1962a, 1973) and formed the basis for papers which subsequently investigated the sedimentology, palaeontology and diagenesis of this part of the Lias. However, despite many years of meticulous fieldwork in this area by Leslie Bairstow, new descriptions of lower parts of the Lias Group were not published until well into the second half of the 20th century. None of these match the detailed descriptions of William Lang (Lang, 1914, 1917, 1924, 1932, 1936; Lang *et al.*, 1923, 1928; Lang and Spath, 1926) on the correlative parts of the Dorset coast succession. Only with the posthumous publication of Bairstow's maps and notes by Howarth (2002) has a detailed account of the succession become available. Sellwood (1972) published a summary graphic log and faunal distribution for the Redcar Mudstone Formation from the Oxynotum Zone to the Ibex Zone, and Phelps (1985) published a comparable graphic log, though with only the distribution of the ammonites indicated, for the Ibex Zone to Stokesi Subzone. More recently, a complete log through the Sinemurian and Lower Pliensbachian succession of Robin Hood's Bay was published by Hesselbo and Jenkyns (1995). Even today the lowest, Hettangian and Lower Sinemurian, part of the succession at Redcar, remains undescribed since the time of Tate and Blake (1876).

Lithostratigraphy and facies

The Lower Jurassic succession of the Cleveland Basin is dominated by mudrocks, with subordinate sandstones and only a relatively minor, though conspicuous, development of ironstones. Limestones are only poorly developed, although diagenetic carbonate nodules form a conspicuous feature at some levels. Despite this predominance of mudrocks, various units within the succession were sufficiently distinctive, or were economically important enough in the past, to have been given lithostratigraphical names since at least the early 19th century (Young and Bird, 1822). These include the 'Staithes Beds', 'Ironstone Series', 'Jet Rock' and 'Alum Shales'. These lithostratigraphical names have been formalized by Cox *et al.* (1999), who recognize five distinct formations (Redcar Mudstone, Staithes Sandstone, Cleveland Ironstone, Whitby Mudstone and Blea Wyke Sandstone) in the Lower Jurassic succession (Figure 6.2). All but the Staithes Sandstone Formation are subdivided into two or more members, or smaller informal divisions, with all of these divisions well exposed at one or more of the seven GCR sites within the basin. An abundance of ammonites has long enabled this lithostratigraphical framework to be tied in precisely to the ammonite biostratigraphy for the Lower Jurassic sequence.

The Redcar Mudstone Formation is by far the thickest, at about 250 m, of the five formations and has been subdivided into four members. The lowest of these, the Calcareous Shale Member, is composed predominantly of mudstones with thin, laterally persistent, shell beds. It rests on the Penarth Group (Upper Triassic) and extends up into the Obtusum Zone. The overlying Siliceous Shale Member comprises shales or silty shales with numerous siltstone or fine sandstone bands, thin silt–sand laminae, and scour fills. It extends up to the Raricostatum Zone (Aplanatum Subzone), and the base of the member was placed by Ivimey-Cook and Powell (1991) and by Hesselbo and Jenkyns (1995) at the base of the lowest significant sandstone. The base of the Pyritous Shale Member is marked by a rapid transition to dark pyritous mudstones. This member spans the Raricostatum–Jamesoni zonal boundary. The succeeding Ironstone Shale Member comprises mudstones, with fine silty streaks becoming increasingly abundant upwards, and bands and nodules of sideritic ironstone. The base of the member is placed at the lowest of these ironstone bands and the top is taken immediately below the Oyster Bed, a distinctive shell bed in the Davoei Zone (Maculatum Subzone) which can be traced across the Cleveland Basin.

The overlying Staithes Sandstone Formation, 25 m thick, is dominated by sandstones and siltstones, often of tempestitic facies. It extends up into the Margaritatus Zone and encompasses the Capricornus, Figulinum and Stokesi subzones. The Cleveland Ironstone Formation, encompassing the remainder of the Margaritatus Zone and the entire Spinatum Zone, is characterized by silty mudstone

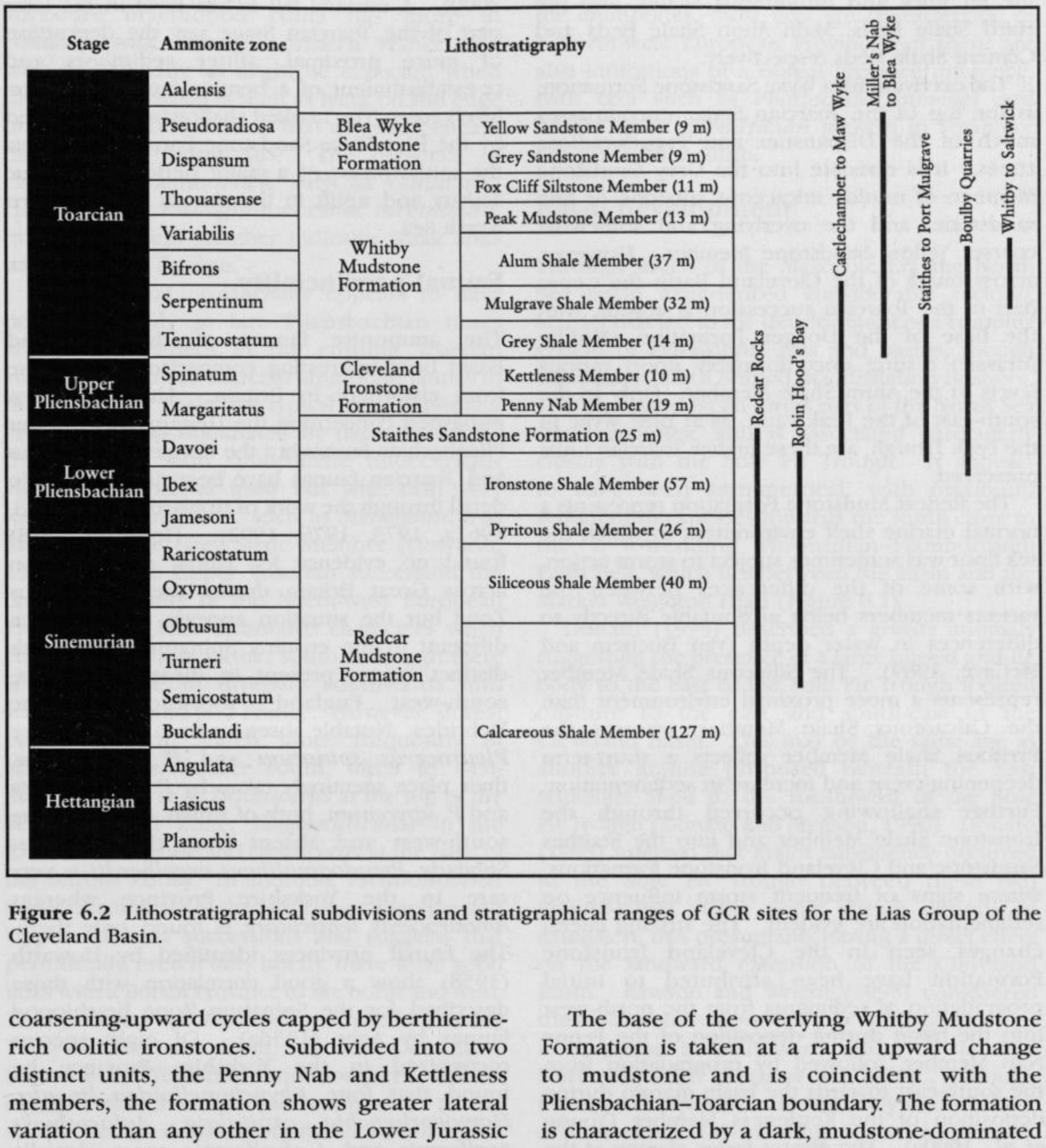

Figure 6.2 Lithostratigraphical subdivisions and stratigraphical ranges of GCR sites for the Lias Group of the Cleveland Basin.

coarsening-upward cycles capped by berthierine-rich oolitic ironstones. Subdivided into two distinct units, the Penny Nab and Kettleness members, the formation shows greater lateral variation than any other in the Lower Jurassic succession of the Cleveland Basin (Young *et al.*, 1990a). The Penny Nab Member comprises up to five ironstone-capped cycles and is coarser, thicker, and more complete in the north-west. An erosion surface, more marked in the south-east, separates it from the overlying Kettleness Member. This shows a striking lateral transition from a well-developed oolitic ironstone in the north-west to interbedded mudstones and sandstones in the south-east, where the member is also thickest and most complete in contrast to the underlying Penny Nab Member.

The base of the overlying Whitby Mudstone Formation is taken at a rapid upward change to mudstone and is coincident with the Pliensbachian–Toarcian boundary. The formation is characterized by a dark, mudstone-dominated sequence, more than 100 m thick. The formation has been divided into five members, commencing with the silty mudstones and calcareous or sideritic nodule bands of the Grey Shale Member, passing through the predominantly bituminous shales of the Mulgrave Shale and Alum Shale members, before passing back into silty mudstones of the Peak Mudstone Member and finally the still more silty Fox Cliff Siltstone Member. The Mulgrave Shale and Alum Shale members have been further subdivided into several informal units, namely the Jet Rock and Bituminous Shales, and the Hard Shale Beds, Main Alum Shale Beds and Cement Shale Beds respectively.

The overlying Blea Wyke Sandstone Formation, at the top of the Toarcian Stage, encompasses much of the Dispansum and Pseudoradiosa zones. It is divisible into the Grey Sandstone Member, of muddy micaceous siltstone or fine sandstone, and the overlying and somewhat coarser Yellow Sandstone Member. However, across much of the Cleveland Basin the upper part of the Toarcian succession is absent, with the base of the Dogger Formation (Middle Jurassic) resting unconformably upon various levels in the Alum Shale Member. Only to the south-east of the Peak Fault, as at Blea Wyke in the Peak Trough, are these higher Toarcian units preserved.

The Redcar Mudstone Formation represents a normal marine shelf environment in which the sea floor was sometimes subject to storm action, with some of the differences between the various members being attributable directly to differences in water depth (van Buchem and McCave, 1989). The Siliceous Shale Member represents a more proximal environment than the Calcareous Shale Member, whereas the Pyritous Shale Member reflects a short-term deepening event and increase in sedimentation. Further shallowing occurred through the Ironstone Shale Member and into the Staithes Sandstone and Cleveland Ironstone formations, where signs of frequent storm influence on sedimentation are evident. The striking lateral changes seen in the Cleveland Ironstone Formation have been attributed to initial progradation of sediments from the north-west into the basin during deposition of the Penny Nab Member, followed by progradation from the south-east towards the basin margin during deposition of the Kettleness Member (Young *et al.*, 1990a). The abrupt facies change at the base of the Whitby Mudstone Formation marks a sudden eustatic rise in sea level (Hallam, 1997) which saw the establishment of very widespread benthic anoxia. This is exemplified by the laminated, organic-rich mudstones of the Mulgrave Shale Member (Wignall, 1991), and precipitated a major extinction event (Little and Benton, 1995; Little, 1996). This anoxic event has recently been attributed to factors, such as climate change and eustatic sea-level rise, associated with flood-basalt volcanism in the Karoo Basin, South Africa (Pálfy and Smith, 2000). A eustatic fall in sea level in the later part of the Toarcian Stage saw the deposition of more proximal, siltier sediments and re-establishment of a benthic fauna as oxygen levels rose. The marked shallowing represented by the Blea Wyke Sandstone Formation reflects the initial phase of a major period of tectonic activity and uplift in the central and northern North Sea.

Faunal provinciality

The ammonite faunas of the Cleveland Basin bear interesting comparison with those from elsewhere in Britain. Little has been published concerning the Hettangian to Lower Plienbachian faunas but the Upper Pliensbachian and Toarcian faunas have been investigated in detail through the work of Howarth (1955, 1958, 1962a, 1973, 1976, 1992). Howarth (1958) found no evidence for faunal differentiation across Great Britain during the Margaritatus Zone but the situation appears to have been different in the ensuing Spinatum Zone, with distinct faunas present in three main areas; south-west England, Yorkshire and the Hebrides. Notable absences from Yorkshire are *Pleuroceras spinatum* and *P. salebrosum*, their place seemingly taken by *P. hawskerense* and *P. apyrenum*, both of which are rare in the south-west and absent from the Hebrides. Similarly, *Pseudoamaltheus engelhardti* is very rare in the Yorkshire Province whereas *Amouroceras lenticulare* is found only there. The faunal provinces identified by Howarth (1958) show a good correlation with those described for the Spinatum Zone brachiopod faunas by Ager (1956a). Of eight species recognized in the Yorkshire Province he found that four, *Rhynchonelloidea lineata*, *Homoeorhynchia capitulata*, *Aulacothyris pyriformis* and *A. fusiformis*, were virtually unknown elsewhere in Britain, as was the *clevelandensis* subspecies of *Lobothyris punctata*. Although some of these species occur occasionally in the northern part of the Midland Province, Ager (1956a) concluded that the Market Weighton High, and the relatively deep-water, mudstone-dominated facies in the southern part of the Cleveland Basin, formed an effective barrier to migration between the two areas. Although there are indications of a link between the Yorkshire and Hebrides provinces in late Pliensbachian times, in general the

Yorkshire brachiopod fauna has more in common with that of northern France and western Germany, as might be expected when the Cleveland Basin is seen as lying on the edge of the Anglo–Dutch Basin that extends beneath the southern North Sea. The presence of rare Tethyan ammonites, such as *Canavaria cultraroi* and *Protogrammoceras turgidulum*, in the Kettleness Member indicates weak links with southern Europe.

This regional provinciality appears to have developed only in late Pliensbachian times and is not evident in the ensuing Toarcian succession. Lower Toarcian ammonite faunas in the Cleveland Basin are typical of a Subboreal Province, being dominated by dactylioceratids, though often with subordinate hildoceratids such as *Hildoceras* itself but with only very rare Tethyan migrants, such as *Meneghiniceras lariense* in the Grey Shale Member (Howarth, 1976). In the Upper Toarcian succession the faunas are firmly of the North-west European Province and lack distinctive characters when compared to those farther south, although there is an increase in diversity southwards into southern England and France. However, Boreal elements occur much more frequently in Yorkshire than farther south, often in well-defined bands (e.g. *Tiltoniceras* at the top of the Tenuicostatum Zone, *Elegantuliceras* in the Exaratum Subzone and *Ovaticeras* at the base of the Bifrons Zone). In addition, *Pseudolioceras* is not uncommon in the late Lower Toarcian and Upper Toarcian successions and suggests that periodically, even if only briefly, there were good links with a Boreal Province to the north and west. The presence of *Frechiella*, a predominantly Tethyan Province form, in the Commune Subzone of Yorkshire and southern Britain suggests that a more open connection to the south was established briefly in mid-Toarcian times, perhaps as a result of eustatic highstand at this time (Hesselbo and Jenkyns, 1998).

Doyle (1987) found evidence for provinciality among Toarcian belemnites, with certain species from Yorkshire, such as *Acrocoelites subgracilis*, being considered characteristic of a Boreal Province while others, such as *Salpingoteuthis trisulcata*, are largely confined in Britain to southern England and hence considered representative of a Tethyan Province. Riding's (1984b) investigation of the Upper Toarcian dinocyst assemblages from Ravenscar also indicated well-developed provinciality. As for the ammonites, most taxa are characteristic of a North-west European Province but there are also indications of a Boreal Province influence, with taxa such as *Phallocysta eumekes* and *Wallodinium cylindricum* present in Yorkshire but not farther south.

Basin development

Through much of the Mesozoic Era the North Sea Basin experienced considerable tectonic activity that led to the development of a complex system of extensional rifts and basins, though these have only a limited manifestation onshore. The Cleveland Basin forms part of the North Sea Basin complex, and is associated particularly closely with the Sole Pit Trough. It appears to have been asymmetrical, with maximum sediment thicknesses towards the south close to the E–W-trending Howardian–Flamborough Fault Belt, which lies between the basin and the Market Weighton High (Figure 6.1).

Donato (1993) described a gravity anomaly suggesting the presence of a large buried granite body to the east of the Sole Pit Trough located offshore to the east and south-east of the Cleveland Basin. This may be the same age as another granite proposed beneath the East Midlands Shelf to the south-west of the Sole Pit Trough (Donato and Megson, 1990). Donato (1993) inferred that major subsidence occurred in the Sole Pit Trough between these two granite-cored stable areas during periods of extension, this presumably having a direct effect on the landward extension of the Cleveland Basin. Rawson and Wright (1995) considered the basin to have developed in late Triassic times in response to southward tilting of the Mid North Sea High (Knox *et al*., 1990). Although the coastal exposures are relatively undisturbed, a number of N–S-trending faults are present. The most significant of these are the Peak Fault, well exposed at the **Miller's Nab to Blea Wyke** GCR site, and the Cayton Bay Fault System to the east. These define a narrow graben, the Peak Trough, about 5 km wide: this can be traced on seismic profiles for some 20–30 km offshore to the north (Milsom and Rawson, 1989). The most complete Toarcian succession in the region is preserved in the Peak Trough. Outside the graben erosion prior to deposition of the Dogger Formation (Middle Jurassic) has cut down to the level of the Alum Shale Member. Milsom and Rawson (1989) considered that fault activity in the Peak Trough began in Triassic times and was renewed during mid-Jurassic times. However, significant thickness and lithostratigraphical differences have also been noted in earlier parts of the Toarcian succession on either side of the Peak Fault (Howarth, 1962a; Gad *et al.*, 1969; Milsom and Rawson, 1989; Doyle, 1990–1992). Although intra-Toarcian subsidence within the Peak Trough might be invoked to account for these differences, and particularly for the preservation of the late Toarcian sediments within the graben, the evidence remains inconclusive. It has also been suggested that these differences are due to, or have at least been accentuated by, up to 8 km of post-Toarcian dextral strike-slip movement on the Peak Fault which has juxtaposed correlative successions originating in different parts of the basin and which experienced different degrees of post-Toarcian erosion (Gad *et al.*, 1969; Hemingway, 1974; Knox *et al.*, 1990). Although Milsom and Rawson (1989) accepted that transcurrent movement on this fault system may have occurred during inversion of the Cleveland Basin, they considered it unlikely that this mechanism alone could account for the observed differences between successions within the basin and beyond it. Inversion of the Cleveland Basin occurred in late Cretaceous or early Tertiary times (Kent, 1980), transforming it into a gentle E–W-orientated pericline. The small dome exposed in the cliffs and foreshore of Robin Hood's Bay is a subsidiary structure within this dome.

Comparison with other areas

The Lower Jurassic succession in the Cleveland Basin provides similarities and contrasts with correlative sequences elsewhere in Britain, reflecting the varying control of climate, sea level and local tectonic influences on sedimentation rates and styles. The area south of the Market Weighton High remained as a stable block throughout early Jurassic times. It effectively separated the Cleveland Basin from the more slowly subsiding East Midlands Shelf to the south. The effects of this are seen most markedly in the Humberside region, where much of the Sinemurian sequence is developed in oolitic ironstone facies, the Frodingham Ironstone Member, in contrast to the siliciclastic sediments at this level in the Cleveland Basin, while substantial parts of the Pliensbachian and Toarcian sequences that are well represented in the Cleveland Basin are absent over a considerable area south of the Market Weighton High (Cope *et al.*, 1980a) (Figure 5.10, Chapter 5). These hiatuses are thought to be due to uplift and erosion, rather than non-deposition (Kent, 1980), but are much less evident in the Cleveland Basin. In the Cleveland Basin the only significant hiatus, other than that which cuts out much of the upper Toarcian succession, is a relatively minor unconformity between the Penny Nab and Kettleness members of the Cleveland Ironstone Formation. Nonetheless, the southward increase in magnitude of this hiatus does suggest that, like the larger hiatuses in Humberside, this too may be attributable to movement on the Market Weighton High.

Farther south on the East Midlands Shelf and in the Severn Basin the succession is again dominated by fine siliciclastic sediments, and hiatuses are greatly reduced in magnitude. Correlatives of the Cleveland Ironstone Formation are represented by other ironstones, especially the Marlstone Rock Formation, which are found towards the top of the Pliensbachian Stage across a large area farther south. These indicate a common control, perhaps representing maximum flooding surfaces associated with eustatic sea-level rise (Hesselbo and Jenkyns, 1998). The strong eustatic signal seen in parts of the Cleveland Basin strata is also evident in correlative sequences across the southern part of the East Midlands Shelf and into the Severn Basin. Hence the coarsening-upward sequence from the Redcar Mudstone Formation into the Staithes Sandstone Formation can broadly be correlated, south of the Market Weighton High, with the transition from the Charmouth Mudstone Formation into the silts and sands of the Dyrham Formation (Cox *et al.*, 1999). Similarly, in the Toarcian Stage the Exaratum Subzone anoxic event represented by the Jet Rock of the Mulgrave Shale Member can be correlated with the paper shales and limestones of the 'Fish Beds' on the East Midlands Shelf (Howarth, 1978) and with a similar facies, the Dumbleton Member, in the Severn Basin (see Chapter 4).

In the Wessex Basin, Hesselbo and Jenkyns (1995) drew comparison between the Yorkshire and Dorset coast successions. On a coarse scale they mostly found close agreement between the facies sequences seen in the two basins, with differences between the two reflecting the more proximal, and generally shallower-water, setting of the Cleveland Basin succession. However, they also noted apparently reciprocal thickness relationships between the two basins in certain parts of the sucession. The most striking of these is seen in comparing the 100+ m of the Whitby Mudstone Formation in the Cleveland Basin with the less than 3 m thickness of its correlative unit, the Beacon Limestone Formation, in the Wessex Basin. They attributed this relationship variously to availability of sediment accommodation space and sediment starvation during periods of changing sea level, although local tectonic factors need also to be considered (Jenkyns and Senior, 1991).

Many similarities can be drawn between parts of the Lower Jurassic succession in the Cleveland Basin and correlative units to the north-west in the Hebrides Basin (Hesselbo *et al*., 1998; Morton and Hudson, 1995). The silty and micaceous shales of the Pabay Shale Formation resemble parts of the Redcar Mudstone Formation whereas the lower part of the Scalpa Sandstone Formation is not dissimilar to the Staithes Sandstone Formation. The anoxic event in the Exaratum Subzone is seen in the Hebrides Basin too, in the dark, organic-rich shales of the Portree Shale Formation, but it is succeeded by an oolitic ironstone, the Raasay Ironstone Formation, which has no analogous facies development farther south.

REDCAR ROCKS, REDCAR AND CLEVELAND (NZ 605 253–NZ 620 253)

K.N. Page

Introduction

The Redcar Rocks GCR site exposes the oldest Jurassic strata seen on the North Yorkshire–Cleveland coast, the Redcar Mudstone Formation, which takes its name from this locality, and the lowest part of the Staithes Sandstone Formation. Redcar Rocks and Coatham Rocks together expose the higher part of the Hettangian Stage, and much of the Lower Sinemurian and parts of the Upper Sinemurian and Lower Pliensbachian substages (Figure 6.3). The lowest part of the Hettangian succession (Planorbis Zone) is not exposed at this site, although it is known to be present inland at Eston, 8 km south-west of Redcar on the eastern outskirts of Middlesborough (Tate and Blake, 1876; Cope *et al*., 1980a). Most of the Upper Sinemurian succession is not exposed, but there are records of loose specimens of that age that have presumably been derived from submarine or sub-beach outcrops. The outcrops expose much of the succession which occurs below the lowest exposures at Robin Hood's Bay (**Normanby Stye Batts–Miller's Nab** GCR site) where the oldest exposures are of Semicostatum Zone age. In addition, although only intermittantly exposed due to beach conditions, the sections yield a good sequence of stratigraphically diagnostic ammonite faunas including some of the best-preserved Semicostatum Zone faunas in Britain. This is the northernmost coastal exposure of Jurassic rocks in England.

The constant movement of beach sand at Redcar Rocks has hindered detailed recording of the sections and there are no modern published measured sections. The only detailed sections were published in Tate and Blake's (1876) classic account of the Yorkshire Lias, subsequently reproduced in Fox-Strangways (1892). Tate and Blake were remarkably thorough in their study, describing how 'our plan of collecting the fossils is to crawl along the scars, during a bright sunny day, in a position so as not to intercept the rays of sunlight – also to wash the fossiliferous shales, as is done for Foraminifera, only that which is retained by the sieve will yield the small molluscan shells'.

The site was also referred to by Wright (1878–1886), Barrow (1888), Blake (1891), Blake *et al*. (1891), Herries (1906a,b), Arkell (1933), and by Wilson *et al*. (1934). Gad (1966), in an unpublished thesis, measured a section across the Hettangian–Sinemurian boundary for a geochemical study, and Getty (in Cope *et al*., 1980a) referred to the Redcar and Coatham rocks sequence based, in part, on his own unpublished records (including sections measured with D.T. Donovan). Powell (1984) established the Redcar Rocks sections as the type locality of the Redcar Mudstone Formation, but did not provide a description of the site. Chemical and gamma-ray analysis of the Hettangian and

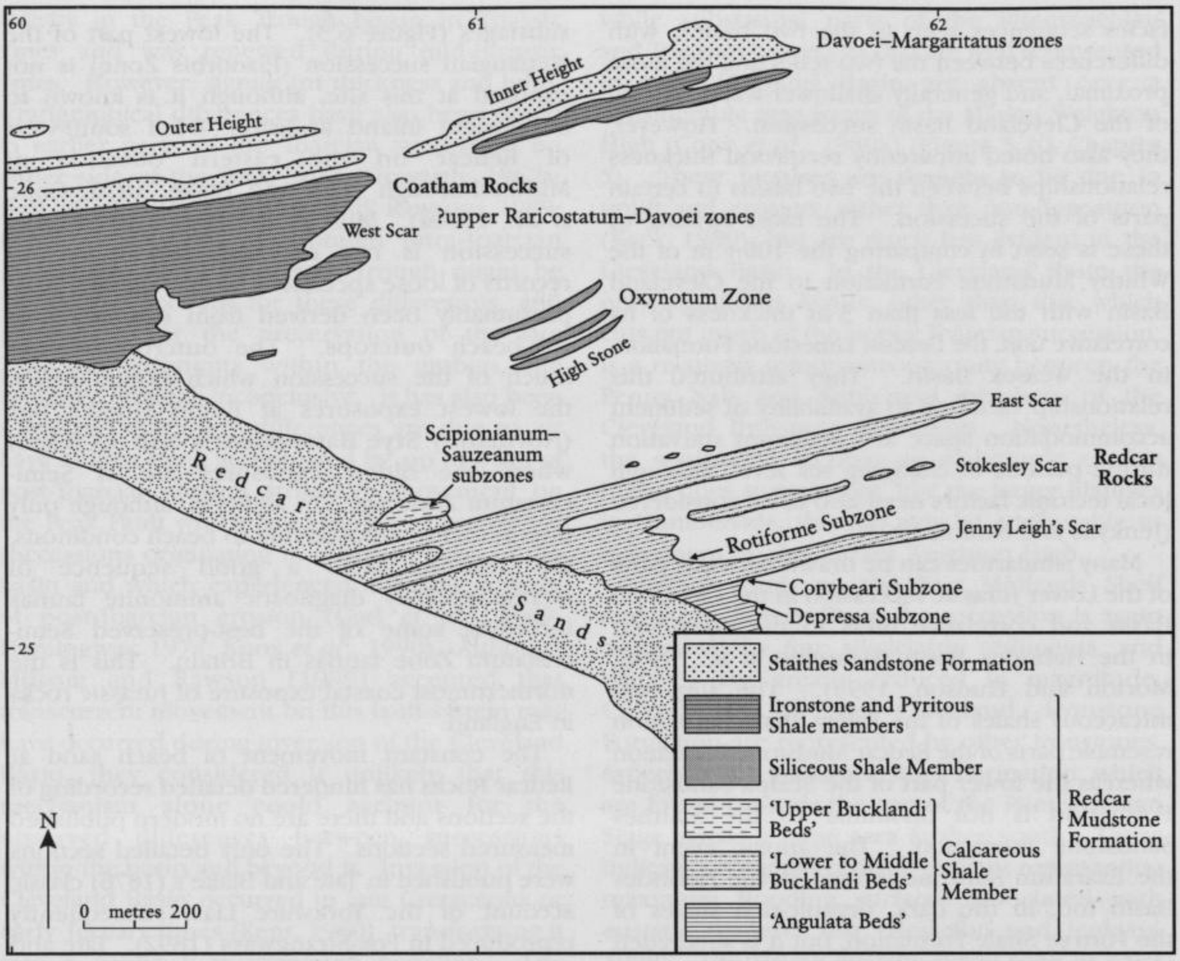

Figure 6.3 Sketch map of Redcar Rocks and Coatham Rocks, showing the location of the named scars and significant ammonite faunas.

Lower Sinemurian part of the succession was undertaken by van Buchem *et al.* (1992). Correlation of the sections is reviewed here based on previous descriptions combined with some new observations, but without a newly measured section.

Description

The only detailed published description of the Redcar Rocks succession is by Tate and Blake (1876). Lord (1971) provided a sketch map of the distribution of part of the Hettangian and Lower Sinemurian succession, and van Buchem *et al.* (1992) published a simplified sketch section and gamma-ray log for essentially the same strata. Herries (1906a,b) noted that the Redcar exposures represent the western limb of a large gentle anticline, with similar strata sometimes exposed on the eastern limb in Marske Bay, some 7 km farther ESE along the coast. Exposures are entirely intertidal and discontinuous (Figure 6.4), with seasonal sand movement often obscuring parts of the succession for long periods of time. The composite section presented here is based on unpublished observations (K.N. Page) and the review of Getty (in Cope *et al.*, 1980a). The lithostratigraphical framework follows Powell (1984), although Tate and Blake's Angulata Beds and Bucklandi Beds, as adopted by Getty (in Cope *et al.*, 1980a), are retained here as informal subdivisions of uncertain status. Thicknesses are taken from Getty (in Cope *et al.*, 1980a), after Tate and Blake (1876).

Figure 6.4 Redcar foreshore after storms have washed away the beach sand, exposing mudrocks of the Redcar Mudstone Formation, Calcareous Shale Member. This area exposes part of the 'Upper Bucklandi Beds' of Tate and Blake (1876), of Scipionianum Subzone to Sauzeanum Subzone age. (Photo: K.N. Page.)

PLIENSBACHIAN STAGE
Staithes Sandstone Formation
Davoei to *Margaritatus zones*
Shales and sandstones, silty, forming the outer part of Coatham Rocks (Inner Height and Outer Height) in the northern part of the site. The fauna includes bivalves (*Oxytoma*, *Pseudopecten*, *Gryphaea*, etc.), belemnites and ammonites (including *Amaltheus* indicating the Margaritatus Zone and *Aegoceras* or *Oistoceras* from the Davoei Zone in the lowest beds of the scar).

?UPPER SINEMURIAN–LOWER PLIENSBACHIAN SUBSTAGES
Redcar Mudstone Formation
Ironstone Shale Member and possibly ***Pyritous Shale Member***
?Raricostatum to *Davoei zones*
Shales with bands of iron-rich (?sideritic) carbonate nodules exposed across West Scar, Coatham Rocks. Ammonite records by the [British] Geological Survey (Sheet 34) and by Getty (in Cope *et al*., 1980a) suggest the presence of the Davoei, Jamesoni, and (?upper) Raricostatum zones.

SINEMURIAN STAGE
Siliceous Shale Member
including *Oxynotum Zone*, *Simpsoni Subzone* and *Obtusum Zone* faunas
Shale, hard, sandy, calcareous, with *Oxynoticeras* and *?Eoderoceras* on High Stone. Oxynotum Zone and possibly early Raricostatum Zone, Densinodulum Subzone. Getty (in Cope *et al*., 1980a) recorded Simpsoni Subzone and Obtusum Zone faunas based on ex-situ specimens, presumably derived from submerged exposures or these reefs.

HETTANGIAN–LOWER SINEMURIAN SUBSTAGES
Calcareous Shale Member
Liasicus to *Semicostatum zones*
'Upper Bucklandi Beds' (beds 1–18) of Tate and Blake (1876): Shale, grey, with silty bands forming low reefs exposed across Redcar Rocks with prominant *Gryphaea*-rich bands in upper part. Van Buchem *et al*. (1992) identified a shelly sandstone with ferruginous ooliths at the base of the Semicostatum Zone, capping a distinct coarsening-upward trend. Page (unpublished observations) has recorded the following sequence of faunas.

	Thickness (m)
Semicostatum Zone, Sauzeanum Subzone	
5: *Euagassiceras* sp..	2
4: *Euagassiceras* sp., *Arnioceras* sp..	2
3: ?*Euagassiceras* sp., ?*Pararnioceras*, *Arnioceras* sp..	2
2: *Euagassiceras* sp. 1, ?*Arnioceras* sp., *Nannobelus* sp..	
Scipionianum Subzone	
1: ?*Agassiceras* sp. (large, crushed, compressed whorled ammonites).	
Grey shale with some bands of calcareous nodules, with at least 3 distinguishable ammonite faunas present (= beds 6? to 10 of Tate and Blake, 1876).	
3: *Agassiceras* sp. (including large crushed specimens).	
2: *Arnioceras* (abundant) and ?*Pararnioceras* sp..	
1: *Agassiceras* sp..	
These levels appear to have yielded *Agassiceras scipionianum*, *A. personatum*, *A.* cf. *decipiens* and *Arnioceras acuticarinatum* according to T.A. Getty (pers. comm.).	
Total thickness for shales and mudstones with Scipionianum and Sauzeanum subzone faunas:	*c.* 15
'Lower and Middle Bucklandi Beds' (beds 11–19): Shales, grey, with sandy and silty bands forming a number of prominent reefs (East Scar, Stokesley Scar and Jenny Leighs Scar) and low subordinate reefs. Some of the harder silty and sandy bands are rich in *Gryphaea*. Ammonites are present at a number of levels, including:	
Lyra Subzone	
5: *Corniceras* cf. *lyra* in the upper part of East Scar (*lyra* Biohorizon). T.A. Getty (pers. comm.) noted that the highest *Coroniceras* is present in Bed 14 of Tate and Blake (1876), with large *Paracoroniceras*, around 1.5 m higher in the succession (probably in Bed 11) – the latter may in fact be the same as the *lyra* fauna noted first.	
?*Bucklandi Zone, Bucklandi Subzone*	
4: *Arnioceras* sp. and a cf. *Arietites* sp. in Stokesley Scar. T.A. Getty (pers. comm.) noted an apparently similar fauna with the addition of *Charmasseiceras*, as also recorded in Tate and Blake (1876).	
Rotiforme Subzone	
3: *Coroniceras* ex grp. *rotiforme* in Jenny Leighs Scar. T.A. Getty (pers. comm.) recorded similar tuberculate *Coroniceras* in beds 57 and 58 of Tate and Blake (1876).	
2: *C. hyatti* common, with some *C.* cf. *rotiforme* in phosphatized nodules assigned to Bed 75 of Tate and Blake (1876) (T.A. Getty pers. comm.).	
Conybeari Subzone	
1: *Metophioceras* spp. in the lowest reef of Jenny Leighs Scar. The genus appears to range up to Bed 31 of Gad (1966) (= Bed 90 of Tate and Blake, 1876; D.T. Donovan, pers. comm.).	
Total for Jenny Leighs scar to East Scar:	*c.* 38
'Angulata Beds' (beds 1–29 of Tate and Blake (1876); or beds 2–31 of Wright 1878–1886): Shales, grey, with some silty bands forming very low reefs and occasional small calcareous nodules; *Gryphaea* present, also occasional levels with ammonites, including:	
3: *Metophioceras* cf. grp. *brevidorsale* in topmost part of shales, in base of Jenny Leighs Scar (*Metophioceras* sp. B Biohorizon or *conybearoides* Biohorizon ?) (= Bed 17 of Gad, 1966 and Bed 1 of Tate and Blake's (1876) Angulatus Beds). According to D.T. Donovan (pers. comm.) there is only an approximate 0.3 m gap between the last Hettangian *Schlotheimia* and the first Sinemurian arietitids.	
HETTANGIAN STAGE	
Angulata Zone, Depressa Subzone	
2: *Schlotheimia* cf. *pseudomoreana* common in a narrow band (?*pseudomoreana* Biohorizon). Specimens resembling *Schlotheimia depressa* itself may also be present close to this level (D.T. Donovan, pers. comm.) although records of *Schlotheimia angulata* (when correctly interpreted, a species of the Extranodosa Subzone) are more ambiguous and require confirmation.	
Liasicus Zone, Laqueus Subzone	
1: *Alsatites liasicus* figured by Wright, 1878–1886. Tate and Blake (1876) recorded '*Ammonites johnstoni*' at Redcar in Leigh Dam Scar, only accessible at low spring tides, but may have mis-identified *Waehneroceras* of the Liasicus Zone (D.T. Donovan, pers. comm., based on a re-examination of specimens in [British] Geological Survey collections).	

There have been no detailed facies analyses of the succession and little documentation of the fauna since the work of Tate and Blake (1876). Wright (1878–1886) figured a specimen of *Alsatites liasicus* from here and several ammonite species were figured by Buckman (1909–1930). Spath (1925d) provided notes on the ammonite faunas of the Hettangian Stage, especially the schlotheimiids, although without any real stratigraphical control. His determinations included *Schlotheimia exeoptycha*, *S.* cf. *complanata*, *S.* cf. *depressa* and 'true' *S. angulata*. Further schlotheimiids are present in the Sinemurian sequence, recorded as *Charmasseiceras* both by

Tate and Blake (1876) and by Spath (1925d). Tate and Blake (1876) also recorded *Microderoceras birchi* from here, indicating the Birchi Subzone.

Tate and Blake (1876) and Wright (1878–1886) gave an extensive list of fossils from the Hettangian–Sinemurian boundary beds, including 44 nominal species of bivalve, 26 gastropods and scaphopods, 3 brachiopods, 3 corals, 4 echinoderms, 6 annelids, a nautiloid, a belemnite and occasional vertebrates, including vertebrae and teeth of ichthyosaurs, plesiosaurs and the fish *Hybodus* and *Acrodus*. The bivalve faunas typically occur in shell beds and seams: Tate and Blake (1876) noted that different bands sometimes contained different assemblages of species. Many bands are dominated by *Gryphaea*, often forming low scars, while others contain *Hippopodium ponderosum* with *Cardinia concinna*, and others have *Lucina limbata* or *Cardinia listeri* with *Unicardium cardioides*. The coral *Montlivaltia guettardi* occurs with *Gryphaea* in one band in the Sinemurian succession, but is also present a little lower in the succession, within the Angulata Zone, in Tate and Blake's Coral Bed (Bed 14) where it is associated with a varied bivalve assemblage and gastropods. Tate and Blake (1876) also recorded the isastreid *Heterastraea excavata*. The Natural History Museum has several intact crowns of *Isocrinus psilonoti* from here, preserved in a dark-grey, micaceous siltstone (Simms, 1989); Tate and Blake (1876) also recorded echinoids which probably can be referred to *Miocidaris lobatum* and *Diademopsis* spp.. Amongst the microfauna, ostracods are recorded from Redcar with 16 species described in Tate and Blake (1876), including *Bairdia redcarensis* and *Cythere redcarensis*, and 13 species in Lord (1971). Tate and Blake (1876) also cited the occurrence of foraminifera and abundant microgastropods in some samples.

Interpretation

Despite the apparently meticulous investigation by Tate and Blake (1876), their description of the section has proved difficult to correlate with that now seen (Lord, 1971). The sequence of ammonite faunas present indicates a remarkably complete Hettangian to Lower Sinemurian succession. Key features include what is probably the best Hettangian–Sinemurian boundary section in northern Britain. The material recorded by Spath (1925d), if correctly determined, suggests that a complete Angulata Zone is present, with evidence of the Extranodosa, Complanata and Depressa subzones. The site also incorporates a virtually unique Scipionianum to Sauzeanum subzone sequence which, once fully documented, will have great potential as a stratigraphical reference section since these two subzones rarely yield well-preserved faunas elsewhere in Britain.

Although higher parts of the succession here are closely similar to those exposed farther south, around Robin Hood's Bay (**Normanby Stye Batts–Miller's Nab** GCR site), precise lithostratigraphical correlation is impossible due to the poor and discontinuous exposures at Redcar Rocks. The lower (mid-Hettangian to Lower Sinemurian) parts of the succession are not seen at Robin Hood's Bay or are exposed only on very low tides, although facies at the two sites would appear, overall, to be broadly similar and dominated by silty mudstones with few limestones. As such this part of the succession at Redcar Rocks, comprising the Redcar Mudstone Formation, contrasts strikingly with correlative sections in basins to the south, such as the exposures of the Blue Lias Formation in Dorset and around the Bristol Channel, and to the north in the Hebrides Basin where a similar Blue Lias Formation facies is developed at this level. However, the presence of ferruginous ooliths near the base of the Semicostatum Zone invites comparison with the succession at the **Conesby Quarry** GCR site, to the south of the Market Weighton High on the East Midlands Shelf. There the Semicostatum Zone coincides with the onset of large-scale oolitic ironstone deposition, in the form of the Frodingham Ironstone Member. The poor development of facies typical of the Blue Lias Formation and the Frodingham Ironstone Member at Redcar Rocks and Robin Hood's Bay, suggests high levels of terrigenous runoff into the Cleveland Basin during Hettangian and Lower Sinemurian times, by comparison with these other basins. This effectively swamped any climatic, tectonic and/or eustatic signal represented by the ironstone and mudstone–limestone facies of the Frodingham Ironstone Member and Blue Lias Formation respectively.

Little detailed interpretation of the benthic fauna is possible in the absence of any precise documentation. Although the bivalve faunas at Redcar Rocks appear typical of clay-rich facies in the early part of the Lower Lias, the relative abundance and diversity of some other elements of the fauna, notably the gastropods and serpulids, is unusual and may reflect factors associated with the atypical facies. The distribution of many taxa, notably the bivalves, indicate significant palaeoecological or taphonomic control on fossil assemblages, but contemporary detailed study is lacking at Redcar Rocks. The presence of intact crinoid material here indicates preservation by obrution and is reminiscent of similar occurrences in the Sinemurian succession at Robin Hood's Bay, while the presence of corals, including isastreids, suggests periods of very low sedimentation and depths well within the photic zone. The abundant microgastropods in some of the samples analysed by Lord (1971) was taken as a tenative indication of a brackish-water influence associated with the proximity of a landmass to the west. However, microgastropods are a common, though poorly documented, element of Lower Jurassic faunas at many sites and there is no evidence here, or elsewhere, that the majority of these microgastropod assemblages are anything other than fully marine.

Conclusions

The mid-Hettangian to Lower Sinemurian succession at Redcar Rocks is remarkably complete and has great potential for further research. Its predominantly fine clastic facies contrasts strikingly with correlative successions in southern Britain and in the Hebrides Basin, where Blue Lias Formation facies of alternating limestone and mudstone are typical. Once fully documented, Redcar Rocks has potential as a key Hettangian–Sinemurian sequence and complements the better-known Robin Hood's Bay succession where the basal Sinemurian and Hettangian stages are not exposed. The Semicostatum Zone sequence, in particular, is one of the best developed anywhere within the North-west European Province.

NORMANBY STYE BATTS–MILLER'S NAB (ROBIN HOOD'S BAY), NORTH YORKSHIRE (NZ 972 025–NZ 952 075)

K.N. Page

Introduction

The cliffs and foreshore of the Normanby Stye Batts–Miller's Nab (Robin Hood's Bay) GCR site (Figure 6.5) expose one of the most important and complete mid-Sinemurian to Pliensbachian sequences in Europe. Several of the lithostratigraphical units of the Cleveland Basin Lower Jurassic succession have type sections in Robin

Figure 6.5 Extensive foreshore exposures of the Redcar Mudstone Formation in Robin Hood's Bay at low tide, viewed from Ravenscar. The concentric disposition of the 'reefs' demonstrates the domed structure of the outcrop here. (Photo: M.J. Simms.)

Hood's Bay; these include the Siliceous Shale, Pyritous Shale and Ironstone Shale members of the Redcar Mudstone Formation (Powell, 1984; Cox *et al.*, 1999). The sections in Robin Hood's Bay have figured prominently in stratigraphical reviews, most importantly as stratotypes for zones, subzones and biohorizons (e.g. Buckman, 1915; Dean *et al.*, 1961; Phelps, 1985; Howarth 1992, 2002; Page, 1992) and in more general accounts of the Cleveland Basin (e.g. in Cope *et al.*, 1980a; Hesselbo and Jenkyns, 1995; Rawson and Wright, 1995). The exposures in the southern part of the bay, at Wine Haven, have been proposed as the Global Stratotype Section and Point (GSSP) for the base of the Pliensbachian Stage (Hesselbo *et al.*, 2000; Meister *et al.*, 2003). Numerous type specimens of stratigraphical indicator species, and other fossils, have also been described, and include the holotype of *Psiloceras erugatum*, the earliest Jurassic ammonite in Europe.

The earliest scientific references to the site are probably those of Young and Bird (1828), describing the Yorkshire coast as a whole, but surprisingly the only detailed published description of the lower part of the section (Sinemurian to Lower Pliensbachian) prior to that of Howarth (2002) was within Tate and Blake's classic work *The Yorkshire Lias* (1876). This was subsequently reproduced many times by later authors such as Fox-Strangways and Barrow (1882) and by Buckman (1915). A further general account, but including an outcrop map of the shore, was published by Herries (1906a,b). Leslie Bairstow spent many years, from at least the 1930s, carefully mapping and measuring the succession on the shore but never published more than the briefest of summaries (e.g. in Sylvester-Bradley, 1953; in Hemingway *et al.*, 1969). The copious notes and specimens he left are now in the Natural History Museum in London and formed the basis of Howarth's (2002) description of the site.

Partial sections were also produced by Gad (1966), Getty (1972), Phelps (1985) and Dommergues and Meister (1992). Hesselbo and Jenkyns (1995) and Howarth (2002) provide complete graphic logs for the succession, but only the latter provides supporting bed-by-bed description. Correlation between the section of Tate and Blake (1876), Hesselbo and Jenkyns (1995) and that compiled by Bairstow has been tabulated by Howarth (2002). Further notes and observations have been incorporated into field excursion guides to the area, such as those by Rawson and Wright (1992, 1995) and Scrutton (1996). The latter includes a useful map of the foreshore outcrops (Figure 6.6) and advice for visitors. Howarth (2002) has published more detailed maps compiled by Bairstow.

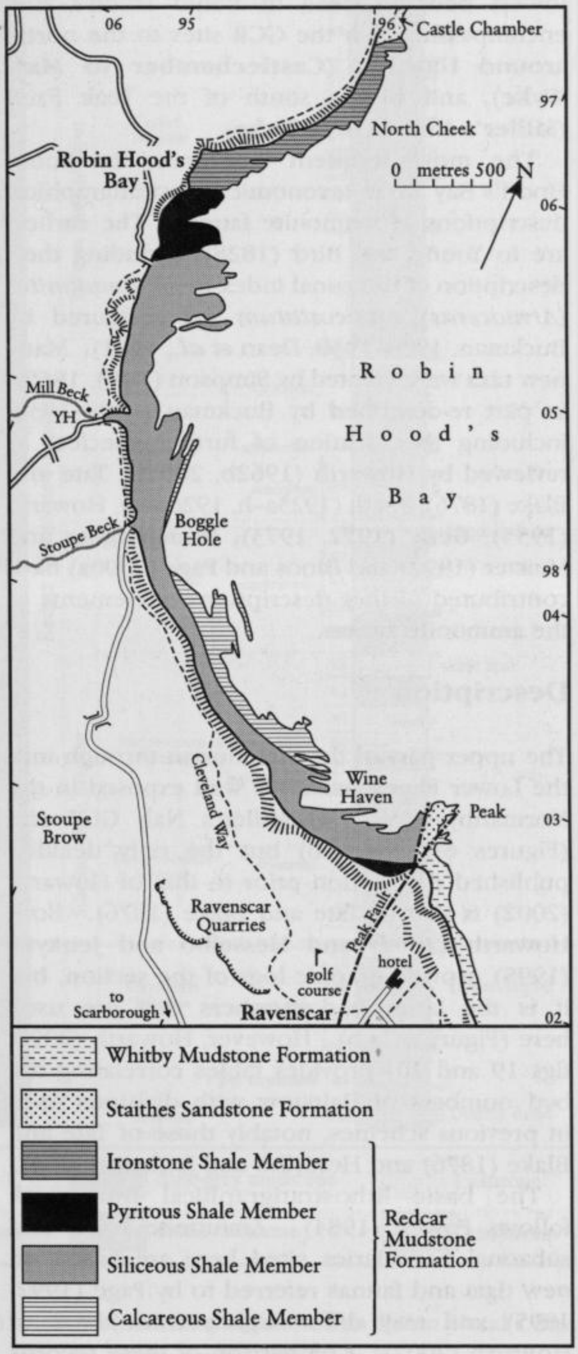

Figure 6.6 Outcrop map of Lower Jurassic strata on the foreshore around Robin Hood's Bay. After Rawson and Wright (1992).

There have been few sedimentological studies of the section, with most concentrated on the Pliensbachian strata (Sellwood, 1970, 1971, 1972; van Buchem and McCave, 1989; Knox *et al.*, 1990). Parkinson (1996) compiled a gamma-ray log at 0.5 m to 1 m intervals through the entire Lower Jurassic succession down to the lowest beds exposed in Robin Hood's Bay, encompassing also the GCR sites to the north, around Hawsker (**Castlechamber to Maw Wyke**), and to the south of the Peak Fault (**Miller's Nab to Blea Wyke**).

The most frequent references to Robin Hood's Bay are in taxonomic and stratigraphical descriptions of ammonite faunas. The earliest are in Young and Bird (1828), including their description of the zonal index fossil, *Ammonites (Arnioceras) semicostatum* (as re-figured by Buckman, 1909–1930; Dean *et al.*, 1961). Many new taxa were created by Simpson (1843, 1855), in part re-described by Buckman (1909–1930; including the creation of further species) as reviewed by Howarth (1962b, 2002). Tate and Blake (1876), Spath (1925a–h, 1926a–d), Howarth (1955), Getty (1972, 1973), Dommergues and Meister (1992) and Bloos and Page (2000a) have contributed further descriptions of elements of the ammonite faunas.

Description

The upper part of the Sinemurian through into the Lower Pliensbachian is well exposed in the Normanby Stye Batts–Miller's Nab GCR site (Figures 6.5 and 6.6) but the only detailed published description prior to that of Howarth (2002) is that of Tate and Blake (1876). Both Howarth (2002) and Hesselbo and Jenkyns (1995) provide graphic logs of the section, but it is the latter bed numbers that are used here (Figure 6.7a,b). However, Howarth (2002, figs 19 and 20) provides tables correlating the bed numbers of Bairstow with divisions used in previous schemes, notably those of Tate and Blake (1876) and Hesselbo and Jenkyns (1995).

The basic lithostratigraphical framework follows Powell (1984). Ammonite zonal and subzonal boundaries cited here are based on new data and faunas referred to by Page (1992, 1995) and may differ slightly from those of Howarth (2002). Comparison of these records with the correlations given by Hesselbo and Jenkyns (1995) and Getty (in Cope *et al.*, 1980a) is not possible as full descriptions have not been published. Preliminary comparisons are, however, now possible with Bairstow's records (e.g. in Hemingway *et al.*, 1969), thanks to the work of Howarth (2002). There remain, however, some discrepancies and differences concerning taxonomic assignments and stratigraphy between the present account and other descriptions. The following summary of the succession therefore incorporates some information from Howarth (2002), in particular in relation to subzonal boundaries, but further re-examination must encompass the correlation of the recorded faunas with the zonal schemes of Page (1992) and Dommergues *et al.* (1994). The following section is a composite section for the Sinemurian and Lower Pliensbachian succession of the Robin Hood's Bay to Castle Chamber area, summarized from Tate and Blake (1876), Howarth (1955, 1973, 1992, 2002), Howard (1985), Phelps (1985), Dommergues and Meister (1992), Hesselbo and Jenkyns (1995) and new observations by K.N. Page between 1990 and 1999. With one or two exceptions, thicknesses are based on the graphic logs of Hesselbo and Jenkyns (1995) and should be considered only approximate. The section is continuous with that described in the **Castlechamber to Maw Wyke** GCR site, which extends up through the Upper Pliensbachian Substage into the Lower Toarcian Substage (Figure 6.6; and see Figure 6.9 – Castlechamber to Maw Wyke GCR site report.).

	Thickness (m)
UPPER PLIENSBACHIAN SUBSTAGE	
Staithes Sandstone Formation	
1–7 (of Howarth, 1955): Shale, sandy, with sandstone band and red calcareous concretions in lower part, with some bands rich in *Gryphaea* and other bivalves. *Amaltheus stokesi* and *A. bifurcus* in Bed 1. Defined base of Stokesi Subzone corresponds to the base of Bed 1 parastratotype (Howarth, 1992).	5.2
LOWER PLIENSBACHIAN SUBSTAGE	
Davoei Zone, Figulinum Subzone, Figulinum Zonule	
62–65 (of Phelps, 1985) (= beds ii–v of Howarth, 1955): Two bands of red calcareous concretions separated by sandy shale and siltstone, with *Oistoceras figulinum*, *O. curvicorne* and a form transitional to *Amaltheus bifurcus* (Phelps, 1985) in the upper band and *O. figulinum* in the lower band.	0.45
Angulatum Zonule	
59–61 (= Bed i): Sandstone, hard, ferruginous, forming the floor of Castle Chamber. *Oistoceras angulatum*.	2.15

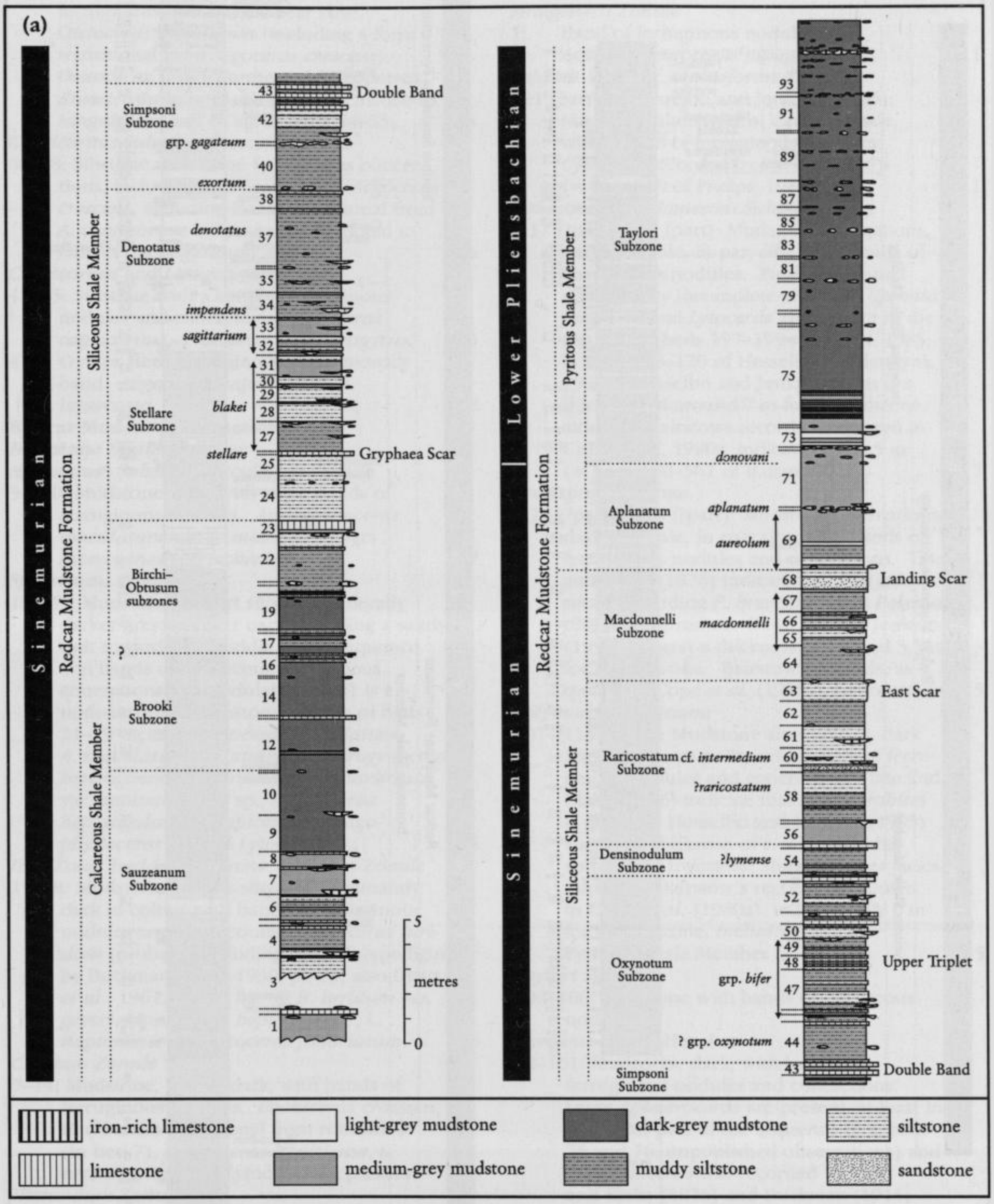

Figure 6.7a The stratigraphy of the Sinemurian and Lower Pliensbachian succession in Robin Hood's Bay. Lithostratigraphy after Hesselbo and Jenkyns (1995).

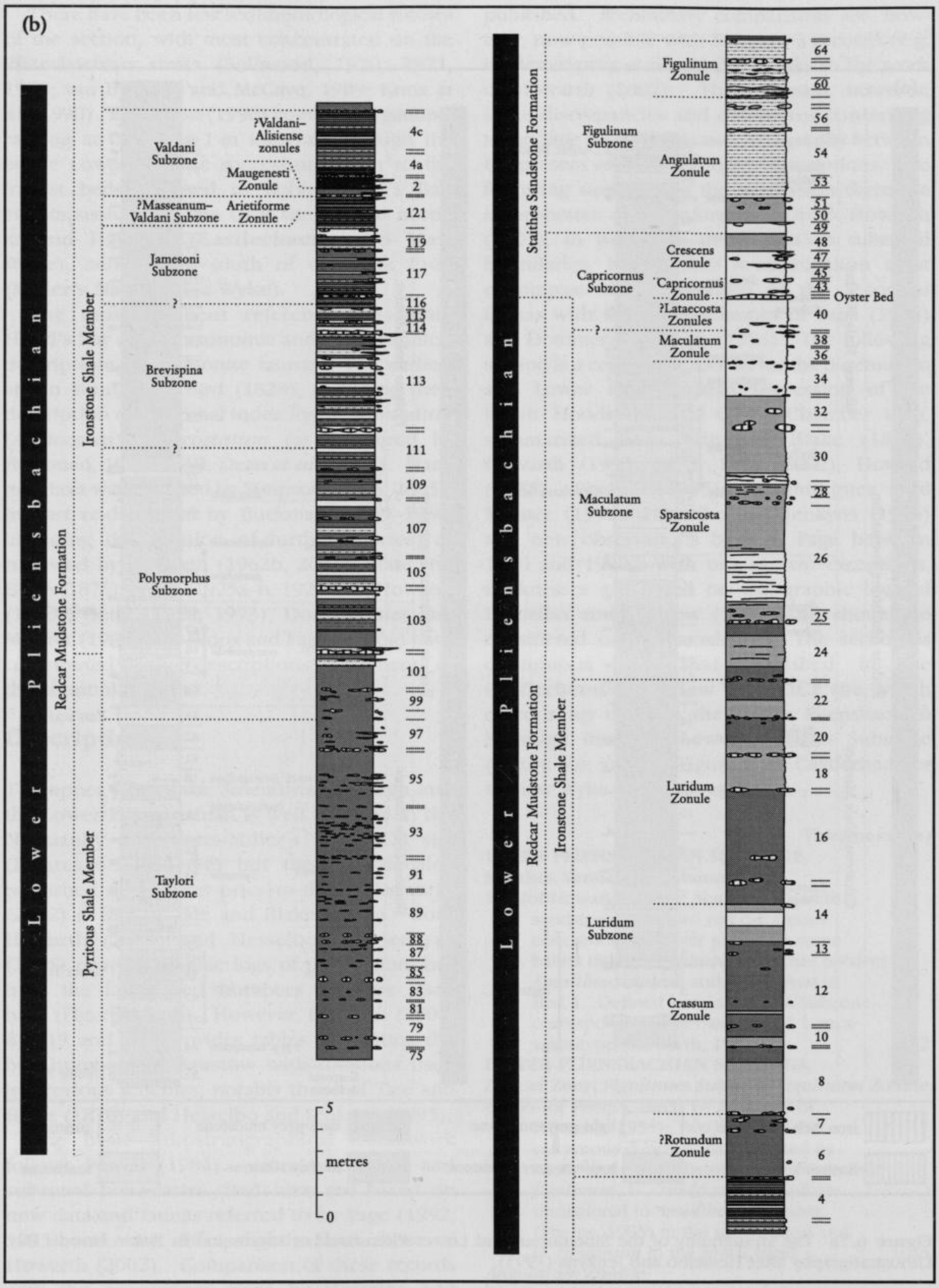

Figure 6.7b The stratigraphy of the Lower Pliensbachian succession in Robin Hood's Bay. Lithostratigraphy after Hesselbo and Jenkyns (1995).

Thickness (m)

49–58: Siltstone with concretionary bands in upper part and mudstone with ferruginous concretions near base. *Oistoceras angulatum* (including a form transitional from *Aegoceras crescens*), *Oistoceras sinuosiforme* and *Liparoceras divaricosta* in beds 49–51, with *Oistoceras ?angulatum* and *O.* sp. in beds 54–55. 6.4

Capricornus Subzone, Crescens Zonule

46–48: Siltstone with some ferruginous concretions, including as a basal band. *Aegoceras crescens*, including forms transitional from *A. capricornus* below and transitional to *Oistoceras angulatum* above. 1.6

Capricornus and *Lataecosta zonules*

42–45: Siltstone with a band of ferruginous nodules and concretions. *Aegoceras capricornus, A. lataecosta, A. artigyrus.* 1.3

41: **Oyster Bed**: Ferruginous concretionary band. *Aegoceras ?capricornus, A. lataecosta.* 0.2

Redcar Mudstone Formation

Ironstone Shale Member

Maculatum Subzone, Maculatum Zonule

36–40: Mudstone, silty, with some bands of ferruginous nodules. *Androgynoceras maculatum* and *A. maculatum* vars *heterogenes* and *leckenbyi*. 2.7

Sparsicosta Zonule

19–?35: Mudstone, in part silty and generally darker grey in lower part, including a sandy unit towards the middle of the sequence and bands of calcareous ferruginous concretions and nodules. Bed 21 is a nodular oolitic ironstone. Fauna of beds 21–29 includes *Aegoceras maculatum, A. maculatum* var. *atavum, Androgynoceras heterogenes, A. sparsicosta, A. sparsicosta* var. *naptonense, A.* sp., *Liparoceras heptangulare, L. naptonense, Tragophylloceras* sp. and *Lytoceras* sp.. 15.5

Ibex Zone, Luridum Subzone, Luridum Zonule

15–18: Mudstone, in part silty and dominantly dark in colour with bands of ferruginous nodules and concretions. *Beaniceras luridum* (probably including the holotype figured by Buckman, 1909–1930, pl. 73; also Dean *et al.*, 1961, pl. 69, fig. 6), *B. luridum* var. *geyeri, Liparoceras heptangulare, L. naptonense* and *Lytoceras fimbriatum*. 7.3

Crassum Zonule

7–14: Mudstone, mainly dark, with bands of ferruginous nodules. *Beaniceras crassum, B. crassum* transitional from *rotundum* (in Bed 7), *Liparoceras ?cheltiense, L. heptangulare* and *Lytoceras* sp. present. 10.8

?Rotundum Zonule

5–6: Mudstone, dark, with a band of ferruginous concretions. *Lytoceras* and *Tragophylloceras*. 2

Valdani Subzone, ?Valdani–Alisiense zonules

4: Mudstones, alternating dark and pale, in part silty. *Acanthopleuroceras lepidum* present in 4b. 1.7

2–3: Mudstones, alternating dark and pale, in part silty, with a band of ferruginous nodules. *Liparoceras cheltiense.* 1

Maugenesti Zonule

1: Band of ferruginous nodules with *Acanthopleuroceras maugenesti.* 0.1

Valdani Subzone, ?Arietiforme Zonule

121 (part) of Hesselbo and Jenkyns (1995): Mudstone alternations, dark and pale, with a band of ferruginous lenticles. *Cymbites* recorded by Phelps (1985) (= 0 or 200 of Phelps, 1985). 1.1

Jamesoni Zone, Jamesoni Subzone

?117 (?part)–121 (part): Mudstone alternations, dark and pale, in part silty, with bands of ferruginous nodules. Published faunal records very incomplete although *Uptonia jamesoni* and *Lytoceras* are present in the top 1.5 m (beds 197–199 of Phelps, 1985; = beds 118–120 of Hesselbo and Jenkyns, 1995). Hesselbo and Jenkyns suggest a thickness of around 7 m for the subzone, although Bairstows records, as quoted in Cope *et al.*, 1980a, indicate only 3.5 m (= beds 550–561 of Bairstow?). 7

Brevispina Subzone

?113 (?part)–?116 (?part): Mudstone alternations, dark and pale, in part silty, with bands of ferruginous nodules and concretions. Tate and Blake (1876) indicate that *Platypleuroceras* (including *P. brevispina* and *Polymorphites*) are present. Hesselbo and Jenkyns (1995) suggest a thickness of around 3.5 m for the subzone. Bairstow's records, as quoted in Cope *et al.* (1980a), indicate 6 m. 3.5

Polymorphus Subzone

107–?113 (?part): Mudstone alternations, dark and pale, in part silty, with bands of ferruginous nodules and concretions. Tate and Blake (1876) indicate that *Polymorphites* is present. Hesselbo and Jenkyns (1995) suggest a thickness of *c.* 9.5 m for the subzone in Ironstone Shale Member facies (although Bairstow's records, as quoted in Cope *et al.* (1980a), indicate only 6 m for the subzone, *including* levels in Pyritous Shale Member facies) 9.5

Taylori Subzone

102–106: Mudstone with bands of calcareous nodules

Pyritous Shale Member

72–101: Mudrocks, dark, with bands of ferruginous nodules and concretions. Large *Apoderoceras* are present, at least in the lower part of the sequence (e.g. beds 75 and 76, unpublished observations) and *Phricodoceras* was recorded by Tate and Blake (1876) and Buckman (1915) in Bed 47 of their Jamesoni Beds and in Bed 1013 of Dommergues and Meister (1992); as *P.* grp *taylori* and associated with *Apoderoceras* sp. (= Bed 72 of Hesselbo and Jenkyns, 1995). 21

71 (part): Mudstone (top *c.* 0.4 m, = Bed 1012 of Dommergues and Meister, 1992). 0.4

Thickness (m)

71 (part): Mudstone, with common small fossils including ammonites, frequently pyritized, especially *Bifericeras donovani* (type locality in Wine Haven, southern Robin Hood's Bay; Dommergues and Meister, 1992, fig. 7, 1–11 and fig. 5, 8–10) and rarer *Apoderoceras* sp. and *Gleviceras* sp.. This is the *donovani* Biohorizon stratotype (*c.* 0.6–0.4 m below top = Bed 1011 of Dommergues and Meister, 1992) and has been proposed as the Global Stratotype Section and Point (GSSP) for the base of the Pliensbachian Stage (Hesselbo *et al.*, 2000). 0.2

UPPER SINEMURIAN SUBSTAGE

Raricostatum Zone, Aplanatum Subzone

71 (part): Mudstone. 1.7

69 (topmost *c.* 0.15 m)–?70: Red-weathering nodular horizon in grey mudstone, with intermittant band of greyer nodules below. *Paltechioceras aplanatum*, *Eoderoceras* and ?*Gleviceras*. This is the stratotype for the *aplanatum* Biohorizon (Page, 1992). (= Bed 1004c–1005 of Dommergues and Meister, 1992; and Bed ?50 of Tate and Blake's Jamesoni Beds; also the Upper Conybeari Bed of Buckman, 1915). 0.2

69 (part): Mudstone, including a siltstone horizon and a band of nodules near its base. *Paltechioceras aureolum* recorded by Getty (1973) and Dommergues and Meister (1992), from at least 0.2 m above the base of Bed 69. This is the stratotype for the *aureolum* Biohorizon (Page, 1992). 2.2

Siliceous Shale Member

68: Sandstone, silty, bioturbated in upper part and forming Landing Scar at Bay Town. *Leptechioceras* grp. *meigeni* recorded by Dommergues and Meister (1992) (= Bed 1 of Tate and Blake's Oxynotus Beds. Probably represents the fauna assigned to '*Paltechioceras*' by Howarth (2002)). 0.8

Macdonnelli Subzone

64 (upper *c.* 0.8 m?)–67: Mudstone with silty horizons and some ferruginous and calcareous lenticles and nodules: *Leptehioceras macdonnelli*, *L.* grp *meigeni*, *Eoderoceras* sp. and *Radstockiceras* (Dommergues and Meister, 1992; Page, 1992). Corresponds to the *macdonnelli* Biohorizon. 2.8

64 (lower part): Mudstone. Forms lower part of cycle above, and hence presumed to be Macdonelli Subzone. 1

63: Sandstone, silty, with siltstone below, bioturbated at top. Forms East Scar. 0.7

61–62: Mudstone, silty in part, with some iron-rich calcareous lenticles. The presence of *Leptechioceras planum* in Bed 61 as recorded by Howarth (2002) indicates the *meigeni* (= *planum*) Biohorizon of the Macdonnelli Subzone (e.g. in Page, 1992). 1.9

Raricostatum Subzone

60: Mudstone with carbonate lenticles and a band of nodules yielding *Echioceras* cf. *intermedium* and *Eoderoceras* sp.. This represents the cf. *intermedium* Biohorizon stratotype (Page, 1992). 0.6

59: Sandstone, calcareous. 0.2

58: Mudstone, silty in part. *Echioceras* ex grp. *raricostatum* abundant, though mainly crushed in shale. Probably includes the *raricostatum* Biohorizon. 2

56–57: Mudrock overlain by a thin sandy siltstone band. *Echioceras* sp. juv. in Bed 56. 0.9

Densinodulum Subzone

53 (upper band)–55: Sandstone, silty, calcareous, thin (Bed 53, part), with small nodules yielding *Crucilobiceras densinodulum* overlain by mudstone, with a second thin sandy bed above (Bed 55). Probably includes the *lymense* Biohorizon. 1.2

Oxynotum Zone, Oxynotum Subzone

50–53 (lower part): Mudstone, including a major (double) bed of calcareous silty sandstone (Bed 51 = *c.* 0.4 m) and some calcareous nodules and lenticles. 2.5

?48–?49: Sandstone, silty, forming a scar overlain by mudstone. Large *Oxynoticeras* grp. *oxynotum* present in top of Bed ?48, with rare *Bifericeras bifer* also present and in Bed ?49. This includes part of the grp. *bifer* Biohorizon. 1.3

45–47: Mudstone with more resistant silty bands and some lenticles. *Bifericeras* sp. present around 0.2 m above base. Includes part of the grp. *bifer* Biohorizon. 2.1

44: Mudstone, with a band of grey calcareous concretions in its lower part rich in small bivalves. *Oxynoticeras* grp. *oxynotum* present and possibly *Cenoceras* sp.. This may represent the grp. *oxynotum* Biohorizon and possibly is the type horizon of *Ophideroceras ziphoides* (Spath, 1925b). 1.6

43: **Double Band**: Conspicuous double band of bioturbated fine sandstone (Figure 6.8), prominent at the base of a small promontory on the north side of Boggle Hole. Rich trace-fossil assemblages including *Diplocraterion*, *Teichichnus*, *Ophiomorpha* and *Chondrites* (= beds 21 and 22 of Tate and Blake's Oxynotus Beds). 0.4

Simpsoni Subzone

42: Mudstone, with harder thin silty band near top. *Oxynoticeras oxynotum* present 0.86 m above base according to Howarth (2002). 1.8

41: Band of calcareous nodules with locally abundant *Gagaticeras* grp. *gagateum* and occasional *Oxynoticeras simpsoni*. This is the stratotype for the grp. *gagateum* Biohorizon (Page, 1992). 0.1

Thickness (m)

38 (topmost *c.* 0.1 m)–39: Silty seam overlain by mudstone with calcareous nodules. *Oxynoticeras simpsoni* and *Gagaticeras* grp. *exortum* common, with occasional *Palaeoechioceras* aff. *pierrei*. Earlier records of *O. simpsoni* in Howarth (2002) may include late *Eparietites* which have a smooth *simpsoni*-like body chamber and a relatively short ribbed stage This is the stratotype for the *exortum* Biohorizon (Page, 1992). 0.2

Obtusum Zone, Denotatus Subzone

37 (topmost *c.* 0.5 m)–38: Mudstone. 1.2

37 (*c.* 1–0.5 m below top): Band of calcareous concretions in mudrock. *Eparietites denotatus* frequent (probably including the holotype re-figured by Buckman, 1909–1930, pl. 67A,B), also very rare ?*Cymbites* sp.. This is the stratotype for the *denotatus* Biohorizon (Page, 1992). 0.5

34 (upper part)–37 (lower part): Mudstone with scattered lenticles and nodules. *Aegasteroceras* cf. *simile* present at the top of Bed 34 and *Eparietites* sp. in Bed 36. This probably includes the *fowleri* Biohorizon. 3

33 (topmost *c.* 0.1 m)–34 (basal *c.* 0.15 m): Mudrock with some calcareous nodules. *Eparietites impendens* and *Aegasteroceras* ex grp. *sagittarium*. This is the stratotype for the *impendens* (= cf. *undaries*) Biohorizon (Page, 1992). In Howarth (2002) this fauna is recorded as '*Epiarietites bairstowi* nov.' in Bed 455 which is stated as correlating with Bed 32 of Hesselbo and Jenkyns, which places it below the *E. impendens* fauna recorded here, thereby suggesting a minor discrepancy between the two sections. 0.25

Stellare Subzone

32–33 (excepting topmost *c.* 0.1 m): Mudstone with triple band of siltstone and calcareous concretions, often formed in ammonite body chambers. *Aegasteroceras* ? spp. common, including *A. sagittarium* in the basal part of Bed 33 (probably including the holotype figured by Wright, 1876–1886, pl. 35, figs 1–3). This is the stratotype for the *sagittarium* Biohorizon (Page, 1992). 1.4

?27–31: Mudstone, silty in part, with scattered lenticles and nodules, some formed inside ammonite body chambers. *Asteroceras* grp. *blakei* and *Promicroceras* common. This includes the the stratotype for the *blakei s.s.* Biohorizon (Page, 1992) (= Bed 39 of Tate and Blake's Oxynotus Beds). 1.9

26: **Gryphaea Scar**: Hard calcareous bed rich in *Gryphaea*, forming the top of a scar. *Asteroceras* sp. present, and probably the source horizon for large ex-situ *Asteroceras* grp. *stellare*. Probably corresponds to the ?*stellare* Biohorizon (= Bed 40 of Tate and Blake's Oxynotus Beds). 0.15

24–25: Mudstone, silty, with a band of nodules near middle and traces of crushed ammonites near base, including *Promicroceras* and *Epophioceras*. 2.6

23: Sandstone, calcareous, forming prominent scar, with concretionary band below (= Bed 42 of Tate and Blake's Oxynotus Beds). 0.6

Calcareous Shale Member

Obtusum Zone, Obtusum Subzone

22: Mudstone with two bands of calcareous nodules. *Asteroceras* spp., *Promicroceras*, *Xipheroceras* and *Cymbites* present. 1.71

LOWER SINEMURIAN SUBSTAGE

Turneri Zone, Birchi Subzone

14 (0.97 m below top)–21: Mudstone with silty bands and some bands of nodules. *Promicroceras capricornoides* and *Microderoceras birchi* present. 7.11

Brooki Subzone

12 (*c.* 30 cm below top)–14: Mudstone with a harder calcareous band near the middle and at its top. *Caenisites* present in the upper part of Bed 12 and in Bed 15, including *C.* cf. *brooki*. This includes the *brooki* Biohorizon. 2.5

Semicostatum Zone, Sauzeanum Subzone

1–12 (part): Mudstone with several harder silty bands in the lower part forming reefs in the centre of the bay, and with scattered calcareous lenticles and some bands of nodules. *Arnioceras* common at several levels including Bed ?7 and Bed ?6, the latter with *Arnioceras* cf. *semicostatum*, with *Euagassiceras* sp. also present. *Pararnioceras* spp. is also recorded by Howarth (2002) as *Coroniceras* (*Arietites*) *alcinoe*. Probably includes the cf. *semicostatum* Biohorizon. 11+

The Lower Lias succession in Robin Hood's Bay includes the stratotypes of the Calcareous Shale, Siliceous Shale, Pyritous Shale and Ironstone Shale members of the Redcar Mudstone Formation of Powell (1984). The Calcareous Shale Member is dominated by medium-grey mudstones, although lower levels are more silty and have scour hollows, now commonly infilled by siderite-cemented mudstone. Occasional shell beds are usually of *Gryphaea*, which otherwise is virtually absent from the mudstones; the thicker shell beds, up to 0.15 m thick, are typically of broken but unworn material. The overlying Siliceous Shale Member contains abundant very fine-grained quartz sand as thin layers and scour fills. The muddy sand units form prominent foreshore scars (Figure 6.8) in the northern and southern parts of the bay, dependent on their thickness and degree of

Figure 6.8 Cliff and foreshore exposures of the Redcar Mudstone Formation in the southern part of Robin Hood's Bay. The level foreshore in the foreground exposes mudstones of Simpsoni Subzone age and the base of the Oxynotum Subzone is immediately above the conspicuous bipartite bed in the middle distance (the 'Double Band' of Tate and Blake, 1876; Bed 43 of Hesselbo and Jenkyns, 1995). The cycles visible in the lower part of the cliff behind are in the upper part of the Siliceous Shale Member, of Raricostatum Zone age. They are overlain by darker and more homogenous mudstones of the Pyritous Shale and Ironstone Shale members, of Jamesoni Zone age, which are exposed in the upper part of the buttress towards the left of the picture. (Photo: K.N. Page.)

cementation. A series of coarsening-upward cycles are developed at this level, as described by Sellwood (1970, 1972), although they are not always clearly discernable in the sections (Knox *et al.*, 1990; Hesselbo and Jenkyns, 1995). Benthic faunas are most abundant in the more sandy horizons at the top of the cycles and include abundant trace fossils, such as *Teichichnus*, *Rhizocorallium*, *Ophiomorpha*, *Diplocraterion* and *Chondrites*, and burrowing bivalves such as *Gresslya*, *Pholadomya*, and *Pleuromya* (Scrutton, 1996). The sandy floors of some scour hollows may be capped with a thin layer of dark clay, beneath which sometimes occur articulated remains of asteroids, ophiuroids, echinoids and the crinoid *Hispidocrinus scalaris* (Simms, 1987). The sideritic concretions, which frequently lie above this clay layer, tend to be almost barren.

Within the Siliceous Shale Member ammonites tend to occur in discrete nodule bands within the mudstones, particularly towards the base of the cycles, although most specimens are small. Larger specimens, some over 0.3 m in diameter, occur only rarely but typically are found towards the top of the sandy horizons. In only the Raricostatum Subzone are crushed ammonites abundant in the shales. The resilient guards of belemnites are common in some of the sandy horizons, though also occurring in the ammonite-bearing nodule bands. Bivalves occur scattered throughout the mudstones.

The overlying Pyritous Shale Member comprises dark-grey and black pyritic mudstones that span the Sinemurian–Pliensbachian boundary, although they appear to be mainly of early Pliensbachian, Taylori Subzone age. Scour fills are developed only near the base and top. The benthic fauna includes thin-shelled bivalves, but ammonites and belemnites also occur though they are only common near the base of the unit, across the stage boundary. Bioturbation is common, especially as pyritized *Chondrites* but also including *Rhizocorallium*, *Ophiomorpha* and *Teichichnus*. At higher levels large *Apoderoceras* occur occasionally.

The Ironstone Shale Member is well exposed in the cliffs and foreshore north of Bay Town and comprises variously silty, and locally sandy, horizons producing a distinctive light and dark banding. This is especially evident in the lower part of the unit, comprising the Polymorphus, Brevispina and Jamesoni subzones, which led to van Buchem and McCave (1989) referring to this part of the succession as the 'Banded Shales' (Hesselbo and Jenkyns, 1995). The lighter bands are coarser grained, more carbonate-rich, have less organic material and a more diverse benthic assemblages than the dark bands (Sellwood, 1972; van Buchem and McCave, 1989; van Buchem *et al.*, 1992, 1994). The fauna of the paler bands includes *Pinna*, *Gryphaea* and pectinids, with more scattered and thin-shelled bivalves in the darker bands (Tate and Blake, 1876; Sellwood, 1972). The organic matter fraction is much more uniform in size and shape than that from the paler layers. Both contain woody material and palynomorphs, but the darker layers have a much lower abundance of plant-tissue fragments (van Buchem and McCave, 1989). Above the Banded Shales, the Ironstone Shale Member contains numerous concretionary siderite layers and also much pyrite dispersed through the mudstone. Towards the top there are silt and fine-sand layers, sand-filled scours and shell beds, with several coarsening-upward cycles from 2 m to 10 m in thickness. The upper part of the member shows a return to finer-grained sedimentation but with coarsening-upwards cycles passing into those in the overlying Staithes Sandstone Formation (Hesselbo and Jenkyns, 1995). The middle part of the Ironstone Shale Member, corresponding roughly to the Ibex Zone, is particularly rich in *Pinna*, which often occur in life position but are also found current-sorted and lying parallel to bedding planes. The shales and silts of the higher levels of the member show common bivalves, including *Pseudopecten*, *Pleuromya* and three horizons of current-sorted *Gryphaea* (Scrutton, 1996). At around this level, in Bed 21 of Phelps (1985), there is a 0.1 m-thick bed of composite sideritic nodules with chamositic ooliths preserved in burrow fills; this is the lowest level in the Jurassic sequence of the Cleveland Basin where an oolitic ironstone is developed (Scrutton, 1996). The transition to the overlying Staithes Sandstone Formation is gradual but is taken at the level of the Oyster Bed, a distinctive 0.3 m-thick shell bed that can be traced across the Lower Jurassic outcrop of the Cleveland Basin.

Offshore exposures may extend down to the base of the Hettangian Stage (see later discussion) but the lowest faunas proven *in situ* in the bay probably indicate the Sauzeanum Subzone. They include ?*Euagassiceras* sp. (Bairstow in Sylvester-Bradley, 1953) and *Arnioceras* ex gr. *semicostatum*. Dean *et al.* (1961) figured a specimen of *Agassiceras scipionianum* from here but this may have come from a loose block. Subdivision of the overlying Turneri Zone is unclear, although *Caenisites* sp. cf. *brooki* is present around the levels of beds 12–14, indicating the Brooki Subzone. *Microderoceras birchi* has also been collected towards the top of Bed 14 (Howarth, 2002), and the earliest *Promicroceras* in Bed 17 probably indicates the higher part of the Birchi Subzone, as in Dorset (Page, 1992). The Obtusum and Stellare subzones are indicated by characteristic species of *Asteroceras* and related taxa between Bed 22 and the lower part of Bed 33. *Eparietites* spp. range through beds 33 to 37 and indicate the Denotatus Subzone, with the incoming of *Oxynoticeras simpsoni* (including the holotype re-figured by Buckman, 1909–1930, figs 66A,B; Dean *et al.*, 1961, pl. 67, fig. 4) at the top of Bed 38 marking the base of the Oxynotum Zone, Simpsoni Subzone (Page, 1992). *Oxynoticeras* ex gr. *oxynotum* in the lower part of Bed 44 indicates the Oxynotum Subzone. References to the faunas of the Raricostatum Zone are present in Getty (1973), Page (1992, 1994b) and Dommergues and Meister (1992) although the basal fauna of the Densinodulum Subzone, with *Plesechioceras delicatum* is not yet recognized here. Consequently the base of the Raricostatum Zone is drawn provisionally at the first occurrence of *Crucilobiceras densinodulum* in Bed 53.

The Raricostatum Zone and the Taylori Subzone (basal Pliensbachian) have been an important source of specimens of Eoderoceratid and related ammonites, including many type specimens of Simpson, S.S. Buckman and others. In the Pliensbachian Stage these have been assigned mainly to the genus *Apoderoceras*, but in the Sinemurian Stage a variety of *Eoderoceras* spp. are known and are particularly common in the upper Raricostatum Zone, cf. *intermedium* Biohorizon, and are locally common in the earlier part of the Aplanatum Subzone. The former level was an important source of figured specimens, such as *Eoderoceras* aff. *armatum* (Wright, 1878–1886, pl. 28, figs 1–5) and *E. aculeatum* (Simpson, 1855, pl. 30, figs 1–7). Rarer forms which have not been stratigraphically well-located include the late schlotheimiids *Charmasseiceras* and/or *Angulaticeras* mentioned by Tate and Blake (1876) and Spath (1925d). Elsewhere in Britain this genus is most common in the Turneri Zone, Denotatus Subzone and especially Oxynotum Subzone (Hollingworth *et al.*, 1990). Its probable descendant, or at least related taxon, is *Phricodoceras* in the Lower Pliensbachian Substage, which is similarly rare.

This Sinemurian sequence in Robin Hood's Bay has yielded many type specimens of stratigraphical importance, including the zonal and subzonal index specimens *Arnioceras semicostatum* (Young and Bird, 1828), *Eparietites denotatus* (Simpson, 1855), *Oxynoticeras simpsoni* (Simpson, 1843) and *Paltechioceras aplanatum* (Hyatt, 1889), with the additional biozonal index specimens *Asteroceras blakei* (Spath, 1925e), *Aegasteroceras sagittarium* (Blake in Tate and Blake, 1876), *Gagaticeras exortum* (Simpson, 1855) and *G. gagateum* (Young and Bird, 1828). The area has international stratigraphical importance, as including provisional stratotypes for the Denotatus, Simpsoni and Aplanatum subzones and the Oxynotum Zone and the stratotypes, by original definition, of the *blakei s.s.*, *sagittarium*, cf. *undaries*, *denotatus*, *exortum*, *gagateum*, cf. *intermedium* and *aplanatum* biohorizons.

Of greater significance is the recognition of one of the most complete and expanded Sinemurian–Pliensbachian boundary sequences known in Europe. The boundary interval was first recognized by Dommergues and Meister (1992) who recognized a new species above the last Sinemurian *Paltechioceras* and below the first typically Pliensbachian *Apoderoceras*. The appropriate zonal, and hence stage, assignment of this new form, *Bifericeras donovani*, was for long unclear (cf. Page, 1995), but is now established as earliest Pliensbachian in age by the confirmed co-occurence of nuclei of *Apoderoceras*. A multi-disciplinary assessment, combining sedimentological, geochemical, micro- and macropalaeontological information, has led to the proposed designation of the Wine Haven section as the Global Stratotype Section and Point (GSSP) for the base of the Pliensbachian Stage (Hesselbo *et al.*, 2000; Meister *et al.*, 2003).

The only published account of higher levels in the Jamesoni Zone is that of Howarth (2002) based on extensive records made by L. Bairstow from the 1930s. The Ibex Zone to early Margaritatus Zone interval was re-described graphically by Phelps (1985) who included a complete re-assessment of the ammonite faunas of this interval and their assignment to a sequence of zonules which could be applied throughout most of north-west Europe. Wright (1878–1886) figured elements of the Lower Pliensbachian faunas, and Spath (1938) provided a review of part of the fauna in his monograph of Liparoceratid ammonites. The latter included several specimens from Robin Hood's Bay, including *Androgynoceras heterogenes* var. *gigas*, *A. maculatum*, *Liparoceras heptangulare*, and *Oistoceras omissum*. Most notable among the later Lower Pliensbachian holotypes of Robin Hood's Bay are the subzonal index fossils *Beaniceras luridum* and *Androgynoceras maculatum*.

Although many authors, most recently Howarth (2002), have figured and described ammonites from the Sinemurian and Pliensbachian sections exposed in the bay, few other elements of the macrofauna have been investigated in recent years. Only the belemnite *Pseudohastites scabrosus* from the Jamesoni Zone of North Cheek (Doyle, 1990–1992), the crinoid *Hispidocrinus scalaris* from the Oxynotum Zone of the central part of the bay (Simms, 1988, 1989), and the mis-identified serpulid *Dentalium giganteum*, common near the base of the Staithes Sandstone Formation at Castle Chamber (Palmer, 2001) have been figured in recent publications.

Interpretation

The ammonite stratigraphy of this site is well established. The lowest exposed beds in the bay have yielded forms indicative of the upper Semicostatum Zone, but older strata may be exposed in the subtidal because pre-Semicostatum Zone ammonite taxa have been collected from beach material. However, there has been discussion as to whether these are derived from outcrops immediately offshore or from far-travelled glacial erratics derived from the till that forms much of the cliffs at the back of the bay. Persistent records from Robin Hood's Bay, rather than any other localities, suggest a local source. Bairstow (1969) considered that the bay had eroded into a dome and that it was unlikely that the offshore exposures extended much lower in the Sinemurian sequence. It seems unlikely that submarine erosion has reached the base of the Lower Lias, which in the nearby Fisons' No. 1 Borehole was about 90 m below the lowest beds at outcrop (Bairstow, 1969).

The most notable of the pre-Sinemurian taxa recorded from Robin Hood's Bay is the type of the early Jurassic ammonite *Psiloceras erugatum*, collected from loose blocks on the beach. Recent studies of basal Jurassic sections and sequences elsewhere in England, have shown this species to be the earliest typical Jurassic ammonite in Europe (Page and Bloos, 1998; Bloos and Page, 2000a). It characterizes an *erugatum* Biohorizon at the base of the Planorbis Zone. Re-examination of the Staithes Borehole has confirmed that *P. erugatum* is present *in situ* in the district in typical concretionary preservation, thereby supporting the case for a local source for the beach material. Yonger faunas are also present as derived material in the till at Robin Hood's Bay and include evidence of the Johnstoni Subzone (e.g. *Caloceras belcheri* and *C. wrighti*), both subzones of the Liasicus Zone, the Angulata Zone (including *Schlotheimia angulata*) and probably the Bucklandi Zone. All may have a local source offshore, but derivation by ice transport from the extensive outcrops of Hettangian strata that crop out on the northern flank of the Cleveland Basin cannot be ruled out.

The boundaries between the members of the Redcar Mudstone Formation are transitional and difficult to define precisely (Hesselbo and Jenkyns, 1995). The absence of stratigraphical hiatuses means that the lithostratigraphical boundaries rarely coincide with ammonite zonal boundaries. Sedimentary cyclicity occurs throughout the Redcar Mudstone Formation. Van Buchem and McCave (1989) interpreted many of the facies changes seen in terms of four main depositional environments, essentially corresponding to four main facies units. They attributed the scours, silt and sand layers and shell beds of the Calcareous Shale and Siliceous Shale members to deposition in a storm-dominated shallow marine setting. The Pyritous Shale Member, with its conspicuous concretionary horizons, was interpreted as a hemipelagic environment. The striking light and dark banding of the lower part of the Ironstone Shale Member, which they termed the 'Banded Shales', was attributed to deposition in a climate-dominated shallow marine setting. Finally, the interbedded sandstones, siltstones and mudstones of the remainder of the Ironstone Shale member was interpreted as evidence for a shallowing-upwards, pro-delta dominated, marine environment.

The silty lower beds of the Calcareous Shale Member have been interpreted as evidence for a more proximal or shallower environment with greater storm influence on sedimentation than the higher parts of the member (Hesselbo and Jenkyns, 1995). The presence of shell beds in the higher parts has been interpreted to be the result of winnowing on a sea floor just above storm wave-base (van Buchem and McCave, 1989). The Siliceous Shale Member contains beds and scour fills of sand: it represents a transition from proximal to distal storm beds in a shallow marine setting (Sellwood, 1972; van Buchem and McCave, 1989; van Buchem *et al.*, 1992). The coarser units were interpreted by Sellwood (1972) as the tops of coarsening-upwards cycles, but Knox *et al.* (1990) interpreted them as tempestites. The presence of articulated echinoderms beneath thin mud drapes in some of the scours suggests occasional re-suspension of massive volumes of sediment sufficient to bury these organisms to a depth beyond the reach of bioturbating scavengers. Time-series analysis of the conspicuous cycles in the Siliceous Shale Member did not detect any consistent pattern indicative of Milankovitch cyclicity (van Buchem and McCave, 1989). The restriction of ammonites largely to nodule bands, suggests that an ecological, or possibly diagenetic, factor has determined their distribution.

In the Pyritous Shale Member most of the recorded benthic fauna comes from near the base and the top of the member. This has led to the suggestion that the Siliceous Shale Member was followed by a relative rapid deepening of the sea and more dysaerobic conditions (Sellwood, 1972; van Buchem and McCave, 1989; Hesselbo and Jenkyns, 1995). Parkinson (1996) recorded an increased uranium content in the Pyritous Shale Member, further evidence of some degree of anoxia in this part of the succession (Wignall and Myers, 1988).

Van Buchem and McCave (1989) attributed the striking dark and light colour banding in the lower part of the Ironstone Shale Member to the influence of climatically driven variations in storm frequency related to Milankovitch cycles (van Buchem *et al.*, 1994). A similar explanation for the more-or-less time-equivalent Belemnite Marl Member in Dorset (Weedon and Jenkyns, 1990) led Hesselbo and Jenkyns (1995) to suggest bed-by-bed correlations between the two members. Van Buchem and McCave (1989) suggested that each couplet represented about 20 000 years, and that deposition took place in water depths of about 70–100 m, at about storm wave-base. The sideritic nodule bands which give the Ironstone Shale Member its name were the subject of investigation by Sellwood (1971), who concluded that the siderite was deposited close to successive sediment–water interfaces that represent minor non-sequences. Changes in the rate of sedimentation produced the rhythmic alternations of mudstone and siderite bands. Peaks in potassium, thorium and uranium contents in the middle of the member were taken by Parkinson (1996) as evidence of decreasing rates of accommodation space creation associated with progradation. The upper part of the Ironstone Shale Member becomes increasingly silty, with coarsening-upward cycles indicative of shallowing, which continued into the Staithes Sandstone Formation above.

Hesselbo and Jenkyns (1995) compared the Robin Hood's Bay succession with its correlative on the Dorset coast and attempted to account for the lithological differences. They found some evidence for correlating the coarser beds in the Redcar Mudstone Formation with calcareous mudstones in the Charmouth Mudstone Formation, and finer-grained beds in Yorkshire with laminated organic-rich mudstones in Dorset, on the basis of transgressive and regressive phases. The overall differences between the lithologies in the two basins were ascribed to a more proximal depositional setting for the Robin Hood's Bay succession.

The Yorkshire succession is lithologically similar in part to that of the Hebrides Basin. However, although broad-scale correlations between the facies units have been made on the basis of sequence stratigraphy (Hesselbo and Jenkyns, 1998), stratigraphical refinement of the Hebridean succession is not yet sufficient for more detailed correlation. In general the Sinemurian and Pliensbachian succession of the Hebrides is developed in a still more proximal depositional setting than that of Yorkshire.

Conclusions

The sections exposing the Redcar Mudstone Formation in the Normanby Stye Batts–Miller's Nab (Robin Hood's Bay) GCR site provide the most complete Sinemurian and Pliensbachian sequence in Britain. The fauna at this site has been little investigated compared with its Dorset counterpart but, nonetheless it is sufficiently well-documented for the section at Wine Haven, on the south side of the bay, to be proposed as the Global Stratotype Section and Point (GSSP) for the base of the Pliensbachian Stage. Robin Hood's Bay also includes stratotypes or potential stratotypes for numerous biohorizons, subzones and zones, and has yielded many type specimens of invertebrate taxa, including stratigraphically important ammonites. This site contrasts with the correlative successions in Dorset, which are more argillaceous and stratigraphically more interrupted. The differences have been attributed to deposition in more proximal environments at Robin Hood's Bay.

CASTLECHAMBER TO MAW WYKE, NORTH YORKSHIRE (NZ 941 082–NZ 959 067)

K.N. Page

Introduction

The cliff and foreshore exposures along the North Yorkshire coast between Castle Chamber and Maw Wyke, near Hawsker Bottoms, provide one of the most complete Pliensbachian–Toarcian boundary sequences in Britain, and a continuous succession through the Staithes Sandstone, Cleveland Ironstone and Whitby Mudstone formations in the Pliensbachian and Toarcian of the North Yorkshire coast. The succession here includes the type sections of the Grey Shale and Mulgrave Shale members of the Whitby Mudstone Formation, while the facies developments in the Staithes Sandstone and Cleveland Ironstone formations below are critical to understanding the sedimentary history of the Cleveland Basin. The site is also the type locality for almost half of the known British species of amaltheid ammonites and has yielded indicator fossils for the basal Toarcian Paltus Subzone.

The strata dip gently west, unbroken by faults or folds, and represent a continuation from the succession exposed in the **Normanby Stye Batts–Miller's Nab (Robin Hood's Bay)** GCR site to the south (Figures 6.6 and 6.9). The base of the Upper Pliensbachian succession lies about 2 m above the floor of Castle Chamber and progressively younger strata come down to shore level to the north-west. Highest beds exposed in the site are at Maw Wyke where the upper part of the Bituminous Shales of the Mulgrave Shale Member is exposed on the shore. Still higher levels are exposed farther north but in the cliffs.

This section of coast was well known to early geologists and was described by Phillips (1875) and Tate and Blake (1876). The latter publication formed the basis for many subsequent

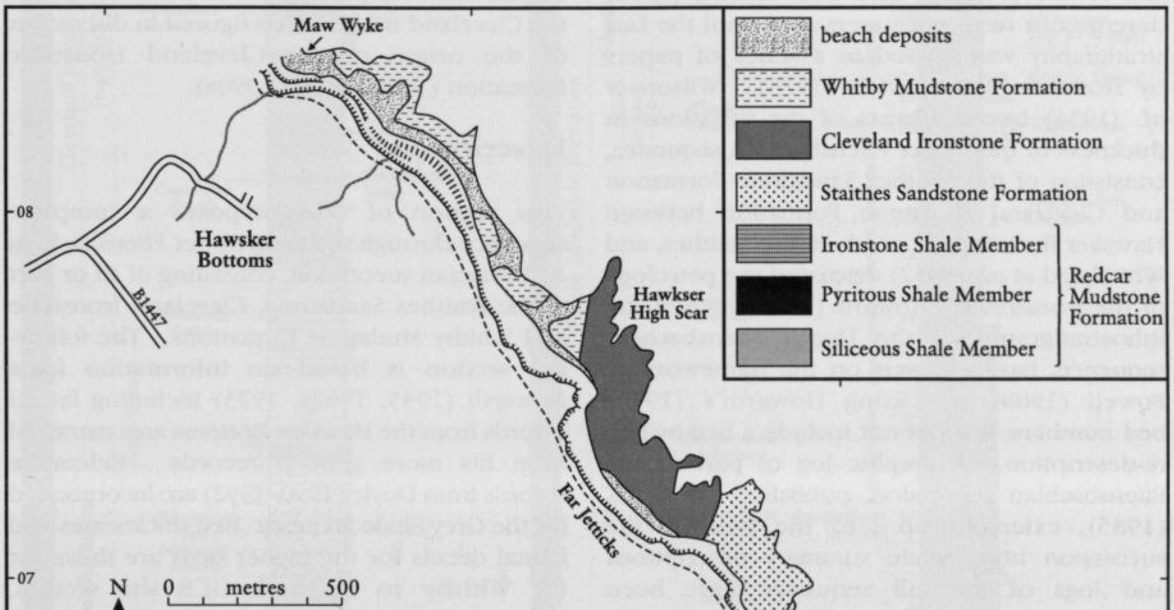

Figure 6.9 **Outcrop map of the main lithostratigraphical units exposed on the foreshore between Robin Hood's Bay and Hawsker Bottoms. After Knox *et al.* (1990).**

accounts of the site. Further descriptions can be found in the [British] Geological Survey memoir for Whitby and Scarborough (Fox-Strangways and Barrow, 1882), although with some errors perpetuated in later memoirs (Fox-Strangways, 1892; Fox-Strangways and Barrow, 1915). Herries (1906a,b) provided an account of the succession, including a sketch section of the cliffs and an outcrop map of the shore. Further descriptions included those of Buckman (1915) and Arkell (1933). Tate and Blake's (1876) descriptions were not superseded until the Lias stratigraphy was revised in a series of papers by Howarth (1955, 1962a, 1973). Wilson *et al.* (1934) traced aspects of the variations in thickness of the Upper Pliensbachian sequence, consisting of the Staithes Sandstone Formation and Cleveland Ironstone Formation between Hawsker Bottoms and north-east of Staithes, and Whitehead *et al.* (1952) discussed the petrology of the ironstones. Howard (1985) revised the lithostratigraphy of the Upper Pliensbachian sequence, based in part on the framework of Powell (1984) and using Howarth's (1955) bed numbers, but did not include a bed-by-bed re-description. A graphic log of part of the Pliensbachian succession, published by Phelps (1985), extended up into the base of the succession here, while summary descriptions and logs of the full sequence have been published by Hesselbo and Jenkyns (1995) (Figure 6.10). Powell (1984) proposed that the section near Hawsker Bottoms should be designated as stratotypes for the Grey Shale Member and Jet Rock of the Mulgrave Shale Member, although clearly the latter should now be located at Port Mulgrave. He also proposed that the section from Hawsker Bottoms to Whitby Harbour be considered the stratotype for the Toarcian Whitby Mudstone Formation. The Toarcian sections at Hawsker Bottoms were referred to by Scrutton (1996), who noted that most of the Alum Shale Member is exposed in the cliff. Elements of the fauna from these higher levels are commonly found amongst fallen material on the beach. Reviews of the sedimentology and petrology of the Upper Pliensbachian succession are included in Hallam (1967a), Chowns (1968), Catt *et al.* (1971), Greensmith *et al.* (1980), Young *et al.*, (1990a) and Parkinson (1996).

The site has long been a rich source of fossil material that was described by the early geologists, including Simpson (1855) and Tate and Blake (1876), and in many other publications since, notably those of Doyle (1990–1992) on the belemnites and Howarth (1958, 1962a, 1973, 1992) on the ammonites. Almost half of the known species of amaltheid ammonite recorded in Britain were described originally from here and the site lends its name to the uppermost Pliensbachian ammonite *Pleuroceras hawskerense*. The section is also an important source of data contributing towards an understanding of patterns and processes of sedimentation in the Cleveland Basin. It has figured in discussion of the origin of the Cleveland Ironstone Formation (Young *et al.*, 1990a).

Description

This section of coast exposes a complete sequence through the local Upper Pliensbachian and Toarcian succession, consisting of all or part of the Staithes Sandstone, Cleveland Ironstone and Whitby Mudstone formations. The following section is based on information from Howarth (1955, 1962a, 1973) including faunal records from the Hawsker Bottoms area extracted from his more general records. Belemnite records from Doyle (1990–1992) are incorporated for the Grey Shale Member. Bed thicknesses and faunal details for the higher beds are those for the **Whitby to Saltwick** GCR site section, although Howarth (1962a) states that there is very little thickness variation between these sites. The graphic log in Figure 6.10, although compiled independently by Hesselbo and Jenkyns (1995), does not differ substantially from the descriptive log below and the same bed numbers, of Howarth (1955, 1962a, 1973) and Phelps (1985), are used.

Thickness (m)

LOWER TOARCIAN SUBSTAGE
Whitby Mudstone Formation
Alum Shale Member
Main Alum Shale Beds (part)

51: Shale, seen on scar north-west of Maw Wyke Hole, above Bed 50. According to Howarth (1962a) no higher levels are exposed on the foreshore here.

Hard Shale Beds (NZ 942 083–NZ 940 085)

49–50: Shale with concretions, capped by a 0.13 m-thick red sideritic mudstone; lower part seen on the eastern side of Maw Wyke Hole and upper part in the scar a short distance north-west of Maw Wyke Hole. Belemnites (including *Acrocoelites*) and ammonites (*Dactylioceras*) present. Includes part of the *commune* Biohorizon. 6.4

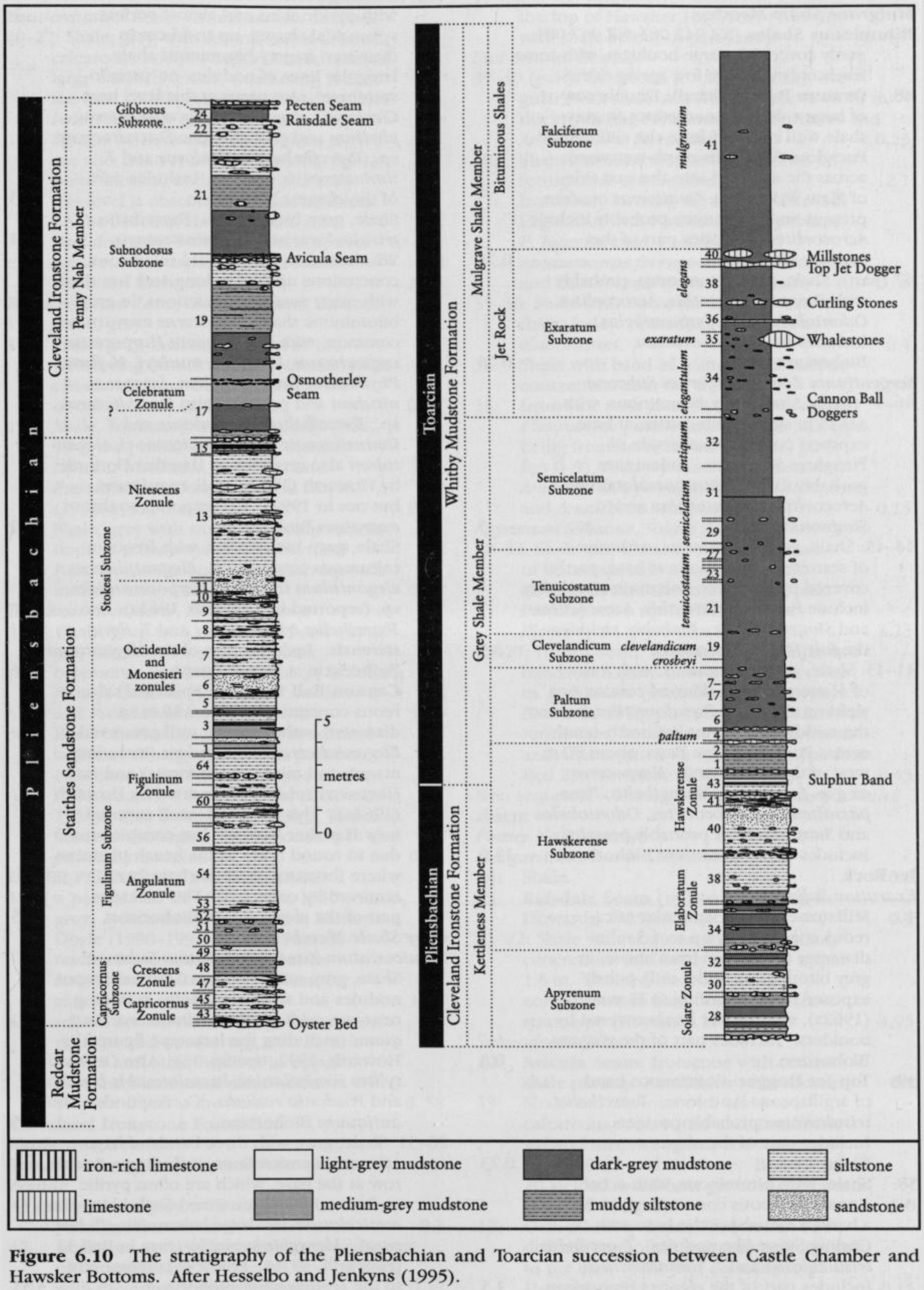

Figure 6.10 The stratigraphy of the Pliensbachian and Toarcian succession between Castle Chamber and Hawsker Bottoms. After Hesselbo and Jenkyns (1995).

Thickness (m)

Mulgrave Shale Member

Bituminous Shales (NZ 942 083–NZ 947 081; partly covered by large boulders, with some levels only visible at low spring tides).

48: **Ovatum Bed** (or Band): Double row of large sideritic, concretions in grey shale well exposed from the cliff behind Pursglove Stye Batts north-westwards across the scar and into the east side of Maw Wyke Hole; *Ovaticeras ovatum* present and belemnites probably include *Acrocoelites*. Includes part of the *ovatum* Biohorizon. 0.25

47 (part): Shale, grey, bituminous, probably with *Parapassaloteuthis*, *Acrocoelites*, *Odontobelus* and *Simpsonibelus*. Includes part of the *ovatum* Biohorizon. 0.75

Serpentinum Zone, Falciferum Subzone

46–47 (part): Shale, grey, bituminous, with a 0.13 m sideritic mudstone at base, exposed on the western side of Pursglove Stye Batts. Belemnites probably include *Parapassaloteuthis*, *Acrocoelites*, *Odontobelus* and *Simpsonibelus*. 5

44–45: Shale, grey, bituminous, with row of scattered concretions at base, partly covered by boulders; belemnites probably include *Parapassaloteuthis*, *Acrocoelites* and *Simpsonibelus*. Probably includes the *falciferum* Biohorizon. 3.5

41–43: Shale, grey, bituminous, with a row of scattered pyrite-skinned concretions yielding abundant *Pseudomytiloides* near the middle (seen running north–south across Pursgrove Stye Batts, about 80 m west of the Millstones). *Harpoceras* ex grp. *falciferum*, *Youngibelus*, *Parapassalteuthis*, *Acrocoelites*, *Odontobelus* and *Simpsonibelus* probably present. Includes the *mulgravium* Biohorizon. 13.6

Jet Rock

Exaratum Subzone

40: **Millstones**: Giant lenticular calcareous concretions, up to 4.5 m in diameter when seen from above, in grey bituminous shale; only poorly exposed here according to Howarth (1962a), with higher levels covered by boulders. Includes part of the *elegans* Biohorizon. 0.3

39: **Top Jet Dogger**: Continuous band of argillaceous limestone. *Toarcibelus trisulculosus* probably present. Includes part of the *elegans* Biohorizon. 0.23

38: Shale, grey, bituminous, with occasional calcareous concretions, including a band 0.3 m above the base with Curling Stone-like nodules. *Toarcibelus trisulculosus* and *T. ilminsterensis*. Includes part of the *elegans* Biohorizon. 1.5

37: **Curling Stones**: Calcareous concretions with pyritic skins and almost perfect spheroidal shapes, up to 45 cm in diameter, in grey bituminous shale. Irregular lines of nodules, or 'pseudo-vertebrae', also occur at this level here. *Cleviceras elegans*, *Phylloceras heterophyllum* and probably also *Dactylioceras* sp., *Toarcibelus trisulculosus* and *T. ilminsterensis* present. Includes part of the *elegans* Biohorizon. 0.3

36: Shale, grey, bituminous. *Toarcibelus trisulculosus* and *T. ilminsterensis*. 1.1

35: **Whalestones**: Large ovoid calcareous concretions up to 3 m long and 1 m thick, with many smaller concretions, in grey bituminous shale. *Cleviceras exaratum* common, with less frequent *Harpoceras serpentinum*, *Hildaites murleyi*, *H. forte*, *Phylloceras heterophyllum*, *Lytoceras nitidum* and probably also *Dactylioceras* sp., *Toarcibelus trisulculosus* and *T. ilminsterensis*. *Elegantuliceras* cf. *elegantulum* also recorded at Hawsker Bottoms by Howarth (1962a, as *E. rugulatum*, but not in 1992). Corresponds to the *exaratum* Biohorizon. 0.9

34: Shale, grey, bituminous, with frequent calcareous concretions. *Elegantuliceras elegantulum* frequent, *Harpoceratoides* sp. (reported by Howarth, 1962a), also *Toarcibelus trisulculosus* and *T. ilminsterensis*. Includes part of the *elegantulum* Biohorizon at Port Mulgrave. 2.6

33: **Cannon Ball Doggers**: Spherical calcareous concretions up to 0.18 m in diameter, with common well-preserved *Elegantuliceras elegantulum* (including macro- and micro-conch forms) and rare *Harpoceratoides* sp. reported by Howarth (1962a). This horizon is well exposed near Hawsker Bottoms but conspicuous due to round holes in the beach platform, where the actual nodules have been removed by collectors. This includes part of the *elegantulum* Biohorizon. 0.15

Grey Shale Member

Tenuicostatum Zone, Semicelatum Subzone

32: Shale, grey, with occasional flat calcareous nodules and some shell beds, including near top, with crushed *Tiltoniceras antiquum* (including the lectotype figured by Howarth, 1992, text-fig. 13). Also *Orthodactylites semicelatum*, *Passaloteuthis bisulcata* and *Posdonia radiata*. Corresponds to the *antiquum* Biohorizon. 1.85

28–31: Shale, grey, with three bands of large calcareous concretions, including a double row at the base, which are often pyritic and contain well-preserved *Orthodactylites semicelatum* and large belemnites (*P. bisulcata*). *Meneghiniceras lariense* in Bed 31 (Howarth, 1976). Probably corresponds to the *semicelatum* Biohorizon. 3.53

Thickness (m)

Tenuicostatum Zone, Tenuicostatum Subzone

20–27: Shale, grey, with several bands of small calcareous nodules and a double band of large calcified lenses, weathering red, at the base. Well-preserved *Orthodactylites tenuicostatum* (including the neotype figured by Buckman, 1909–1930, pl. 57; see also Dean *et al.*, 1961, pl. 72, fig. 1) occur in small nodules but generally this level is obscured beneath boulders on the beach at Hawsker Bottoms. *Passaloteuthis bisulcata* probably also present. Corresponds to the *tenuicostatum* Biohorizon. 2.72

Tenuicostatum Zone, Clevelandicum Subzone

19c: Shale, grey. 0.8

19b: Shale, grey, including a band of red-weathering lenticles with *Orthodactylites clevelandicum*. Corresponds to the *clevelandicum* Biohorizon. 0.05

19a: Shale, laminated and bituminous (Bed 19 is the probable source of *Passaloteuthis bisulcata, P. milleri* and *Pseudohastites longiformis* in Doyle (1990–1992, text-fig. 3)). 0.41

18: Shale, grey with small calcareous concretions. *Orthodactylites crosbeyi* and *Passalotheuthis bisulcata*. Corresponds to the *crosbeyi* Biohorizon. 0.38

Tenuicostatum Zone, Paltus Subzone

4–17: Shale, grey, with six bands of calcareous and sideritic concretions. Some belemnites and bivalves present, including *Passalotheuthis bisulcata, P. milleri* and *Pseudohastites longiformis*. 5.42

3c: Band of sideritic, calcareous mudstone with rare *Protogrammoceras paltum* (Buckman), *Dactylioceras* sp. and also *P. bisulcata* (= Bed 45, part, of Howarth, 1955). This is the lowest typical Toarcian fauna in the region, corresponding to the *paltus* Biohorizon. 0.08

UPPER PLIENSBACHIAN SUBSTAGE

1–2 (= part of Bed 45 of Howarth, 1955): Shale, grey. *Lytoceras* sp. recorded at Kettleness. Doyle (1990–1992) records *Passaloteuthis bisulcata, Pseudohastites longiformis* and *Parapassaloteuthis zieteni* in the district. *c.* 1.15

43 (part)–44 (of Howarth, 1955): Limestone, nodular, red-weathering, with *Pseudopecten* and other bivalves in upper part and bituminous shale of the Sulphur Band at the base. 0. 58

Cleveland Ironstone Formation

Kettleness Member

Spinatum Zone, Hawskerense Subzone, Hawskerense Zonule

43 (part): Shale, grey, with calcareous nodules yielding *Pleuroceras hawskerense*. 0.3

42: Ironstone, red, with irregular top and nests of *Tetrarhynchia tetrahedra*, and bivalves, with *Pleuroceras hawskerense*. *c.* 0.12

40 (part)–41: Sandstone, calcareous, forming the top of Hawsker High Scar (0.45 m), with shale below, in part sandy. *c.* 1.7

Elaboratum Zonule

39–40 (part): Ironstone (*c.* 0.08 m thick), irregular, with shale and siltstone above (0.15 m thick) yielding *Pleuroceras elaboratum* and *Amauroceras ferrugineum*. 0.23

38: Shale and siltstone with occasional ferruginous concretions. 2.1

37: Ironstone, forming the base of Hawsker High Scar, with *Pleuroceras apyrenum, P. hawskerense, P. elaboratum, Amauroceras ferrugineum, A. lenticulare* and *Pseudoamaltheus engelhardti*. 0.08

35–36: Shale with ironstone band (0.1 m thick) below containing *Pleuroceras elaboratum*. 0.4

34: Shale with band of scattered calcareous concretions near the middle. 1.35

33: Ironstone with abundant bivalves and *Pleuroceras paucicostatum* (the holotype being from here; Howarth, 1958, pl. 6, figs 6–9), *P. apyrenum, P. elaboratum, Amauroceras ferrugineum, A. lenticulare* and *Amaltheus reticularis*. 0.15

Apyrenum Subzone, Solare Zonule

28–32: Shale and siltstone with two bands of ironstone below and a band of calcareous nodules in the upper part. *Pseudopecten equivalvis* present. *Pleuroceras apyrenum* in Bed 30. 3.75

25–27: Pecten Seam. Ironstone, oolitic, in two bands with shale between. *Pleuroceras* ex grp. *solare* (including the neotype; Howarth, 1958, pl. 5, fig. 1), *P. solare* var. *solitarium, Amaltheus* aff. *margaritatus* and *A. laevigatus* Howarth (holotype from Bed 25; Howarth, 1958, pl. 4, fig. 1). 0.43

Non sequence – *Transiens* and *Salebrosum zonules* absent

Penny Nab Member

Margaritatus Zone, Gibbosus Subzone

24: Shale. 0.5

23: **Raisdale Seam** (= Two Foot Seam in Howarth, 1955): Ironstone. 0.1

21–22: Shale with siltstone above and sandy concretions and sandy streaks in upper 1.5 m. Defined base of subzone corresponds to base of Bed 21 parastratotype (Howarth, 1992). 4.95

Subnodosus Subzone

20: **Avicula Seam**: Ironstone with central shale parting. *Amaltheus subnodosus*. 0.4

19: Shale and siltstone with scattered calcareous concretions and *Amaltheus subnodosus, A. striatus* and *A. margaritatus* 0.45 m above base. Bed 19 or 20 yielded *Amaltheus gloriosus* (Howarth, 1958, pl. 3, fig. 3). 5.0

18: **Osmotherley Seam**: Ironstone. The defined base of the subzone corresponds to the base of the bed parastratotype in Howarth (1992). 0.15

	Thickness (m)
Stokesi Subzone, Nitescens (?part) and *Celebratum zonules*	
17: Shale with scattered calcareous concretions.	2.1
Staithes Sandstone Formation	
14–16: Double band of sandy ironstones with *Amaltheus stokesi* separated by sandy shale and siltstone. Nests of *Protocardia truncata* in upper ironstone.	0.8
Nitescens Zonule, ?part	
12–13: Ironstone, thin, red (*c*. 0.08 m thick), overlain by thick sandy shale and siltstone with scattered calcareous concretions. *Amaltheus stokesi, A. wertheri* frequent, *A. bifurcus* (holotype from 1.7 m from top of Bed 13; Howarth, 1958, pl. 1, fig. 6) and rare *Protogrammoceras nitescens* (possibly including the holotype from here or near Staithes re-figured by Howarth, 1992, pl. 4, fig. 4, and probably also the holotype of *P. geometricum*, pl. 4, fig. 2 and pl. 5, fig. 2).	5.6
Occidentale and *Monestieri zonules*	
8–11: Sandstone and sandy shale and siltstone, with a basal band of calcareous concretions rich in *Protocardia truncata*.	1.8
1–7: Shale, sandy, with sandstone band and red calcareous concretions in lower part, with some bands rich in *Gryphaea* and other bivalves. *Amaltheus stokesi* and *A. bifurcus* in Bed 1. Defined base of Stokesi Subzone corresponds to the base of Bed 1 parastratotype (Howarth, 1992).	5.2
LOWER PLIENSBACHIAN SUBSTAGE	
Davoei Zone, Figulinum Subzone, Figulinum Zonule	
62–65 (of Phelps 1985) (= beds ii–v of Howarth, 1955): Two bands of red calcareous concretions separated by sandy shale and siltstone, with *Oistoceras figulinum, O. curvicorne* and a form transitional to *Amaltheus bifurcus* (Phelps, 1985) in the upper band and *O. figulinum* in the lower band.	0.45
Angulatum Zonule	
59–61 (= Bed i): Sandstone, hard, ferruginous, forming the floor of Castle Chamber.	*c*. 2.15
49–58: Siltstone with concretionary bands in upper part and mudstone with ferruginous concretions near base. *Oistoceras angulatum* (including a form transitional from *Aegoceras crescens*) and *Liparoceras divaricosta* present in beds 49–51, with *Oistoceras ?angulatum* and *O.* sp. in beds 54–55 (thicknesses estimated from Hesselbo and Jenkyns, 1995).	*c*. 6.4
Capricornus Subzone, Crescens Zonule	
46–48: Siltstone with some ferruginous concretions, including as a basal band. *Aegoceras crescens* present, including forms transitional from *A. capricornus* below and transitional to *Oistoceras angulatum* above (thickness estimated from Hesselbo and Jenkyns, 1995).	*c*. 1.6
Capricornus Zonule	
42–45: Siltstone with a band of ferruginous nodules and concretions. *Aegoceras capricornus* present (thickness estimated from Hesselbo and Jenkyns, 1995).	*c*. 1.3
41: **Oyster Bed**: Ferruginous concretionary band. *Aegoceras ?capricornus*.	0.2

The lower part of the Staithes Sandstone Formation is exposed in and around Castle Chamber (Figure 6.9). The base of the formation is taken at the distinctive ferruginous shelly sandstone of the Oyster Bed. The formation here is about 25.8 m thick and dominated by siltstones with some mudstone units near the base and fine sandstone around the middle. Small-scale coarsening- and fining-upward cycles are evident. Most units are bioturbated, but some preserve hummocky cross-beds, wave ripples or gutter casts. Ironstone nodules are common at certain levels in the lower part of the formation and were noted by Parkinson (1996) as having anomalously high thorium–potassium ratios. Calcareous nodules occur at several levels towards the top of the formation.

The position of some of the lithostratigraphical boundaries has been the subject of some discussion. Cope *et al.* (1980a) placed the base of the Cleveland Ironstone Formation at the base of Bed 14, but Powell (1984) placed it at the base of Bed 12, and Howard (1985) placed it at the base of Bed 17 (Figure 6.10), a shale with scattered clay nodules, which is the position adopted in this account. The formation is 25.4 m thick and dominated by metre-scale coarsening-upward cycles of light to dark mudstones and siltstones with ironstone nodules common at some levels and with several thin (< 0.3 m thick) but continuous ironstone bands at the tops of the cycles. Unlike the ironstone bands at the top of the cycles at Staithes (Myers, 1989), only the Pecten Seam shows a significant increase in thorium–potassium ratios (Parkinson, 1996). Some of the nodules and ironstone beds are richly fossiliferous and this locality has yielded more species types of amaltheid ammonite than any other site. These include *Amaltheus bifurcus* from Bed 13; possibly *A. striatus* from Bed 19; *Amaltheus laevigatus*, *Pleuroceras solare* and *P. solare* var. *solitarium* from Bed 25; *Amaltheus reticularis* and *Pleuroceras paucicostatum* from Bed 33; *Amouroceras ferrugineum*, *Pleuroceras birdi* and possibly *Amouroceras lenticulare* from Bed 33 or Bed 37; *Pleuroceras hawskerense* transient *elaboratum* from Bed 40; and *P. hawskerense* from Bed 42 (Howarth, 1958). The silty mudstones of Bed 21 at Far Jetticks yielded the holotype of the crinoid *Balanocrinus solenotis* (Simms, 1989). Morgans (1999) examined calcitized and pyritized driftwood from the Penny Nab Member at this site, finding evidence for a seasonally wet and dry climate.

The base of the Whitby Mudstone Formation was placed at the base of Bed 45 by Powell (1984), and around the middle of Bed 43 by Cope *et al*. (1980a) and by Hesselbo and Jenkyns (1995); the latter is the postion adopted in this account. Towards the middle of Bed 43 (Howarth, 1955) is a finely laminated shale, taken to represent the Sulphur Band. The lowest 0.3 m of Bed 43 is a sandy mudstone (Howarth, 1955).

The lower unit of the Whitby Mudstone Formation, the Grey Shale Member, is 13.3 m thick and consists of silty, micaceous, pyritic, mudstone with bands of typically small calcareous concretions, which tend to be more sideritic and weather a red colour in the lower part of the sequence, passing into laminated shales above. Ripple-laminated siltstones are also present in the lower part of the sequence. Howarth (1973) recognized that the general sequence of beds within the member is remarkably constant, in terms of lithology and fauna, throughout the coastal sections from Ravenscar to Port Mulgrave. Consequently he presented only a single composite section for the unit, but identified the individual source localities of the cited faunas. The first definite records of Toarcian style ammonites, namely *Protogrammoceras paltum* and *Dactylioceras* sp., are from Bed 3 of the Grey Shale Member at Hawsker Bottoms (Howarth, 1973, 1992; = Bed 45 of Howarth, 1955) and mark the base of the Toarcian Stage in the Cleveland Basin. The type of *Tiltoniceras antiquum* was obtained from Bed 17 here or at Staithes. A single specimen of *Meneghiniceras lariense* recovered from Bed 31 represents the only known British occurrence of this exclusively Tethyan juraphyllitid genus and is also stratigraphically younger than any other juraphyllitid in Britain (Howarth, 1976; Howarth and Donovan, 1964).

The base of the overlying Mulgrave Shale Member is taken at a prominent bed, the Cannon Ball Doggers (Bed 33) (Powell, 1984). The Mulgrave Shale Member is remarkably consistent in thickness throughout its coastal exposure, with a figure of 32.3 m (105 ft) cited by Howarth (1962a). It is dominated by organic-rich laminated shales with several distinctive bands of often large calcareous nodules. The fauna is dominated by nektonic and planktonic taxa, particularly ammonites and belemnites. Rare remains of teuthids, recorded as *Geoteuthis* by Tate and Blake (1876), also probably are from the Mulgrave Shale Member here. Vertebrate remains have rarely been recorded from here. Benton and Taylor (1984) listed an example of the ichthyosaur *Leptopterygius acutirostris* from an unspecified horizon, although examples of this species from elsewhere have been recorded from the Mulgrave Shale and Alum Shale members.

Interpretation

The ammonite faunas of the Upper Pliensbachian part of the succession were described by Howarth (1955, 1958). They include proposed stratotypes, or parastratotypes, for the bases of the Stokesi, Subnodosus, Gibbosus, Apyrenum and Hawskerense subzones and hence the Margaritatus and Spinatum zones themselves. The lectotype of the subzonal index fossil *Pleuroceras hawskerense* (Young and Bird, 1828) came from Hawsker Bottoms (Buckman, 1923). Meister (1988) discussed further the evolution of the Amaltheidae and figured a good selection of specimens from Hawsker. Howarth (1955) proposed that the base of the Hawskerense Subzone should be taken at the base of Bed 38 of the Cleveland Ironstone Formation at Hawsker. However, older faunas with *Pleuroceras elaboratum* were considered by Dommergues *et al*. (1997) to characterize an Elaboratum Zonule in the lower part of this subzone. Hence the base of the Hawskerense Subzone should be drawn lower according to this latter scheme, probably at the base of Bed 33 according to records by Meister (1988). Ammonites characteristic of the Solare Zonule are known from the Pecten Seam at Hawsker Bottoms, while the bed immediately below it near Staithes yields *Amaltheus gibbosus* (see **Staithes to Port Mulgrave** GCR site report), hence the base of the Apyrenum Subzone can be drawn at the base of the Pecten Seam, Bed 25. However, information from France and elsewhere indicates that there are earlier *Pleuroceras* faunas, corresponding to the Transiens and Salebrosum zonules of the Apyrenum Subzone (Dommergues *et al*., 1997), that are not present in Yorkshire. The absence of early *Pleuroceras* faunas in Yorkshire, including *P. transiens* which is known elsewhere in Britain on Raasay (Howarth, 1958), indicates a widespread non-sequence as already predicted on lithological and sedimentological grounds by Howard (1985).

The succession here can be correlated with equivalent sections elsewhere along the Yorkshire coast on the basis of marker beds and ammonite faunas. Although the Toarcian succession remains relatively constant in thickness and facies (Howarth 1962a, 1973), there are marked variations in the Upper Pliensbachian successions. At the **Staithes to Port Mulgrave** GCR site, the Staithes Sandstone and Cleveland Ironstone formations are coarser than at Hawsker Bottoms, and the ironstone bands, poorly developed at Hawsker, are significantly thicker (Figure 6.11). This north-westerly thickening continues across to the iron workings at Eston, where the ironstone beds in the Kettleness Member form a single bed several metres thick with thin shale partings (Young *et al.*, 1990a). Hesselbo and Jenkyns (1995) suggested that the finer-grained sediments at Hawsker were indicative of a more distal position within the basin. However, in apparent contradiction to this, the non-sequence at the base of the Kettleness Member (see Figure 6.11) is more marked at Hawsker than elsewhere,

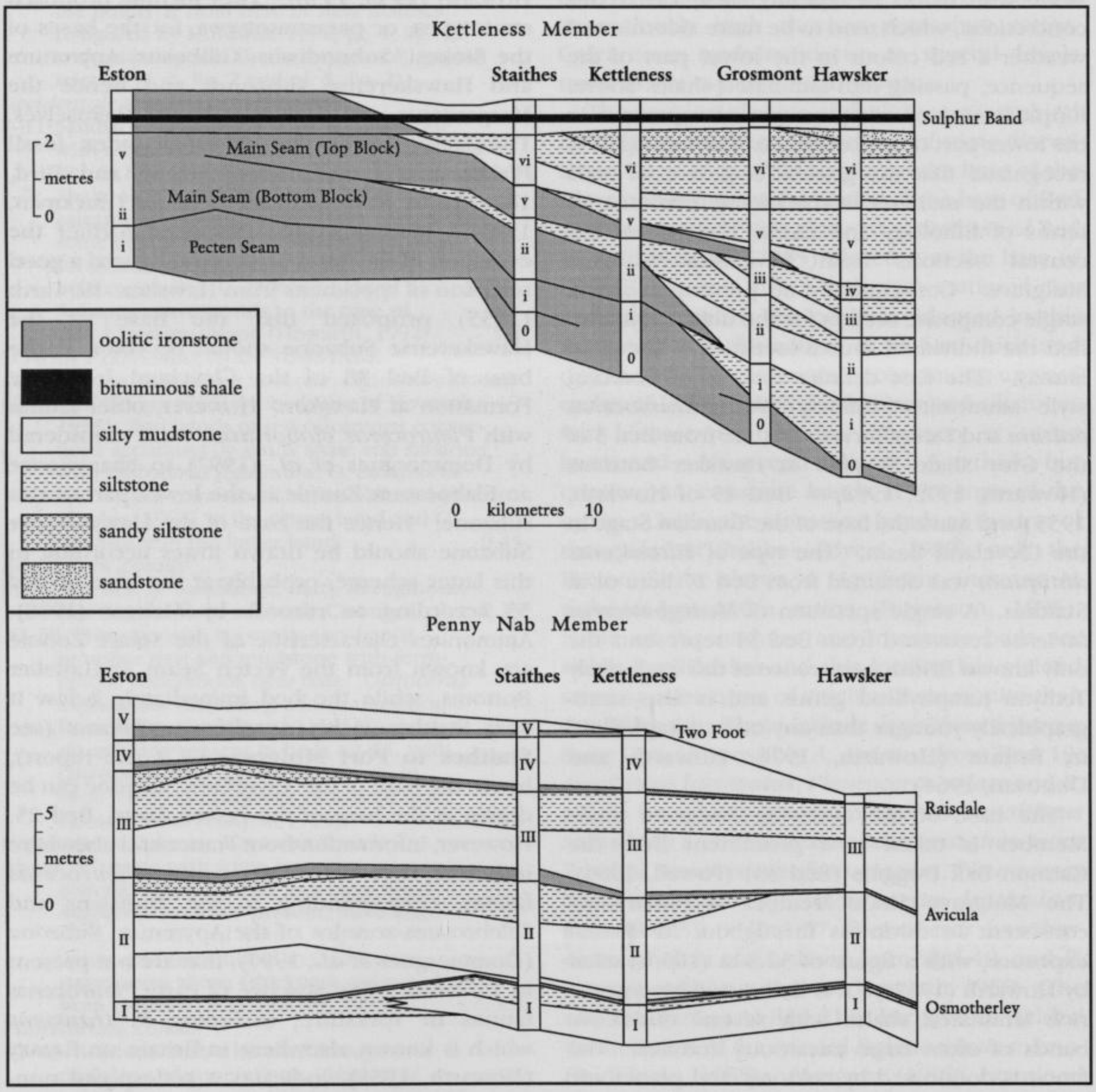

Figure 6.11 Lateral variation in the Cleveland Ironstone Formation along NW–SE transects between Eston and Hawsker. Datum for the Kettleness Member is the Sulphur Band; datum for the Penny Nab Member is the base of the Two Foot Seam. Roman numerals indicate the cycles of Howard (1985). After Young *et al.* (1990a).

perhaps reflecting opposing directions of sediment progradation during the Penny Nab and Kettleness members. The thin laminated mudstone of the Sulphur Band has been attributed to eustatic sea-level rise. The influence of this becomes even more pervasive in the Mulgrave Shale and Alum Shale members which, except within the Peak Trough, show a remarkable uniformity of thickness and facies development along the entire coast.

Conclusions

The coastline between the Castle Chamber and Hawsker Bottoms area exposes a continuous section following on from that on the north side of Robin Hood's Bay (**Normanby Stye Batts–Miller's Nab** GCR site), extending from the base of the Upper Pliensbachian Substage, through the Pliensbachian–Toarcian boundary, and well into the mid-Toarcian, encompassing the Staithes Sandstone Formation, the Cleveland Ironstone Formation and the Whitby Mudstone Formation. Facies developments in the Staithes Sandstone and Cleveland Ironstone formations here are fundamental to understanding the history of sedimentation in the Cleveland Basin. The Toarcian section here complements that nearer Whitby, where the lower part of the Toarcian succession is not exposed. The site is the location for the type populations of almost half of the known species of amaltheid ammonite and hence is of international importance for Upper Pliensbachian biostratigraphy.

MILLER'S NAB TO BLEA WYKE, NORTH YORKSHIRE (NZ 968 027–NZ 989 014)

K.N. Page

Introduction

The cliffs and foreshore of the Miller's Nab to Blea Wyke GCR site, located below the village of Ravenscar, expose a Toarcian succession that is famous in Yorkshire and unique in Britain, being almost stratigraphically complete and in relatively expanded mudrock facies. The succession is the type locality for the higher subdivisions of the Whitby Mudstone Formation in the Cleveland Basin, namely the Peak Mudstone and Fox Cliff Siltstone members, and the Blea Wyke Sandstone Formation, comprising the Yellow Sandstone and Grey Sandstone members. The succession also has the most completely developed and expanded Lower–Upper Toarcian boundary sequence seen anywhere in Britain, and provides the only exposure in the basin where the Upper Toarcian succession is present beneath the unconformity at the base of the Middle Jurassic Dogger Formation. This Upper Toarcian succession is absent from sites elsewhere along the Yorkshire coast, and the thickness and lithostratigraphy of the Lower Toarcian succession also differs significantly from other Yorkshire coast sites, which has important implications for basin history. At Peak, on the south-east side of Robin Hood's Bay, the coastline is cut by a major fault that juxtaposes Toarcian strata to the south against Sinemurian strata to the north (Figure 6.6).

The cliffs here are high and the beach platform narrow and boulder strewn, these factors being a significant hindrance to investigation of the site (Dean, 1954; Rawson and Wright, 1995). Wright (1860b) was the first to describe the Upper Toarcian part of the section, followed by Hudleston (1874). The description by Tate and Blake (1876) was based largely on Wright's (1860b) account with only minor modification. Fox-Strangways (1892) described a section near Blea Wyke. Rastall (1905) and Herries (1906a) provided further descriptions of the section, while Buckman's (1915) account was largely a review of earlier work. Davies (in Evans and Stubblefield, 1929) was the first to identify the position of the Lower–Middle Jurassic boundary: this was followed by a description by Rastall and Hemingway (1939). These descriptions of the site show significant variations in thickness and reflect the difficulties inherent in measuring the section.

Arkell (1933) and Sylvester-Bradley (1953) described the site briefly. Dean (1954) provided a detailed description of the upper part of the Toarcian Alum Shale Member and Howarth (1962a) described the beds between the Grey Shale Member and the Peak Mudstone Member. Hemingway *et al.* (1969) referred to the succession, and Knox (1984) established a formalized lithostratigraphical framework for the upper part, in part based on the scheme of Powell (1984). This was correlated with the ammonite zonation of Dean (1954). Hesselbo and Jenkyns (1995) used the same biostratigraphical account. Rawson and Wright (1995) figured sections extending from the top of the Grey Shale Member to the base of the Peak Mudstone Member here. Doyle (1990–1992) described the complete succession, the only author to do so. He used the bed numbers of Howarth (1962a) for the lower part of the succession, but he re-numbered the higher beds found only at this site, making comparison with earlier descriptions difficult.

Decriptions of the faunas are included in works by Simpson (1855), Buckman (1909–1930), Howarth (1992) and Doyle (1990–1992). Riding (1984b) reviewed the palynology of the sequence using Knox's (1984) sections.

Description

At the northern end of the site at Peak Steel the Peak Fault has a downthrow to the east of about 150 m (Milsom and Rawson, 1989). The Staithes Sandstone Formation is exposed at low tide as a fault-bounded wedge on the north side of the Peak Fault. The oldest strata exposed on the south side of the fault are the top beds of the Cleveland Ironstone Formation, equivalent to beds 43–44 of the Hawsker Bottoms (**Castlechamber to Maw Wyke** GCR site) section. The Grey Shale Member is poorly exposed on the foreshore, with strata equivalent to beds 12–27 of other sites obscured by boulders. The lower part of the Mulgrave Shale Member, the Jet Rock, is exposed on the shore with higher strata present in the cliff. A low southerly dip brings progressively younger strata to shore level between Peak Steel and Blea Wyke. Much of the outcrop is obscured by beach deposits and cliff falls. At the southern end of the site, the Blea Wyke Sandstone Formation forms part of the headland of Blea Wyke.

The following account is a composite based on several accounts. Notes on the Grey Shale Member follow Howarth (1973), and descriptions of the Mulgrave Shale and Alum Shale members are from Howarth (1962a, 1992). Howarth (1962a, 1992) used roman numerals as bed numbers for this site (Figure 6.12a,b) to distinguish the succession from the Whitby section. Dean's (1954) notes for the Upper Toarcian succession have been incorporated into the lithostratigraphical framework established by Powell (1984) and Knox (1984) and his bed numbers have been used for all but the lowest five beds of the Upper Toarcian Substage.

Thickness (m)

AALENIAN STAGE (part)
Dogger Formation
? Opalinum Zone
Terebratula Bed: Sandstone, hard, sideritic, with abundant phosphatic pebbles, derived from the Toarcian Stage below; with abundant *Lobotyris trilineata*, with *Gresslya*, *Trigonia*, crinoidal and woody debris. Belemnites, in part at least derived from below include *Acrocoelites pyramidalis*, *A. vulgaris*, *A. levidensis*, *A. subtricissus*, *Brevibelus breviformis* and *Megateuthis rhenana*.

UPPER TOARCIAN SUBSTAGE
Blea Wyke Sandstone Formation
Yellow Sandstone Member
Pseudoradiosa Zone, ?Levesquei–Pseudoradiosa subzones
82 (= Bed 81 of Doyle): Sandstones, massive, yellow, fine grained, with scattered impersistent ferruginous layers; bivalves and brachiopods present, including *Homeoeorhynchia cynocephala*, *H. acuta*, *Lobotyris* aff. *trilineata*, *Gresslya* sp., *Gervillia tortuosa*, *G. lata*, *Modiolus* sp., *Oxytoma inaequivalvis*, *Pinna cuneata* and *Trigonia striata*, also *Megateuthis rhenana*. Ammonites reported by Dean include *Dumortieria* spp. (*D. moorei*, *D. lata*, *D.* aff. *munda* and *D.* cf. *penexigua*). Top surface of unit burrowed, with *Skolithos*. — 8 (26 ft)

Grey Sandstone Member
?Dispansum Zone
81 (= Bed 80 of Doyle): Sandstone, grey, massive, with very uneven upper surface. Scattered ferruginous concretions, especially near top. *Homeoeorhynchia cynocephala*, *H. acuta*, *Serpula deplexa*, *S. ?compressa*, *Oxytoma inaequivalvis*, *Aulacothyris*, *Acrocoelites vulgaris*, *Simpsonibelus expansus*, *S. dorsalis*, *Brevibelus breviformis* and *Megateuthis glaber*. — 1.7 (5 ft 6 in.)

79–80 (= beds 78–79? of Doyle): Sandstone, grey, massive, forming part of the headland of Blea Wyke Point. Ferruginous hard band at base contains *Phylseogrammoceras dispansum*, *Hudlestonia affinis*, *Lingula beani*, *S. deplexa* and *O. inaequivalvis*. Upper 0.15 m is also ferruginous and rich in fossils, including *S. deplexa*, *S. ?compressa*, *Discinisca reflexa*, *Dentalium elongatum*, *Eryma birdi* and many belemnites (from beds 78–79 of Doyle, these include *Acrocoelites pyramidalis*, *A. levidensis*, *A. subtricissus*, *Simpsonibelus dorsalis* and *Megateuthis rhenana*). — 2 (6 ft 6 in.)

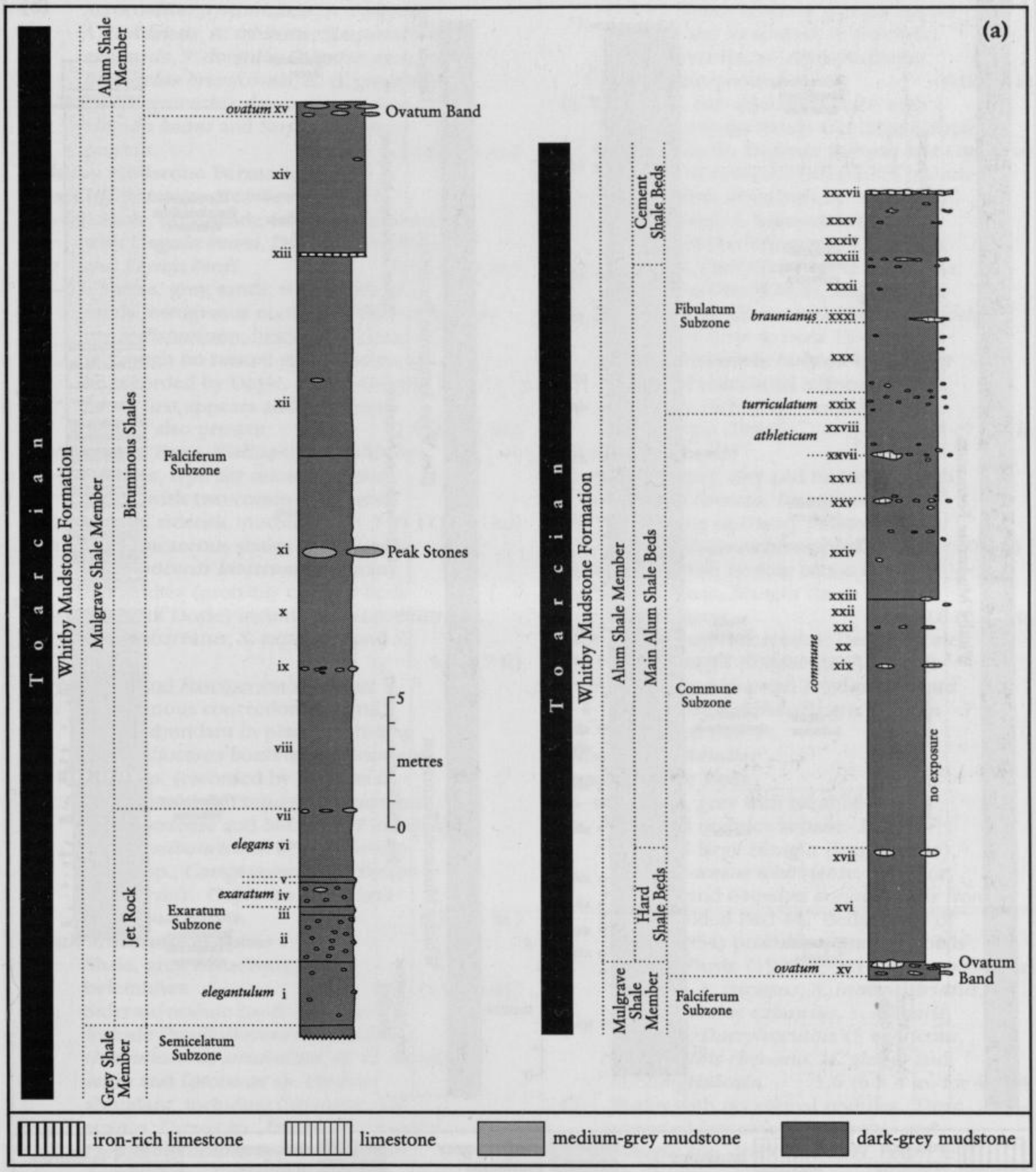

Figure 6.12a The Lower Toarcian succession exposed at Blea Wyke. Based on Hesselbo and Jenkyns (1995) and Howarth (1962a).

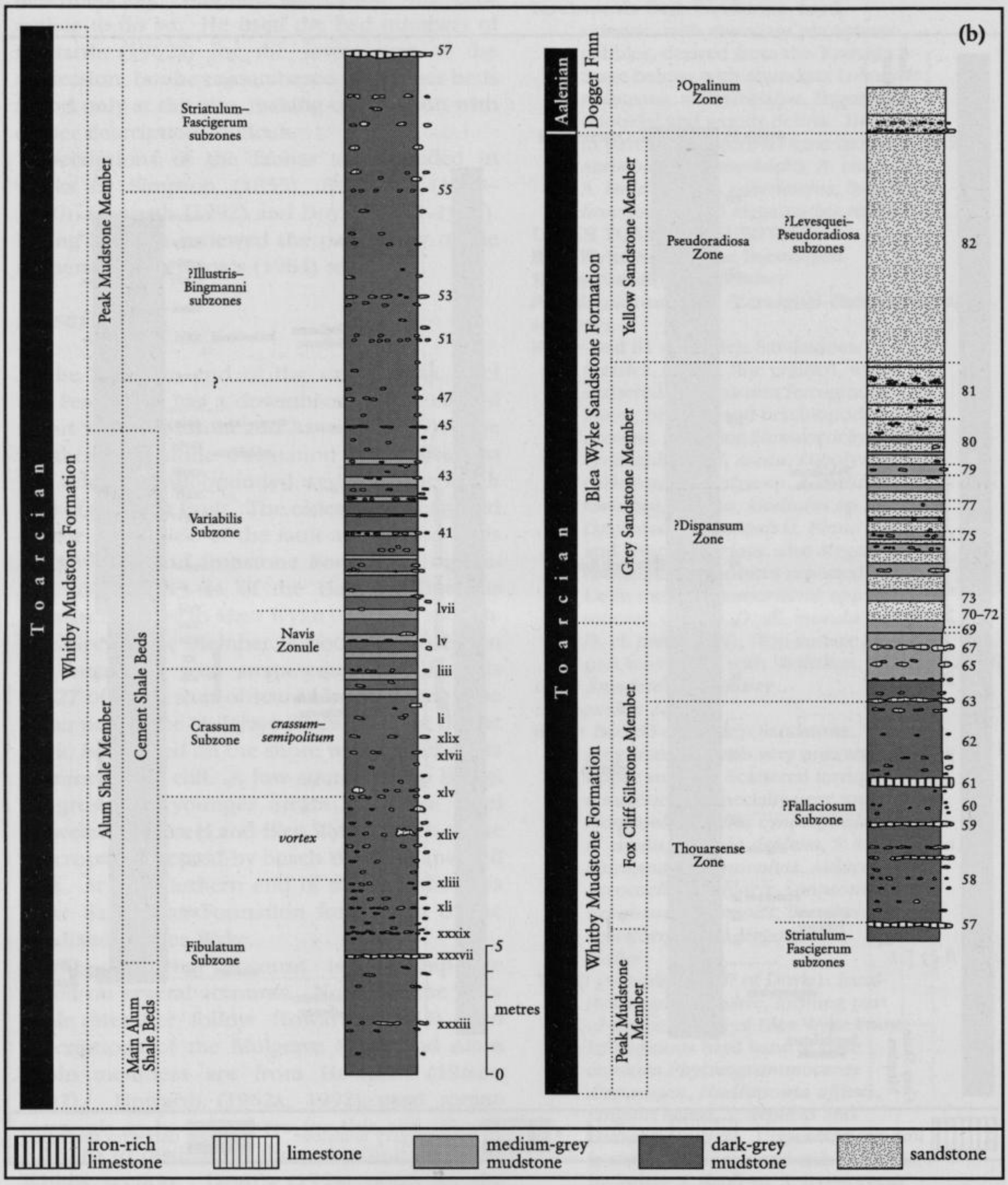

Figure 6.12b The Lower and Upper Toarcian succession exposed at Blea Wyke. Based on Hesselbo and Jenkyns (1995) and Howarth (1962a).

Thickness (m)

70–78 (= beds 58–77? of Doyle): Siltstone (?), grey, sandy, with ferruginous bands, and some concretions. Belemnites frequent, mainly in upper part, including *Acrocoelites pyramidalis*, *A. vulgaris*, *A. levidensis*, *A. tricissus*, *Simpsonibelus expansus*, *S. dorsalis*, *S. lentus* near base; *Brevibelus breviformis*, *B.* cf. *gingensis* and *Megateuthis rhenana* near top. *Lingula beani* and *Serpula deplexa* present. 6.3 (20 ft 6 in.)

Whitby Mudstone Formation

Fox Cliff Siltstone Member

68–69: Shale, grey, sandy, ferruginous above, with *Lingula beani*, *Discinisca reflexa* and *Eryma birdi*. 0.5 (1 ft 8 in.)

63–67: Shales, grey, sandy, with bands of sandy ferruginous nodules. *Phlyseogrammoceras dispansum*, belemnites common (although no named species seem to be recorded by Doyle, 1990), *Lingula beani* first appears and *Disciniscа reflexa* also present. 2.5 (8 ft 1 in.)

Thouarsense Zone, ?Fallaciosum Subzone

59–62: Shales, typically micaceous and sandy, with two continuous bands of hard sideritic mudstone. 3.85 (12 ft 6 in.)

58: Grey micaceous shales with *Pseudogrammoceras latescens* and many belemnites (probably close to beds 31–37 of Doyle) including *Acrocoelites inaequistriatus*, *S. expansus* and *S. lentus*. 5.2 (17 ft)

Striatulum and *Fascigerum subzones*

57: Ferruginous concretionary band, fossils abundant in places including *Pseudolioceras boulbiense*, *Grammoceras* sp. (recorded by Dean as *G.* cf. *striatulum*), *Pseudogrammoceras* (aff. *doertense* and ?aff. *audax* in Dean), *Ostrea subauricularis*, *Pseudomytiloides* sp., *Camptonectes* sp., *Pecten disciformis*. *Oxytoma substriata* and *Venus tenuis*. 0.23 (9 in.)

Peak Mudstone Member

56: Shale, grey, micaceous, with belemnites. 4.15 (13 ft 6 in.)

55: Sideritic nodule band. Ammonites include *Pseudolioceras boulbiense*, *Grammoceras striatulum*, *G.* cf. *thouarsense* and *Lytoceras* sp. bivalves abundant, including *Oxytoma substriata*, *Ostrea* sp., *Pecten disciformis*, *Pseudomytiloides* sp., *Venus tenuis*, *Actaeon*? sp., *Camptonectes* sp., and *Protocardia* sp.. 0.15 (6 in.)

Variabilis Zone, ?Illustris–Vitiosa subzones to *Thouarsense Zone, Bingmanni Subzone*

54: Shale, grey, micaceous, with abundant belemnites (probably equivalent to Bed 19 of Doyle) with *Acrocoelites tricissus*, *Simpsonibelus expansus*, *S. dorsalis* and *S. lentus*. 2.5 (8 ft)

53 (= Bed 18 of Doyle?): Mudstone, sideritic, with uncrushed body chambers, and occasionally parts of other whorls, of large *Podagrosites/Denckmannia* (aff. *bodei* in Dean). *Ostrea subauricularis*, *Camptonectes*, *Acrocoelites levidensis*, *A. tricissus*, *A. inaequistriatus*, *Simpsonibelus lentus* also present. 0.08 (3 in.)

49–52: Shales, silty and micaceous, with several nodular bands and large *Haugia* sp. (crushed); *Trigonia literata* and *Oxytoma substriata* present. Belemnites include *Acrocoelites levidensis*, *A. tricissus*, *A. subtricissus*, *A. inaequistriatus*, *Simpsonibelus expansus*, *S. dorsalis*, *S. lentus*, *Dactyloteuthis* cf. *venticosa*, *Brevibelus breviformis*, *Megateuthis rhenana*, *M. glaber* and *M.*? *longisulcata* (probably close to beds 15–17 of Doyle). Probable horizon of *c.* 0.5 m length of articulated icthyosaur vertebrae (K.N. Page, unpublished observation, 1985). 2.4 (7 ft 9 in.)

?Variabilis Subzone

48: Shales, grey, silty and micaceous with *Trigonia literata*, *Haugia variablis* (according to Dean), *Pelecoceras* sp. and *Phylloceras heterophyllum*. 0.9 (3 ft)

45–47: Shale with nodule bands at top and bottom; *Haugia* (large and fragmentary). 0.8 (2 ft 7 in.)

44b: Shale, grey, ?micaceous; Dean reported large *Haugia* (fragmentary), *Pseudolioceras whitbiense*, *Trigonia literata* and *Gresslya donaciformis* from an undivided Bed 44. 0.3

Alum Shale Member

Cement Shale Beds

43–44a: Shale, grey with band of large flattened nodules at base. Dean reported large *Haugia* (fragmentary), *Pseudolioceras whitbiense*, *Trigonia literata* and *Gresslya donaciformis* from an undivided Bed 44. Beds 43–48 of Dean (1954) probably equates to beds 5–13 of Doyle (1990–1992) with *Acrocoelites vulgaris*, *A. tricissus*, *A. inaequistriatus*, *Simpsonibelus expansus*, *S. dorsalis*, *S. lentus*, *Dactyloteuthis* cf. *venticosa*, *Megateuthis rhenana*, *M. glaber* and *M.*? *longisulcata*. 1.6 (6 ft 4 in. for 43–44b)

42: Shales with occasional nodules. Dean reported *Lytoceras cornucopia* and *Haugia* spp. (reported as *H. beani* and *H. illustris*, although these identifications may need revising). 0.8 (2 ft 6 in.)

39–41: Shale, grey, with nodule bands; *Dacromya ovum* last appears at this level, *Gresslya* and *Oxytoma substriata* also present. 0.8 (2 ft 6 in.)

lviii (= Bed 38 of Dean): Shale. *Haugia* sp., *Catacoeloceras dumortieri*, *Phylloceras heterophyllum*. 0.9 (3 ft)

Thickness (m)

lvii (= Bed 37 of Dean): Band of calcareous nodules in grey shale. *Oxytoma substriata* and *Trigonia literata* first appear at this level. 0.08 (3 in.)

liv–lvi: Shale with band of flat nodules or red limestone. *Catacoeloceras dumortieri*, *C. crassum*, *Pseudolioceras boulbiense*, *Phylloceras heterophyllum*, and *Acrocoelites levidensis*. This corresponds to at least part of the Navis Zonule (= Horizon) of Elmi *et al.* (1997). 1.9 (6 ft 1 in.)

LOWER TOARCIAN SUBSTAGE

Bifrons Zone, Crassum Subzone

xlviii–liii: Shale with bands of calcareous nodules. *Catacoeloceras crassum*, *Hildoceras semipolitum*, *Dacromya ovum*, *Trigonia literata*, *Gresslya donaciformis*, *Acrocoelites levidensis*, *A. subtricissus*, *A. wrighti*, *A. inaequistriatus*, *Simpsonibelus dorsalis*, *Dactyloteuthis* cf. *venticosa*, *Megateuthis rhenana* and *M. glaber*. This corresponds to part of the *crassum–semipolitum* Biohorizon. 2.5 (8 ft 1 in.)

xlv–xlvii: Shale with double row of large concretions at base and band of small nodules at top. *Catacoeloceras crassum*, *Hildoceras bifrons*, *Dacromya ovum*, *Trigonia literata*, *Gresslya donaciformis*. Corresponds to part of the *crassum–semipolitum* Biohorizon. 1.3 (4 ft 1 in.)

Fibulatum Subzone

xlii–xliv: Shale with many calcareous concretions. *Porpoceras* ex grp. *vortex*, *Hildoceras bifrons* and occasional *Pseudolioceras lythense* and *Harpoceras subplanatum*. *Dacromya ovum*, *Gresslya donaciformis*, *Acrocoelites pyramidalis*, *A. vulgaris*, *A. levidensis*, *A. tricissus*, *A. subtricissus*, *A. wrighti*, *Simpsonibelus expansus*, *S. dorsalis* and *Dactyloteuthis crossotela*. The *vortex* Biohorizon extends down to the base of Bed xliv, around 1 m below the top. 3.1 (10 ft 1 in.)

xxxiii–xli (= Whitby Beds 65–71 of Howarth 1962a): Shale with bands of nodules and a 0.15 m-thick cementstone band at base; *Hildoceras* ex grp. *bifrons*, *Pseudolioceras lythense*, *Acrocoelites pyramidalis*, *A. vulgaris*, *A. levidensis*, *A. tricissus*, *A. subtricissus*, *A. inaequistriatus*, *Simpsonibelus expansus*, *S. dorsalis*, *S. lentus*, *Dactyloteuthis* cf. *venticosa*, *D. crossetela*, *Megateuthis rhenana*, *M. glaber* and *M? longisulcata*, *Dacromya ovum*, *Gresslya*, *Pseudomytiloides* and pentacrinitid ossicles (in lower part). 4.6 (15 ft)

Main Alum Shale Beds

xxxii: Shale with many nodules; *Hildoceras* ex grp. *bifrons*, *Pseudolioceras lythense*, *Acrocoelites vulgaris*, *A. tricissus*, *A. inaequistriatus*, *Simpsonibelus expansus*, *S. dorsalis*, *S. lentus* and *Dacromya ovum*. 2.0 (6 ft 6 in.)

xxxi: Band of large calcareous concretions in shale. *Peronoceras subarmatum*, *Zugodactylites braunianus*, *Z. thompsoni*, *Hildoceras* ex grp. *bifrons* and occasional *Pseudolioceras lythense*. This corresponds to the *braunianus* Biohorizon. 0.15 (6 in.)

xxx: Shale with few nodules. *Peronoceras fibulatum*, *P. perarmatum*, *Hildoceras* ex grp. *bifrons*, *Pseudolioceras lythense*, *Phylloceras heterophyllum*, *Acrocoelites pyramidalis*, *A. vulgaris*, *A. tricissus*, *A. subtricissus*, *A. inaequistriatus*, *Simpsonibelus expansus*, *S. dorsalis* and *S. lentus*. 2.15 (7 ft)

xxix: Shale with many small nodules. *Peronoceras turriculatum* common, also *P. fibulatum* and *P. subarmatum*, *Dacromya ovum*, *Gressyla donaciformis* and *Simpsonibelus expansus*. This corresponds to the *turriculatum* Biohorizon. 0.9 (3 ft)

Commune Subzone

xxvii–xxviii: Shale with scattered nodules. *Dactylioceras athleticum* common, with rare *Hildoceras* cf. *lusitanicum*, *Dacromya ovum* and *Simpsonibelus expànsus*. Corresponds to the *athleticum* Biohorizon. 1.4 (4 ft 6 in.)

xxvi: Shale with occasional nodules. *Dactylioceras praepositum*, *Hildoceras* ex grps *lusitanicum* or *sublevisoni* and *Acrocoelites vulgaris*. 1.28 (4 ft 3 in.)

xviii–xxv: Shale with several bands of nodules, including a level with large concretions at top and many small nodules between (Bed xxv). *Dactylioceras commune* common and occasional *D. temperatum*, with *D. praepositum* and *D. crassiusculum* only recorded in Bed xxv. *Hildoceras* ex grp. *sublevisoni* and *Phylloceras heterophyllum* also present. Dean recorded *Frechiella subcarinata* in Bed xxi (his Bed 7) and *Frechiella* sp. in Bed xviii (Bed 4). *Dacromya ovum* first appears in Bed xxii. Belemnites in Bed xxiv include *Acrocoelites vulgaris*, *A. subtricissus*, *A. inaequistriatus*, *Simpsonibelus expansus* and *S. dorsalis*. Corresponds to at least part of the *commune* Biohorizon. 12.6 (40 ft 11 in.)

Hard Shale Beds

xvi–xvii: Shale with band of large flat nodules at top. *Parapassaloteuthis robusta*, *Acrocoelites subtenuis* and *Simpsoniteuthis dorsalis*. 4 (13 ft)

Mulgrave Shale Member

xv: **Ovatum Bed** (= Bed 48 at Whitby): Double row of red-weathering large concretions with some pyritic masses, *Ovaticeras ovatum*, *Dactylioceras* sp., *Phylloceras heterophyllum*. Corresponds to the *ovatum* Biohorizon. 0.35 (1 ft 2 in.)

	Thickness (m)
Bituminous Shales	
Serpentinum Zone, Falciferum Subzone	
xii–xiv: Shale, grey, bituminous, with a band of red-weathering sideritic mudstone. *Dactylioceras* sp. and belemnites; *Parapassaloteuthis robusta*, *P. polita*, *Acrocoelites subtenuis*, *A. pyramidalis* (at top only), *A. vulgaris*, *A. subtricissus*, *A. inaequistriatus*, *Simpsonibelus dorsalis*, *Youngibelus tubularis* and *Y. simpsoni* (latter two only near base).	13.7 (44 ft 7 in.)
xi: **Peak Stones**: Large lenticular concretions, typically around 1.5 m diameter but sometimes larger, in grey shale with occasional *Harpoceras* ex grp. *falciferum*. They cap conspicuous pedestals of shale on the foreshore below Ravenscar and were termed the 'fairy tables' by Bairstow and Hemingway (1961).	0.22 (9 in.)
viii–x: Shale, grey, bituminous, with scattered row of pyrite-skinned concretions with *Pseudomytiloides* just above the middle (= Bed 42 at Whitby). *Harpoceras* ex grp. *falciferum*, *Dactylioceras* spp. (including *D. gracile*) and rare *Phylloceras heterophyllum* and *Lytoceras* sp. present, though all typically crushed. *Hildaites* sp. present in lowest 1.5 m.	9.7 (31 ft 6 in.)
Jet Rock	
Exaratum Subzone	
vi–vii: Shale, grey with many flat concretions, capped by a level with occasional lenticular concretions, no more than 1.2 m in diameter; these are the Millstones (= Bed 40) of sections to the north-west. *Harpoceras elegans* present with *Phylloceras heterophyllum* and *Acrocoelites trisulcolosus*. Corresponds to the *elegans* Biohorizon.	2.6 (8 ft 6 in.)
v: Shale, grey with paler calcareous laminations weathers to form a small step on the scar.	0.22 (9 in.)
iv: Shale, grey, with numerous small calcareous concretions and occasional large Whalestones (= Bed 35 of sections to the north-west) up to 1.5 m long and 0.6 m thick, with some jet; *Harpoceras exaratum*, *Hildaites* sp. and *Elegantuliceras* sp. present. Corresponds to the *exaratum* Biohorizon.	0.9 (3 ft)
iii: Shale, grey with paler calcareous laminations. Weathers to form a small step on the scar.	0.3 (1 ft)
ii: Shale, grey with many small calcareous concretions. *Elegantuliceras elegantulum*, crushed, especially near base. Corresponds to the *elegantulum* Biohorizon.	1.85 (6 ft)
i: Shale, grey, with rare concretions.	2.45 (8 ft)
Grey Shale Member	
Tenuicostatum Zone, Semicelatum Subzone	
28–32: Grey shale with occasional bands of calcareous nodules, well exposed below the base of the Jet Rock; *Dactylioceras semicelatum* present. According to Howarth (1973), beds 28 and 30 were similar in lithology and thickness to the same levels farther north (e.g. **Castlechamber to Maw Wyke** and **Staithes to Port Mulgrave** GCR sites).	No overall thickness recorded
Tenuicostatum Zone, Tenuicostatum, Clevelandicum and *Paltus* (part) *subzones*	
12–27: Obscured by boulders.	No overall thickness recorded.
Tenuicostatum Zone, Paltus Subzone (part)	
3–11: Shale, grey with red-weathering sideritic concretions exposed near Mean Low Water. Beds 3 and 5 were well exposed and similar in lithology and thickness to the same levels farther north (e.g. **Castlechamber to Maw Wyke** and **Staithes to Port Mulgrave** GCR sites). No overall thickness recorded. Bed 3 elsewhere yields the lowest typical Toarcian fauna in the region, e.g. at Hawsker Bottoms (**Normanby Style Batts–Miller's Nab** GCR site) and at Kettleness.	
UPPER PLIENSBACHIAN SUBSTAGE	
Spinatum Zone, Hawskerense Subzone	
1–2: Shale, grey exposed near Mean Low Water. Basal shales of Grey Shale Member probably also present as Cleveland Ironstone Formation is present below (e.g. equivalent to beds 43–44 at Hawsker Bottoms, see **Normanby Style Batts–Miller's Nab** GCR site report).	No overall thickness recorded
Cleveland Ironstone Formation	
Kettleness Member	
Seen below near Mean Low Water (Howarth, 1973).	

The Toarcian Whitby Mudstone Formation contains relatively few marker beds. Beds of sideritic or calcitic nodules, and a few more continuous beds occur throughout the succession from the Grey Shale Member to the lower part of the Fox Cliff Siltstone Member, but most are inconspicuous. The distinctive nodule bands in the Mulgrave Shale Member at the **Castlechamber to Maw Wyke** and **Staithes to Port Mulgrave** GCR sites are mostly absent here, with only the Whalestones and the Millstones recognizable, though more poorly developed than farther north (Howarth, 1962a). An additional band of large, circular, flattened nodules, the Peak Stones (Figure 6.13) is present and forms a conspicuous feature on the shore

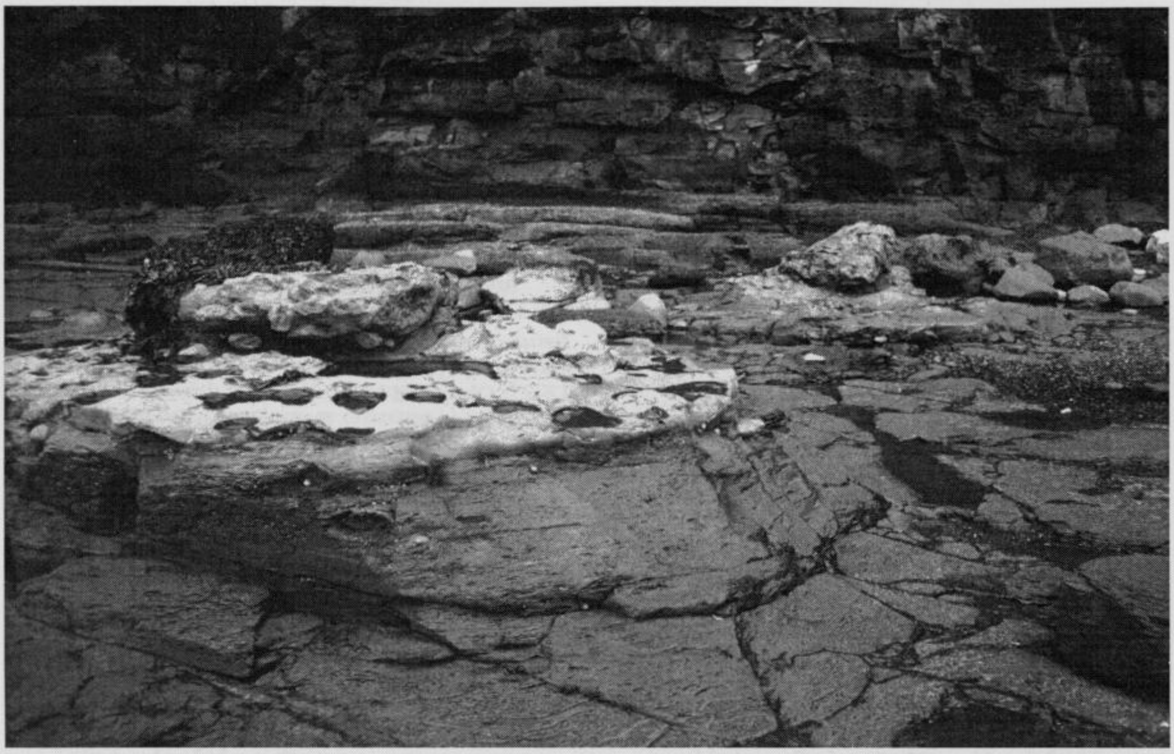

Figure 6.13 Concretions of the Peak Stones at least 1.5 m in diameter (Bed xi of Howarth, 1962a) in the Bituminous Shales of the Mulgrave Shale Member (Falciferum Subzone), on the shore below Ravenscar Hotel. (Photo: K.N. Page.)

where, perched on pillars of shale, they form the 'Fairy Tables' of Bairstow and Hemingway (1961). The Ovatum Bed at the top of the member also is well exposed but, between there and the base of the Dogger Formation there are only two or three ferruginous bands in the Peak Mudstone and Fox Cliff Siltstone members that form useful markers. Phosphatic nodules occur in abundance at some levels in the Peak Mudstone Member, and continue up into the Fox Cliff Siltstone Member. Chamositic clay and ooliths first appear near the base of the latter member. Knox (1984) identified five sedimentary cycles in the Upper Toarcian succession at Ravenscar. The first comprises the Peak Mudstone Member, its base marked by a sharp upward increase in silt and mica content, followed by a slow upward decrease in grain size. Cycles two and three, also fining upwards, are developed in the Fox Cliff Siltstone Member. An increase in grain size at the base of the Grey Sandstone Member is followed by a (fourth) upward-coarsening cycle. The fifth cycle, represented by the Yellow Sandstone Member, is also upward-coarsening.

The fauna of the Toarcian succession is abundant and diverse at some levels. The ammonite assemblages from the lower part of the succession have been described by Howarth (1962a, 1973, 1992), and those for the upper part by Dean (1954). This was the type locality for the zonal index fossil *Grammoceras striatulum* (J. de C. Sowerby, 1812–1846; Buckman, 1887–1907), presumably from the Peak Mudstone Member but now apparently lost (Dean *et al.*, 1961); for the holotype of *Lytoceras cornucopia* (Young and Bird, 1822), from the Alum Shale Member or Peak Mudstone Member at Ravenscar; and for the holotypes of Simpson's (1855, 1884) *Pseudolioceras simplex* (= *P. boulbiense*) and *Pseudolioceras leptophyllus* (= *P. lythense*), re-figured by Howarth (1962b). The last specimen was considered by Howarth (1962b) to originate from the Grey Sandstone Member at Peak Steel (beds 79–81 of Dean, 1954) and it remains the youngest record of *Pseudolioceras lythense* (Howarth, 1992). The holotype of *Pseudolioceras boulbiense* was thought to be from the Striatulum Subzone here (Howarth, 1992). Several hildoceratid species from the site were figured by Howarth (1992). Doyle (1990–1992) figured numerous specimens from here, including the lectotypes of *Odontobelus levidensis*, *Megateuthis rhenana* and *M. glaber*, and other material was used by Doyle (1985) to argue for the existence of sexual dimorphism in the belemnite genus *Youngibelus*. Doyle and Macdonald (1993) described a 'condensation and predation concentration' type of 'Belemnite Battlefield' from the Ovatum Bed (Bed xv), with abundant aligned specimens of *Acrocoelites vulgaris* and *A. subtenuis* associated with belemnite hooklets and ichthyosaur vertebrae. The types of the crustacea *Glyphaea prestwichi* and *Eryma birdi* were described and figured from the Blea Wyke Sandstone Formation by Woods (1925–1931), and disarticulated remains of the crinoid *Chariocrinus wuerttembergicus*, abundant in the Grey Sandstone Member, were figured by Simms (1989). Examples of commensalism between the bivalve *Dacromya ovum* and the encrusting brachiopod *Discinisca reflexa* were described from the Alum Shale Member here (Watson, 1982). A list of 77 nominal species from the upper part of the succession, above the Mulgrave Shale Member, was included by Dean (1954) in his descriptive section. Few vertebrates have been recovered from this site: Dean (1954) reported a 'specimen of *Ichthyosaurus* ... the bones relatively undisturbed' from shales about 3 m above the Ovatum Bed (Bed xv). Ichthyosaur vertebrae were also reported from the Ovatum Bed (Doyle and Macdonald, 1993), and an articulated series of ichthyosaur vertebrae was found in beds 49–52 of the Peak Mudstone Member (K.N. Page, unpublished observation, 1985). Broadhurst and Duffy (1970) and Benton and Spencer (1995) reported a skeleton of the plesiosaur *Macroplata longirostris* from the Bifrons Zone (beds xv–liii) between Peak and Blea Wyke. In addition to the ammonites and belemnites, other taxa provide stratigraphical markers within the section, and were recognized as such in the earliest descriptions. The upper part of the Grey Sandstone Member is sufficiently rich in serpulids to have been termed the 'Serpula Beds' in most accounts from Wright (1860b) to Dean (1954). The brachiopod *Lingula beani* is common in the 'Lingula Beds' in the lower part of this member. The Blea Wyke Sandstone Formation contains a richer and more diverse benthic fauna than lower parts of the Toarcian succession. Unequivocally benthic elements are absent from the Mulgrave Shale Member and lowest part of the Alum Shale Member, but diversity gradually increases upwards. The Alum Shale Member benthos is virtually confined to a few species of bivalve, notably *Dacromya ovum* (beds 7–41), *Gressyla donaciformis* (beds 12–44) and *Trigonia literata* (beds 32–50) (Dean, 1954). In the siltier beds of the Peak Mudstone and Fox Cliff Siltstone members these are joined by an increasingly diverse bivalve fauna, and in the Blea Wyke Sandstone Formation by several species of brachiopod.

Interpretation

It has long been appreciated by geologists that the succession to the south-east of the Peak Fault shows significant differences, and in particular is substantially more complete than, the correlative sections farther along the coast to the north-west. Early observers (Wright, 1860b; Hudleston, 1874; Tate and Blake, 1876; Fox-Strangways, 1892; Rastall, 1905; Buckman, 1915) differed in their placement of the Lower–Middle Jurassic boundary in the succession close to the village of Ravenscar. These ranged from a level within the Peak Mudstone Member (Fox-Strangways, 1892) to one well above the base of the Dogger Formation (Rastall, 1905). The position of the Toarcian–Aalenian boundary is now well-established here, on the basis of the ammonite assemblages, and lies immediately below the Terebratula Bed at the base of the Dogger Formation.

Lithological correlations between the succession here and at other sites to the north-west, such as those at Whitby and Port Mulgrave (the **Whitby to Saltwick** and **Staithes to Port Mulgrave** GCR sites), become increasingly uncertain upwards. Howarth (1973) considered the Grey Shale Member succession here to be sufficiently similar to that to the north-west for the same bed numbers to be applicable. In contrast, the Mulgrave Shale and Alum Shale members are sufficiently different to require different numbering schemes (Howarth, 1962a). Howarth (1962a) showed that although the thickness of the Mulgrave Shale Member was similar on both sides of the Peak Fault, the Alum Shale Member was significantly thicker on the east side of the fault at Ravenscar. Knox (1984) showed that the Upper Toarcian succession between Blea Wyke and Peak Steel also showed significant thinning to the north-west.

The Upper Toarcian part of the succession is of especial interest at the Miller's Nab to Blea Wyke GCR site, because equivalent strata have been removed by pre-Dogger erosion in more northerly sections. All descriptions of the Upper Toarcian Substage at Ravenscar published over the last two decades (Knox, 1984; Howarth, 1992; Hesselbo and Jenkyns, 1995) have used the ammonite zonation established by Dean *et al.* (1961). This has been recently refined by work in France, Germany and Spain, notably by Elmi *et al.* (1997), and their scheme is provisionally applied here although some of the specimens will need to be re-examined. For example, a fauna with *Catacoeloceras dumortieri*, considered by Howarth (1962b, 1992) to be from the latest Lower Toarcian succession, would be interpreted as indicative of the basal Upper Toarcian sequence by Elmi *et al.* (1997) on the basis of the associated ammonites. Further collecting is needed. This illustrates the importance of the site as the most completely developed and expanded Lower–Upper Toarcian boundary sequence known in Britain is exposed at this site. Cox (1990) considered that the sections here could provide reference sections for the Bifrons, Variabilis, Thouarsense and Levesquei zones, as defined in Dean *et al.*, (1961).

A hiatus exists at the top of the sequence and cuts out the Aalensis Zone at the top of the Toarcian Stage. *Leioceras* aff. *opaliniforme* is recorded from the middle of the Dogger Formation at Ravenscar by Cope *et al.* (1980b) and hence the base of the formation here is presumed to be of basal Aalenian, Opalinum Subzone, age.

Knox (1984) attributed the discontinuous, but apparently cyclic, grain-size changes in the Upper Toarcian succession to a single underlying shallowing trend culminating in the intensely bioturbated sands at the top of the Yellow Sandstone Member. Brief episodes of epeirogenic uplift were superimposed on this coarsening-upwards trend. These are cycles which were linked to stages in the development of the North Sea dome. Knox (1984) noted that the incoming of chamositic ooliths and clay in the upper part of the Whitby Mudstone Formation, was associated with an influx of coarser sediment. He suggested that this material was swept into the area from lagoonal areas bordering the western margin of the Cleveland Basin. Hemingway's (1974) observation of chamosite enrichment at similar stratigraphical levels in the Rosedale area, some 30 km to the west of Ravenscar, lends support to this hypothesis. The overall upward grain-size increase from the Alum Shale Member to the Blea Wyke Formation is accompanied by a change from calcitic to sideritic concretions (Hallam, 1967b), and a changing and increasingly diverse benthic fauna (Dean, 1954). However, despite the upward shallowing indicated by these changes there is no evidence of littoral or restricted marine facies. Ammonites and brachiopods are present throughout and indicate that fully marine conditions prevailed throughout the Whitby Mudstone and Blea Wyke Sandstone formations and into the Dogger Formation (Knox, 1984).

It is unclear whether Upper Toarcian sediments similar to those at the Miller's Nab to Blea Wyke GCR site were once present throughout the Cleveland Basin. Knox (1984) considered it unlikely that a continuous and uniform spread of such sediments had existed. At Ravenscar the succession thins from south-east to north-west, and there are rapid thickness and facies changes in the late Toarcian successions preserved in several inland sub-basins (Hemingway, 1974). The absence of derived phosphate nodules in the Blea Wyke Sandstone Formation was taken by Knox (1984) as evidence that there was little, if any, erosion of older sediments. Alexander (1986) considered that fault activity started during the Toarcian Stage and was responsible for the thick Middle Jurassic sands in the Peak Trough area. Milsom and Rawson (1989) and Rawson and Wright (1995) considered that Upper Toarcian sediments were preserved in small troughs.

The Toarcian succession at this GCR site is strikingly different from those in the Wessex Basin both on the Dorset coast and at the **Hurcott Lane Cutting** and **Babylon Hill** GCR sites. In the Wessex Basin, the Beacon Limestone Formation, rarely more than 2–3 m thick but encompassing seven ammonite zones, is overlain by the Bridport Sand Formation which spans only two ammonite zones but is 70 m thick. Farther north, in the Severn Basin, the Lower Toarcian sequence is typically developed in more expanded mudstone facies, reaching a thickness of almost 100 m north of Cheltenham (Whittaker and Ivimey-Cook, 1972), but the Upper Toarcian sequence is mostly in a condensed sand or carbonate facies only a few metres thick as, for instance, at the **Wotton Hill** GCR site. Toarcian successions on the East Midlands Shelf and in the Hebrides Basin are far from complete and the only other succession comparable with that at Ravenscar is the extraordinarily thick sequence seen in the Mochras Borehole. At nearly 262 m thick it is more than twice as thick as that at Ravenscar, comprising a rather monotonous series of mudstones with subordinate limestones and nodule bands (Woodland, 1971). The Mochras succession shows no evidence of an overall coarsening-upwards sequence comparable with that in passing from the Alum Shale Member to the Yellow Sandstone Member at Ravenscar.

Conclusions

The Toarcian succession at Ravenscar represents the most complete and expanded section of this part of the Lower Jurassic sequence exposed anywhere in Britain. It provides the only substantial evidence for late Toarcian events in the Cleveland Basin and is the type locality for the two uppermost members of the Whitby Mudstone Formation, and for the Blea Wyke Sandstone Formation and its two constituent members. As such it is likely to form a cornerstone of any future work on this much neglected subdivision of the Jurassic System in Britain. It contrasts strikingly with the truncated Toarcian sections seen farther north in the Cleveland Basin, where only the Lower Toarcian sequence is preserved beneath the unconformity at the base of the Dogger Formation.

STAITHES TO PORT MULGRAVE, NORTH YORKSHIRE (NZ 784 189–NZ 797 175)

K.N. Page

Introduction

The 3 km stretch of cliffs and foreshore between Staithes and Port Mulgrave exposes the type sections of the Staithes Sandstone Formation and the Cleveland Ironstone Formation, including the Penny Nab Member, and the Mulgrave Shale Member of the Whitby Mudstone Formation. There are also excellent exposures of the Grey Shale Member at the base of the Whitby Mudstone Formation. It provides one of the best exposures in Britain of the Upper Pliensbachian to Lower Toarcian succession, including the Pliensbachian–Toarcian stage boundary. It has been the location for many investigations into the palaeoenvironments and diagenesis of this part of the Lower Jurassic succession in Yorkshire and the source of a rich fossil fauna.

The Cleveland Ironstone Formation that crops out in the Staithes to Port Mulgrave GCR site (Figure 6.14) was historically important as a source of iron. The remains of mine workings are still visible in the cliffs; mostly at the level of the highest quality seam known simply as the 'Main Seam'. Ore was shipped from Port Mulgrave to the smelters of Tyneside (Rawson and Wright, 1992). In 1920, 6 million tonnes were extracted from the Main Seam in Cleveland (Lamplugh *et al.*, 1920). Arkell (1933) noted that the low lime content of the ore (around 5%), necessitated the extraction of large quantities of limestone for use as a flux. This came from quarries in the Oxfordian Corallian Group of the Pickering district. In the latter part of the 19th century, jet was also mined in the area, with the remains of old adits still visible in the cliff at Thorndale Wyke, where the Top Jet Dogger forms their roofs. The Jet Rock was also quarried on the foreshore and stacks of large nodules, such as the Curling Stones, are still visible as a by-product of this activity (Rawson and Wright, 1995).

Young and Bird (1822, 1828), in their attempt to develop a systematic review of the geology of the Yorkshire coast, first used the terms 'Staithes Beds' and 'Kettleness Beds' for the lower and upper subdivisions respectively of the (Upper Pliensbachian) Middle Lias, and figured fossils from the Upper Pliensbachian succession of the region. Phillips (1829) provided a detailed section for the Upper Pliensbachian at Staithes, which he divided into a lower 'Marlstone Series' and an upper 'Ironstone Series', together with a long list of fossils. Tate and Blake (1876) provided sections which were to prove the basis for most later work, and Wright (1878–1886) also included a detailed section. The results of these early studies, including the work of the [British] Geological Survey (e.g. Barrow, 1888), was reviewed by Fox-Strangways (1892), and additional brief descriptions were provided by

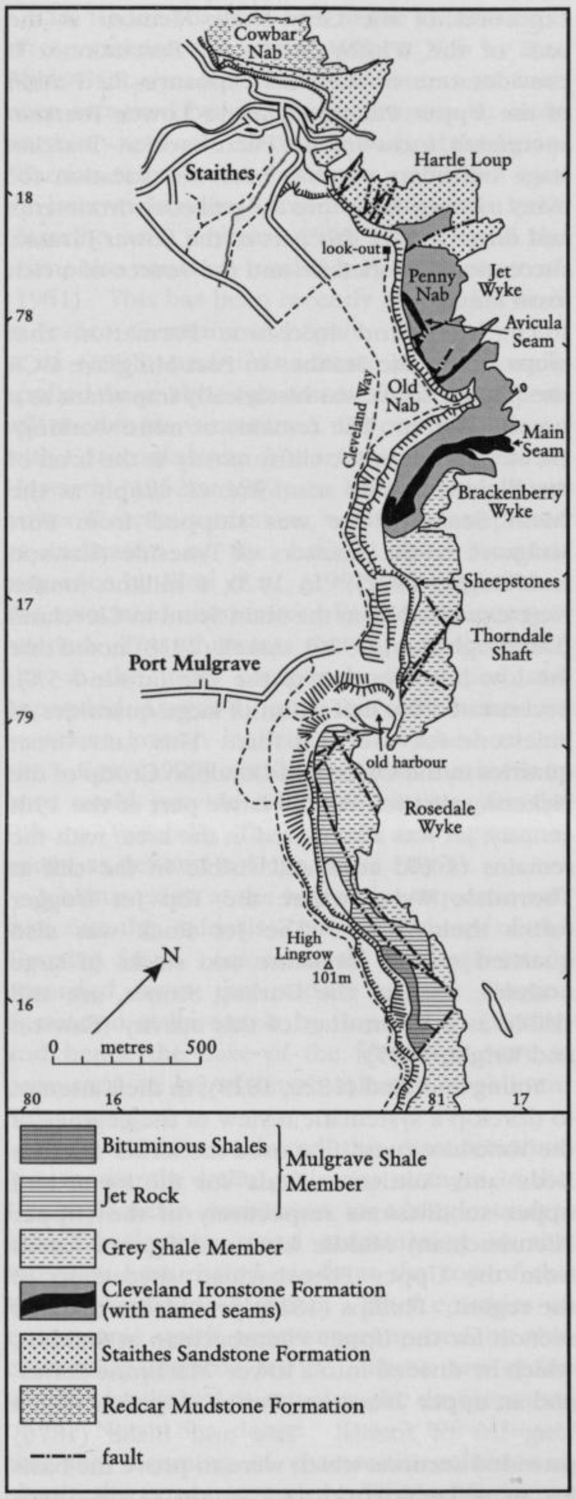

Figure 6.14 Outcrop map of the main lithostratigraphical units between Staithes and Port Mulgrave. After Rawson and Wright (1992).

Herries (1906a,b). These works remained the basis for the reviews of Buckman (1915) and Arkell (1933). Wilson *et al.* (1934) described a section through the Ironstone Series at Staithes, and Whitehead *et al.* (1952) discussed the petrology of the ironstones. Howarth's (1955) sections have served as the standard stratigraphical framework on which most subsequent work has been based (e.g. Cope *et al.*, 1980a; Hemingway *et al.*, 1969). The lithostratigraphy of the Upper Pliensbachian sequence was revised by Howard (1985) based, in part, on the framework of Powell (1984) and using Howarth's bed numbers.

Tate and Blake's (1876) general description of the Grey Shale Member is useful but incomplete. Howarth (1962a) described the Mulgrave Shale Member and the Grey Shale Member (Howarth, 1973). Further details of both are included in Howarth (1992). Rawson and Wright (1995) published logs of the Staithes Sandstone, Cleveland Ironstone and Whitby Mudstone formations here, based largely on the work of Howarth (1955, 1962a, 1992), and Hesselbo and Jenkyns (1995) published a re-measured section through the Staithes Sandstone, Cleveland Ironstone and the lower part of the Whitby Mudstone formations. Walkden *et al.* (1987) published a graphic log of the Mulgrave Shale Member. All of these used the bed numbers of Howarth (1955, 1962a). Aspects of the sedimentology, petrology, geochemistry and palaeoecology of parts of the succession have been discussed by Hallam (1962a, 1967b), Chowns (1968), Gad *et al.* (1969), Catt *et al.* (1971), Raiswell (1971, 1976), Raiswell and White (1978), Morris, (1979), Greensmith *et al.* (1980, 1983), Coleman and Raiswell (1981), Pye and Krinsley (1986), Myers and Wignall (1987), Knox *et al.* (1990), Young *et al.* (1990a), Macquaker and Taylor (1996, 1997), Hesselbo (1997) and Morgans (1999).

Description

The succession dips gently eastward with the oldest part exposed at Cowbar Nab, and the youngest at Port Mulgrave (Figure 6.14). Only a few minor faults interrupt the sequence. The following synthesis of the Redcar Mudstone, Staithes Sandstone, Cleveland Ironstone and

Whitby Mudstone formations (Figure 6.15a,b and description below) is based primarily on Howarth (1955, 1962a, 1973 and 1992) with additions and modifications based on Howard (1985) and Hesselbo and Jenkyns (1995). Bed numbers for the Whitby Mudstone Formation are taken from Howarth (1962a, 1973), with those for the Pliensbachian succession from Howarth (1955). Details of the lowermost beds are from Howard (1985).

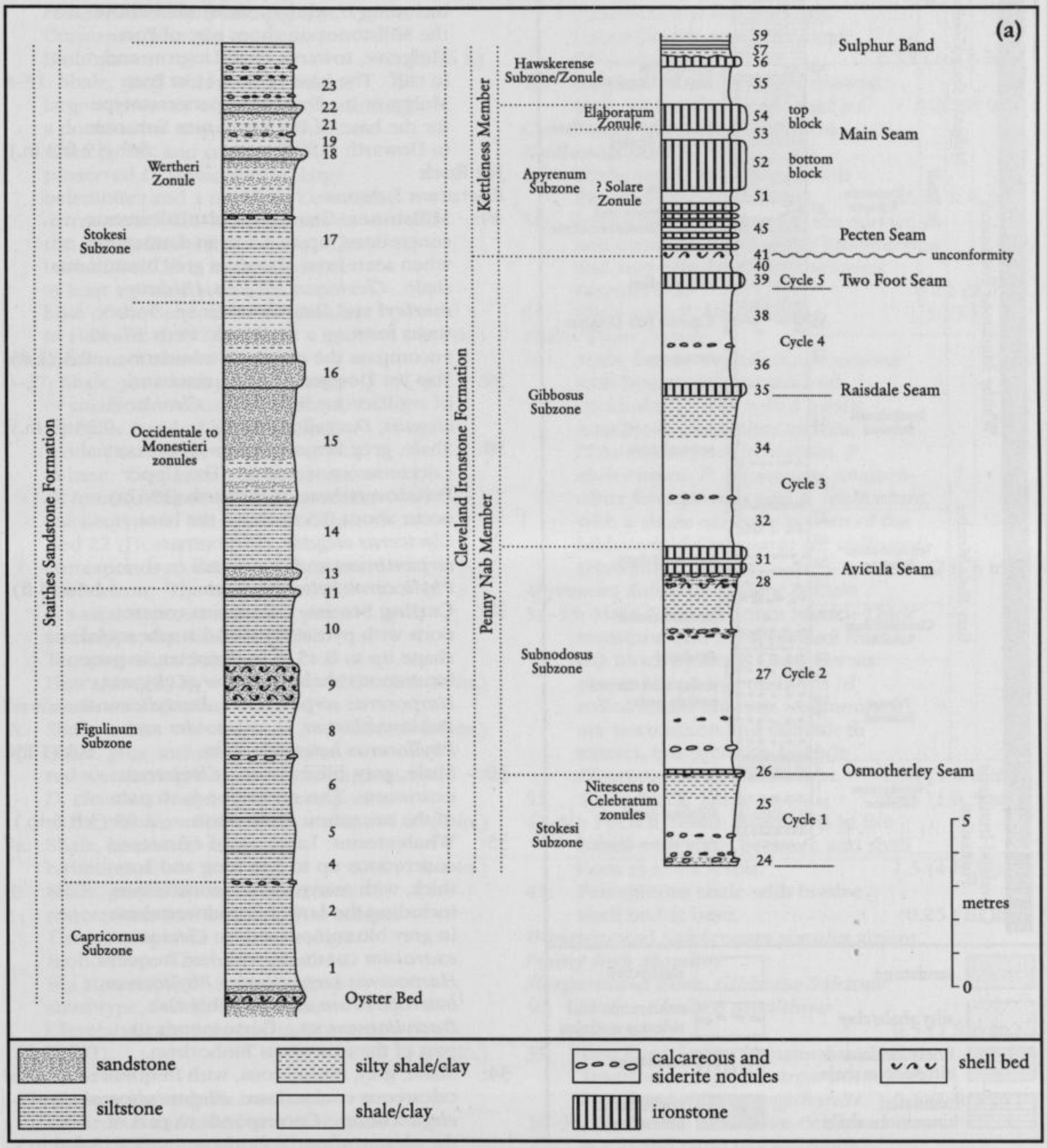

Figure 6.15a Section through the Staithes Sandstone and Cleveland Ironstone formations between Cowbar Nab, Staithes, and Rosedale Wyke, Port Mulgrave. After Rawson and Wright (1995). Bed numbers are those of Howarth (1955, 1962a, 1973). The Cleveland Ironstone Formation cycles of Howard (1985) are indicated.

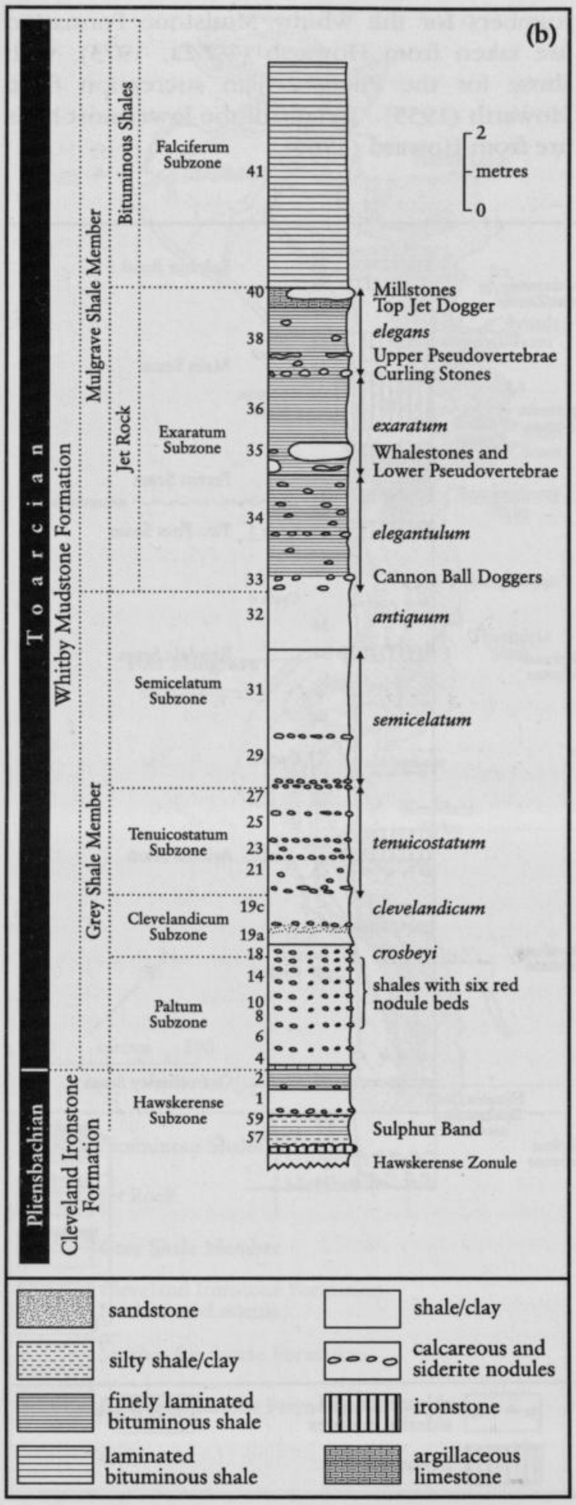

Figure 6.15b Section through the top of the Cleveland Ironstone and the Whitby Mudstone formations between Cowbar Nab, Staithes, and Rosedale Wyke, at Port Mulgrave. After Rawson and Wright (1995). Bed numbers are those of Howarth (1955, 1962a, 1973).

Thickness (m)

LOWER TOARCIAN SUBSTAGE
Whitby Mudstone Formation
Mulgrave Shale Member
Bituminous Shales (part)
Serpentinum Zone, Falciferum Subzone

41: Shale, grey, bituminous, with crushed *Harpoceras* ex grp. *falciferum* (probably including *H. mulgravium*) seen above the Millstones on shore east of Port Mulgrave, towards High Lingrow and in cliff. The base of Bed 41 at Port Mulgrave is effectively a parastratotype for the base of the Falciferum Subzone in Howarth (1992). 5.9 (19 ft 3 in.)

Jet Rock
Exaratum Subzone

40: **Millstones**: Giant lenticular calcareous concretions, up to 4.5 m in diameter when seen from above, in grey bituminous shale. *Cleviceras elegans*, *Hildaites murleyi* and *Dactylioceras* sp., sometimes forming a shell bed. Beds 37–40 encompass the *elegans* Biohorizon. 0.3 (1 ft)

39: **Top Jet Dogger**: Continuous band of argillaceous limestone. *Cleviceras elegans*, *Dactylioceras* sp.. 0.23 (9 in.)

38: Shale, grey, bituminous, with occasional calcareous concretions. The Upper Pseudovertebrae of Howarth (1962a) occur about 0.3 m above the base. *Cleviceras elegans*, *Harpoceras serpentinum* and occasional *Phylloceras heterophyllum*. 1.54 (5 ft)

37: **Curling Stones**: Calcareous concretions with pyritic skins and a spheroidal shape up to 0.45 m in diameter, in grey bituminous shale. *Cleviceras elegans*, *Harpoceras serpentinum*, *Dactylioceras semiannulatum*, *D. crassoides* and *Phylloceras heterophyllum*. 0.3 (1 ft)

36: Shale, grey, bituminous. *Cleviceras exaratum*. This corresponds to part of the *exaratum* Biohorizon. 1.08 (3 ft 6 in.)

35: **Whalestones**: Large ovoid calcareous concretions up to 3 m long and 1 m thick, with many smaller concretions, including the Lower Pseudovertebrae, in grey bituminous shale. *Cleviceras exaratum* common, with less frequent *Harpoceras serpentinum*, *Phylloceras heterophyllum* and probably also *Dactylioceras* sp.. Corresponds to part of the *exaratum* Biohorizon. 0.9 (3 ft)

34: Shale, grey, bituminous, with frequent calcareous concretions. *Elegantuliceras elegantulum*. Corresponds to part of the *elegantulum* Biohorizon. 2.7 (8 ft 6 in.)

33: **Cannon Ball Doggers**: Spherical calcareous concretions up to 0.18 m in diameter, with common well-preserved *Elegantuliceras elegantulum* (including macro- and micro-conch forms). Corresponds to part of the *elegantulum* Biohorizon. 0.15 (6 in.)

Thickness (m)

Grey Shale Member

Tenuicostatum Zone, Semicelatum Subzone

32: Shale, grey, with occasional flat calcareous nodules and widespread shell beds, especially near base, full of crushed *Tiltoniceras antiquum*. *Dactylioceras semicelatum* and *Posidonia radiata* also present. Corresponds to the *antiquum* Biohorizon. 1.85 (6 ft)

28–31: Shale, grey, with three bands of large calcareous concretions, including a double row at the base, which are often pyritic and contain well-preserved *D. semicelatum*, large belemnites and a nautiloid *Cenoceras astracoides*. This corresponds to the *semicelatum* Biohorizon. The base of Bed 28 is a stratotype, or at least a parastratotype, for the base of the Semicelatum Subzone in Howarth (1992). 3.55 (11 ft 7 in.)

Tenuicostatum Subzone

20–27: Shale, grey, with several bands of small calcareous nodules and a double band of large calcified lenticular masses, weathering red, at base. Common well-preserved *D. tenuicostatum* in small nodules; the neotype of the species is from Bed 22 (Howarth, 1973). This corresponds to the *tenuicostatum* Biohorizon. The base of Bed 20 is a stratotype, or at least a parastratotype, for the base of the Tenuicostatum Subzone in Howarth (1992). 2.75 (8 ft 11 in.)

Clevelandicum Subzone

19c: Shale, grey. 0.81 (2 ft 8 in.)

19b: Shale, grey, including a band of red-weathering lenticles and common *D. clevelandicum*. This corresponds to the *clevelandicum* Biohorizon. 0.05 (2 in.)

19a: Shale, laminated and bituminous. 0.41 (1 ft 4 in.)

18: Shale, grey, with small calcareous concretions and frequent *D. crosbeyi*. This corresponds to the *crosbeyi* Biohorizon. The base of Bed 18 is a stratotype, or at least a parastratotype, for the base of the Clevelandicum Subzone in Howarth (1992). 0.38 (1 ft 3 in.)

Paltus Subzone

4–17: Shale, grey, with six bands of calcareous and sideritic concretions. Some belemnites and bivalves present. 2.75 (9 ft 1 in.)

3: This level elsewhere (e.g. at Hawsker Bottoms and at Kettleness) yields the lowest typical Toarcian fauna in the region, with *Protogrammoceras paltum* and *Dactylioceras* sp. indet. (Howarth, 1973). 0.08 (3 in.)

UPPER PLIENSBACHIAN SUBSTAGE

Spinatum Zone, Hawskerense Subzone, Hawskerense Zonule

2: Shale, dark grey, laminated and bituminous. *Lytoceras* sp. recorded from base at Kettleness. 0.53 (1 ft 9 in.)

1: Shale, grey. 0.51 (1 ft 8 in.)

59–60: Shale, with row of calcareous concretions at top, yielding *Pseudopecten equivalvis* and *Pholadomya*. 0.45 (1 ft 6 in.)

58: **Sulphur Band**: Finely laminated shale with many lenticles of jet. 0.20 (8 in.)

Cleveland Ironstone Formation

Kettleness Member

57: Shale, sandy, micaceous, with *Pleuroceras hawskerense*. 0.45 (1 ft 6 in.)

56: Ironstone, with irregular top surface and common *Pleuroceras hawskerense* and very rare *Protogrammoceras turgidulum*. 0.22 (9 in.)

55: Shale with *P. hawskerense*. 1.23 (4 ft)

Elaboratum Zonule

54: **Main Seam** (top block): Ironstone with branching burrows and concentrations of rolled fossils. Amaltheid ammonites include *Pleuroceras paucicostatum*, *P. elaboratum*, *P. apyrenum*, *Amauroceras ferrugineum* and *A. lenticulare*, with a single example known of the hildoceratid *Canavaria* aff. *cultraroi* (Howarth, 1992). 0.75 (2 ft 6 in.)

Apyrenum Subzone, ?Solare Zonule

52–53: **Main Seam** (bottom block): Thick ironstone (1.4 m) separated from top block by shale. Burrows are present but concentrations of rolled fossils are rare. Ammonites are uncommon and difficult to extract, but probably include *Pleuroceras paucicostatum*. 1.70 (5 ft 6 in.)

51: Shale, black, hard. 0.45 (1 ft 5 in.)

42–50: **Pecten Seam**: Ironstone, in five bands with shale between and shell beds at some levels. 1.3 (4 ft 2 in.)

41: Ferruginous shale with bivalve shell bed at base. 0.25 (10 in.)

Transiens and *Salebrosum zonules* absent

Penny Nab Member

Margaritatus Zone, Gibbosus Subzone

40: Shale. Crushed *Amaltheus gibbosus*. 0.5 (1 ft 8 in.)

39: **Two Foot Seam**: Ironstone with rare *Amaltheus* ex grp. *margaritatus* and *Pseudoamaltheus engelhardti*. 0.4 (1 ft 3 in.)

36–38: Shale with belemnite-rich band at top and band of calcareous concretions 1.1 m above base yielding *Amaltheus gibbosus*, *A. margaritatus*, *Pseudoamaltheus engelhardti* and *Amauroceras ferrugineum*. 2.9 (9 ft 5 in.)

35: **Raisdale Seam**: Ironstone with many *Protocardia truncata* and rare *Amaltheus* cf. *margaritatus*. 0.25 (10 in.)

Thickness (m)

32–34: Siltstone and shale with pyritic masses in the lower part and a band of calcareous concretions 1.25 m above base. The latter yield *Amaltheus gibbosus*, with *Amauroceras ferrugineum* in the 0.6 m of shale above. The base of Bed 32 is a parastratotype for the base of the Gibbosus Subzone in Howarth (1992). 5 (16 ft 2 in.)

Subnodosus Zone

31: **Avicula Seam**: Ironstone, fine grained, with pale-green chamositic ooliths, and a 0.1 m-thick mudstone parting in places around the middle. *Amaltheus* ex grp. *margaritatus* and many bivalves, especially *Oxytoma cygnipes* and protocardiid burrows. 0.6 (2 ft)

27–30: Silty sandstone, siltstone and shale with bands of calcareous concretions and a 0.05 m shell bed 0.58 m below top with *Protocardia truncata*, *Entolium* and other bivalves. *Amaltheus subnodosus*, *A. striatus* and *A. margaritatus* occur at several levels and are especially abundant in the lowest nodule band (Bed 27a), which yielded the neotype of *A. subndosus* (Howarth, 1958). 6.5 (21 ft 1 in.)

26: **Osmotherley Seam**: Band of small calcareous concretions with *Amaltheus subnodosus*, *A. striatus* and *A. stokesi*, and many bivalves. The base of Bed 26 is a parastratotype for the base of the Subnodosus Subzone in Howarth (1992). 0.08 (3 in.)

Stokesi Subzone, *Nitescens* to *Celebratum zonules*

24–25: Shale with bands of calcareous concretions, the lowest containing abundant *Amaltheus stokesi* and *A. wertheri*. 2.6 (8 ft 6 in.)

Staithes Sandstone Formation

Celebratum and *Nitescens zonules*

23: Shale and sandstone with three bands of calcareous concretions, the middle of which contains *Amaltheus stokesi* and *A. wertheri*. 1.95 (6 ft 4 in.)

17 (part)–22: Thinly bedded sandstones with thin shales and bands of calcareous, and sometimes fossiliferous, concretions. A thin shell-bed at the base yields *Amaltheus stokesi* and *A. wertheri*. 5.5 (17 ft 10 in.)

Occidentale to *Monestieri zonules*

12–17 (part): Thinly bedded sandstones with some sandy shale and bands of calcareous concretions and lenticles, which often weather red and may be rich in bivalves; *Amaltheus stokesi* present sporadically. The base of Bed 12 is a parastratotype for the base of the Stokesi Subzone in Howarth (1992). 8.5 (27 ft 7 in.)

LOWER PLIENSBACHIAN SUBSTAGE

Davoei Zone, *Figulinum Subzone*

11: Sandstone with bivalve shell beds. 0.3 (1 ft)

10: Shale with scattered calcareous concretions, including abundant *Oistoceras figulinum* in upper 0.3 m and *O.* aff. *figulinum* near the middle. 1.7 (5 ft 6 in.)

4–9: Mainly sandstone alternating with sandy shale. Bivalve-rich shell beds occur near the top, with *Gryphaea* present below: *Oistoceras* sp. recorded from beds 4 and 8. Howard (1985) and Hesselbo and Jenkyns (1995) included Bed 2 in the Figulinum Subzone although without supporting evidence. 6.55 (21 ft 3 in.)

Capricornus Subzone

1–3: Sandstone forming base of cliff at Cowbar Nab, with sandy shale capped by band of calcareous concretions above. *Androgynoceras lataecosta* var. *pyritosum* figured by Spath (1938, pl. 19, fig. 6) probably came from this level. 2.7

Oyster Bed: Sandstone, calcareous and ferruginous, with *Gryphaea*, *Oxytoma* and *Pseudopecten*. Marks the base of the Capricornus Subzone and of the Staithes Sandstone Formation. 0.3

Redcar Mudstone Formation

Ironstone Shale Member

Maculatum Subzone

Shale with some siltstone in upper 7.5 m, and with calcareous nodules and a thin oolitic ironstone 1.5 m above the base. *Androgynoceras maculatum* var. *rigida* from 8 m below sandy series at Staithes figured by Spath (1938). 20.25

The base of the Staithes Sandstone Formation, exposed at Cowbar Nab, is gradational with the underlying Redcar Mudstone Formation. It has been drawn at the base of the 'Oyster Bed' (Howard, 1985), a ferruginous sandstone packed with the bivalves *Gryphaea gigantea*, *Oxytoma inaequivalvis* and *Pseudopecten equivalvis*. The formation is 28.6 m thick here and superbly exposed to either side of Staithes harbour (Figure 6.16). The lower 12.6 m has been assigned to the Davoei Zone (Capricornus and Figulinum subzones) and the remainder to the lower part of the Stokesi Subzone (Hesselbo and Jenkyns, 1995; Rawson and Wright, 1995). Intensely bioturbated silty sandstones dominate the succession, becoming coarser in the middle of the formation before fining again towards the top. Poorly bioturbated, fine sandstone bands occur at various levels and are thickest (up to about 4 m) in the middle of the formation. They

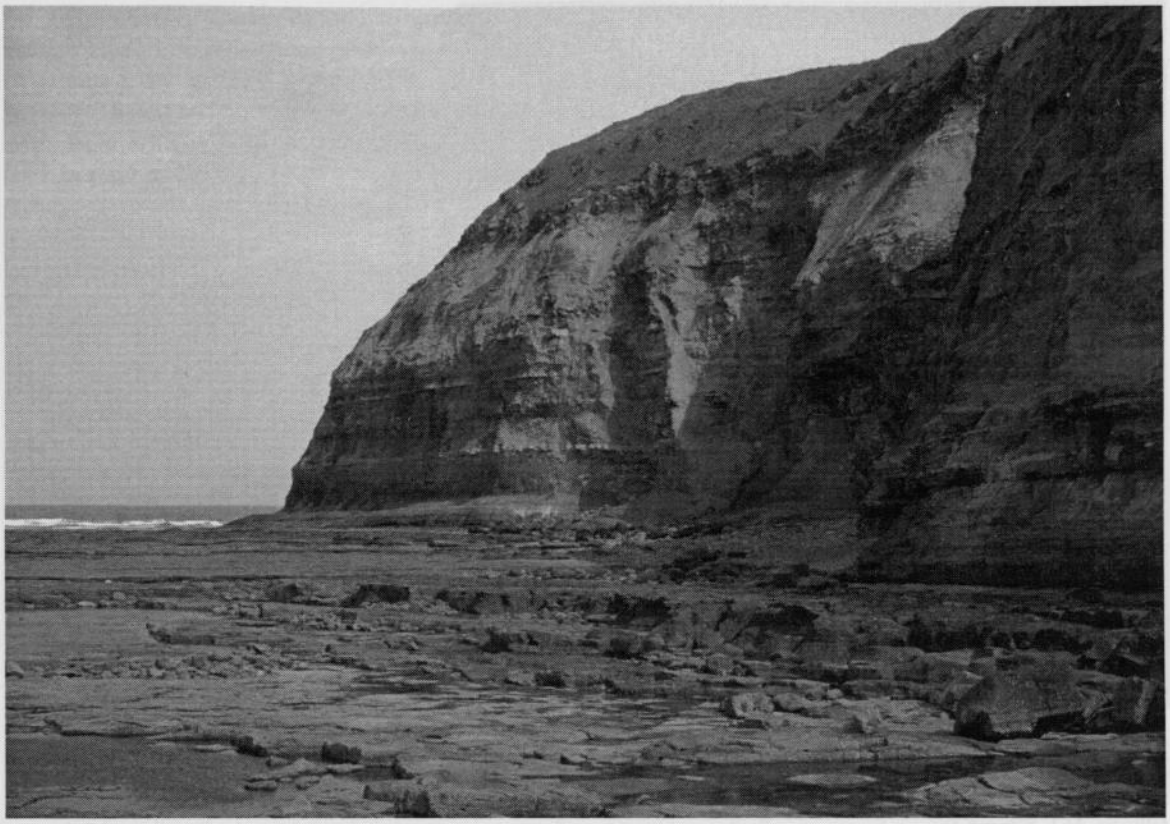

Figure 6.16 Foreshore and cliff exposures of the Staithes Sandstone Formation, of Stokesi Subzone age, on the west side of Penny Nab, Staithes. Sandstones and sandy mudstones form the steep lower portion of the cliff (mostly in shade) and are overlain by mudstones, siltstones and ironstones of the Cleveland Ironstone Formation, Penny Nab Member (mainly Subnodosus–Margaritatus subzones) in the less steep (and well-lit) upper part of the cliff. (Photo: K.N. Page.)

show planar- and cross-lamination and some hummocky cross-stratification (Rawson *et al.*, 1983). The bases of some bear small erosional channels or gutter casts, up to 5 m long and 0.5 m wide, with a predominant east–west trend which is roughly perpendicular to ripple marks in the same sequence (Greensmith *et al.*, 1980). One hummocky cross-stratified unit at about the middle of the formation is associated with abundant intact, but poorly preserved specimens of the crinoid *Balanocrinus gracilis*. Other macrofossils occur sparsely except in some nodules and shelly bands towards the top of the formation. They include the type of *Rudirhynchia huntcliffensis* (Ager, 1956–1967). Scrutton (1996) observed that the more muddy tops of the sandstone beds have a benthos dominated by burrowing bivalves, such as *Protocardia truncata* and *Oxytoma inequivalvis*, the serpulid '*Dentalium*' *giganteum* (Palmer, 2001), and other species. Some assemblages are mixed, especially in coquinas of *Protocardia* which form the nuclei for sideritic nodule development. Elsewhere there are current-aligned clusters of belemnites and fragments of driftwood.

The Staithes Sandstone Formation passes up into the shaley mudstones with scattered siderite nodules of the Cleveland Ironstone Formation. The ironstone is superbly exposed from Penny Nab (Figure 6.16) and Brackenberry Wyke. Its base has been taken at the base of a row of scattered siderite nodules with *Amaltheus stokesi*. This marks the lowest of several coarsening-upward cycles within the formation (Rawson *et al.*, 1983; Howard, 1985). The Penny Nab Member comprises four beds of oolitic ironstone (the Osmotherley, Avicula, Raisdale and Two Foot seams) separated by clastics with siderite nodules (Figure 6.17). Except for that beneath the Two Foot Seam, each clastic unit coarsens upwards from silty pyritic shale to argillaceous fine sandstone, and a sharp

Figure 6.17 Silty mudstones and ironstone bands in the Cleveland Ironstone Formation at Penny Nab, south of Staithes. The Two Foot Seam, the six thin ironstones of the Pecten Seam, and the various beds of the Main Seam above can easily be recognized. The higher part of the cliff face is in the Whitby Mudstone Formation. (Photo: M.J. Simms.)

erosional contact with the ironstone above, marked by reworked and bio-eroded siderite nodules. Macquaker and Taylor (1996, 1997) maintained that the ironstones occur at the top of upward-coarsening successions and are succeeded by units which fine upwards to clay-rich mudstones with phosphate-rich carbonate concretions, in turn overlain by the next coarsening-upwards unit.

Beneath the Raisdale Seam is the 'upper striped bed' of Greensmith *et al.* (1980). This comprises a series of thin laminated siltstones that fine up to dark mudstone, each with a basal erosion surface and often with E–W-orientated gutter casts up to 0.5 m wide and several metres long. The oolitic ironstones are intensely bioturbated at their base, with ooids commonly deformed and broken. Petrologically the ironstones comprise altered berthierine ooids in a more-or-less strongly sideritized muddy matrix (Young *et al.*, 1990a). Catt *et al.* (1971) and Myers (1989) noted that the ironstones have remarkably high thorium–potassium ratios.

The base of the Kettleness Member is taken at a minor erosion surface with occasional phosphatic pebbles at the base of the Pecten Seam. This member is less obviously cyclic in nature than the Penny Nab Member. The Pecten Seam comprises five thin (< 0.15 m) ironstone beds separated by thin silty shale bands, and is almost immediately succeeded by the Main Seam, divided by another thin silty shale into two distinct units. Small, often angular, phosphate clasts are common in the top block of the Main Seam. The top of the member is placed above a minor un-named ironstone seam with a highly irregular top (Bed 56 of Howarth, 1955), which lies just below the top of the Spinatum Zone.

Ammonites are a conspicuous element of the macrofauna throughout the Cleveland Ironstone Formation (Howarth, 1955), providing good biostratigraphical control, although common only at certain levels. Virtually all are members of the Amaltheidae, and include the neotype of *Amaltheus subnodosus* from Bed 27, and possibly that of *Amaltheus striatus* (Howarth, 1958). Howarth (1955, 1992) also recorded single specimens of two species of Tethyan hildoceratid, *Canavaria cultraroi* and *Protogrammoceras turgidulum* (= aff. *bassanii*), from beds 54 and

56 respectively; these remain unique in the British Lias. The remainder of the macrofauna is dominated by a fairly diverse assemblage of bivalves, listed in Young *et al.* (1990a), together with belemnites, rhynchonellid and terebratuloid brachiopods (Ager, 1956–1967, 1990), and other fossils. These include the type of *Rhynchonelloidea lineata* from near the base of the Pecten Seam. The fauna of the shales of the Cleveland Ironstone Formation generally shows a reduction in benthos diversity compared to that of the Staithes Sandstone Formation beneath, and a greater proportion of pelagic elements, such as ammonites and belemnites. Intact specimens of the crinoid *Hispidocrinus schlumbergeri* have been found in the mudstones of Bed 40, above the Two Foot Seam, while well-preserved stems, cirri, and occasionally crowns, of *Balanocrinus solenotis* are common a little lower in the succession, in the mudstones of beds 32 and 34 (Simms, 1989). Certain fossil species are characteristic of particular units; for instance, the Avicula Seam is characterized by abundant specimens of *Oxytoma* (= *Avicula*) *cygnipes*, whereas the Pecten Seam contains abundant *Pseudopecten equivalvis*. Fossil driftwood from the Penny Nab Member comprised part of a broader investigation of Pliensbachian to Bathonian tree growth-rings by Morgans (1999). The macrofauna of the Kettleness Member is less diverse and more poorly preserved than that of the Penny Nab Member, and is largely confined to the lower part of the Pecten Seam and the top block of the Main Seam. Trace fossils are abundant and diverse at many levels in the Cleveland Ironstone Formation (Young *et al.*, 1990a), particularly in certain of the ironstone seams, and there seems to be a distinction between these assemblages and those seen in the clastic units. They are particularly spectacular in the top block of the Main Seam, where profuse *Rhizocorallium* burrows preserve scratch marks made by the crustaceans that inhabited them (Farrow, 1966). Catt *et al.* (1971) reported a very impoverished microfauna from the Pliensbachian succession of this site, with only occasional specimens of four species of ostracod and a few benthic foraminifera.

The base of the Whitby Mudstone Formation is taken at the base of the Sulphur Band, a 0.2 m-thick, laminated, pyritic mudstone with lenses of jet. The Grey Shale Member is dominated by pyritic, silty, micaceous mudstones with thin, ripple-laminated siltstones and numerous nodule bands in the lower part. Many of these nodules weather distinctly red and can be easily traced across the foreshore and into the cliff. At some levels almost every nodule contains an ammonite; at others they are absent. The base of the predominantly laminated, organic-rich mudstones of the Mulgrave Shale Member is taken here, the type locality, at the base of the distinctive Cannon Ball Doggers (Cope *et al.*, 1980a; Howarth, 1992). The Mulgrave Shale Member is divided into two informal subdivisions. The lower subdivision, the Jet Rock, is characterized by bands of often large nodules (the Whalestones, Curling Stones, and the Upper and Lower Pseudovertebrae), which form a conspicuous feature of the foreshore at Rosedale Wyke. These nodules have formed the subject of several papers. General accounts of the formation and diagenesis of these nodules have been given by Hallam (1962a) and Raiswell (1976). More specific accounts have investigated the spatial distribution, size and orientation of the Curling Stones exposed *in situ* at Port Mulgrave (Raiswell and White, 1978); the diagenetic history of the Cannonball Doggers and Curling Stones (Coleman and Raiswell, 1981); and the trace-element geochemistry of concretionary pyrite (Raiswell and Plant, 1980). The lower part of the upper subdivision, the Bituminous Shales, crops out on the foreshore on the eastern side of Rosedale Wyke and are also well exposed, but mostly inaccessible, in the adjacent cliffs. As their name implies they comprise mainly laminated, organic-rich, mudstones. They contain fewer calcareous nodule bands and a greater abundance of pyrite than the Jet Rock.

Through most of the Grey Shale and Mulgrave Shale members the fauna is dominated by planktonic and nektonic forms, with benthic taxa largely confined to just a few horizons. Ammonites, particularly dactylioceratids and hildoceratids (Howarth, 1962a, 1973, 1992), are a conspicuous element of the fauna and the site is the type locality for *Dactylioceras tenuicostatum*. Several species of belemnite (Doyle, 1990–1992) and the bivalves *Pseudomytiloides dubius* and *Bositra radiata* are the only other common invertebrate fossils at many levels. Hemingway (1974) noted that *B. radiata* is abundant only in the lower 2 m of the Mulgrave Shale Member, being replaced in higher beds by *P. dubius*. The pseudoplanktonic crinoids *Pentacrinites dichotomus* and *Seirocrinus* *subangularis* occur rarely in the Bituminous Shales (Simms, 1989). Port Mulgrave was one of the sites examined by Morris (1979) in his palaeoenvironmental investigation of this part of the succession and was also included by Myers and Wignall (1987) in their study of potential correlation between gamma-ray spectrometry and palaeoecological indices. Few vertebrates have been recorded from this site although the organic-rich shales of the Mulgrave Shale Member might be expected to yield well-preserved remains. Benton and Taylor (1984) referred to the skeleton of a crocodilian found here in 1791 and assumed it had fallen from the Alum Shale Member. However, Walkden *et al.* (1987) demonstrated that crocodilians are present in the Mulgrave Shale Member and described a partial skeleton of *Steneosaurus* from the upper part of the Jet Rock.

The jet, which forms such a well-known, but scarce, component of the Mulgrave Shale Member is the product of diagenetically altered driftwood. Hemingway (1974) provided one of the few scientific descriptions of this material. 'Hard' jet, the relatively tough form used in carving, is found in the upper 3 m of the Jet Rock. The more brittle 'soft' jet is found in the Bituminous Shales and elsewhere in the Lower Jurassic succession. It may occur as thin 'seams' or as cylindrical masses with a silicified core in which original cell structure may be well preserved. Rounded quartz and garnet grains, and even an 80 mm-diameter quartzite pebble, have been found lodged in fissures in some pieces of jet.

Interpretation

The succession exposed in the Staithes to Port Mulgrave GCR site differs in only minor respects from those sites at this stratigraphical level elsewhere in the Cleveland Basin. The extensive foreshore exposures have enabled the succession to be studied in detail, and it is the type site for the Staithes Sandstone Formation, the Cleveland Ironstone Formation and Penny Nab Member, and for the Mulgrave Shale Member of the Whitby Mudstone Formation. The abundance of ammonites at many horizons has enabled all of the ammonite zones and subzones from the Maculatum Subzone (Lower Pliensbachian), to the Falciferum Subzone (Toarcian) to be identified at this site. Higher parts of the Toarcian succession are present in the cliffs but are not generally accessible. More detailed biostratigraphical analysis has established the presence of numerous ammonite-correlated 'horizons' and 'zonules' within the subzones (Page, 1995).

Cox (1990) suggested that the succession between Staithes and Port Mulgrave could provide reference sections for the Margaritatus, Spinatum, Tenuicostatum and Serpentinum (formerly Falciferum) zones. Howarth (1992) designated the site as stratotype, or at least parastratotype, for all three subzones of the Margaritatus Zone and for three of the four subzones of the Tenuicostatum Zone. He also suggested that the base of the Hawskerense Subzone could be defined at the base of Bed 55 in the Kettleness Member. However, *Pleuroceras elaboratum* occurs in Bed 54, and was considered by Dommergues *et al.* (1997) to characterize the lower part of the subzone. Information from France and elsewhere indicates the existence of *Pleuroceras* faunas earlier than those recorded from Yorkshire: these correspond to the Transiens and Salebrosum zonules of Dommergues *et al.* (1997). The base of the Apyrenum Subzone was taken by Howarth (1992) at a level higher than that used here. Solare Zonule (basal Apyrenum Subzone) faunas have been recorded from the Pecten Seam at Hawsker Bottoms. The absence of the Transiens and Salebrosum zonules in Yorkshire indicates a non-sequence between the Penny Nab and Kettleness members (Figure 6.11).

There is considerable uncertainty as to the position of the Pliensbachian–Toarcian boundary. The highest unequivocally Pliensbachian species is *Pleuroceras hawskerense* in Bed 57 but the lowest definite Toarcian taxa are not found until Bed 3, almost 1.7 m higher in the succession. Cope *et al.* (1980a) and Howard (1985) placed the Pliensbachian–Toarcian boundary at the base of Bed 58. Howarth (1955) placed the base of the Tenuicostatum Zone immediately above Bed 60, but subsequently (1992) proposed the base of Bed 58 at Staithes, and an equivalent level at Kettleness (Bed 38), as parastratotypes for the base of the Paltus Subzone, and hence the Toarcian Stage. On current criteria, the Pliensbachian–Toarcian boundary is taken at the base of Bed 3, the level at which the earliest typical Toarcian ammonites occur.

The Mulgrave Shale Member here must have been the source of the unhorizoned holotype of *Harpoceras mulgravium* (Young and Bird, 1822). Despite its name, this was said to be from

Whitby, although the poorly localized nature of many specimens collected in the early 19th century certainly does not preclude an origin from Port Mulgrave. Howarth (1992) considered this nominal species to be a synonym of *Harpoceras falciferum*. Evidence from France and Somerset (K.N. Page, unpublished observations) indicates that relatively evolute and slender *Harpoceras* ex grp. *falciferum* such as this are typical of the lower part of the Falciferum Subzone, and that the species can be considered distinct from the later, more involute and stout, *H. falciferum sensu stricto*. This led to the recognition of a Pseudoserpentinum Zonule in France (Elmi *et al*., 1997), the index fossil of which is considered here to be a synonym of *H. mulgravium*. Howarth (1992) had already considered *Harpoceras pseudoserpentinum* to be an early subspecies of *H. falciferum*.

The superb cliff and foreshore exposures have made this a favoured site for investigating palaeoenvironments and diagenetic processes in the Upper Pliensbachian and Lower Toarcian Staithes Sandstone Formation and Cleveland Ironstone Formation. The vertical grading, planar or low-angle cross-laminations, gutter casts and scours in the Staithes Sandstone Formation have been interpreted as tempestites (Greensmith *et al*., 1980; Knox *et al*., 1990). The orientation of the cross-laminations and the gutter casts indicates eastward-flowing storm-surge ebb currents. Wave ripples on the tops of the cross-laminated sands are orientated roughly perpendicular to this. The occurrence of intact crinoids and ophiuroids at certain levels, which clearly represent obrution konservat lagerstätten (Seilacher *et al*., 1985), support a tempestitic origin. The intervening 'fair weather' deposits often were intensely bioturbated. Knox *et al*. (1990) interpreted the lower part of the Staithes Sandstone Formation as an innermost shelf facies, passing into a middle shelf facies in Bed 17. This may reflect a local transgression but was quickly followed by shallowing, indicated by upward-coarsening, in the succeeding part of the formation. The Cleveland Ironstone Formation was interpreted by Knox *et al*. (1990) as a middle to outer shelf environment, but Hesselbo and Jenkyns (1995) considered the formation to be the best example of a storm-influenced, lower-shoreface, facies in the British Jurassic System. The coarsening-upward cycles, each capped by an erosively based ironstone band, have been interpreted as evidence for repeated episodes of shoaling, leading to deposition of tempestites, followed by transgressions that cut off the sediment supply and allowed the deposition of ironstones. The lack of upward-coarsening in the clastic units beneath the Two Foot Seam suggests that the transgression terminated clastic input before any significant shoaling had occurred. Macquaker and Taylor (1996, 1997) considered that the ironstones and the intervening phosphate-rich units formed during prolonged breaks in sedimentation. The non-sequence between the Penny Nab and Kettleness members is considered to reflect local tectonic movement, rather than the effects of upward shoaling or eustatic change, since on a regional scale this boundary is seen to be markedly unconformable.

There has been considerable debate surrounding the origin of the ironstones (Hallam, 1966, 1975; Chowns, 1968; Catt *et al*., 1971; Myers, 1989; Young *et al*., 1990a). Most interpretations have favoured a terrigenous source for the iron, the result of intense subaerial weathering of thorium-bearing kaolinite being considered to account for the high thorium–potassium ratio. Such a weathering regime is perhaps supported by observations of Early and Middle Jurassic tree rings, which were interpreted by Morgans (1999) as evidence for an increasingly seasonal, Mediterranean-type, climate through this interval. However, Young *et al*. (1990a) consider that both iron and thorium may have been enriched on the sea floor during periods of reduced sedimentation through degradation of the background clastic sediment, in a process analogous to the formation of lateritic soils. Textures observed within the ironstone beds probably are not primary but reflect biological mixing and reworking of grainstone and mudstone interbeds, with some further modification by compaction, though the ooids may have been generated concurrently with reworking (Young *et al*., 1990a).

There is a striking facies change between the sandy micaceous shale at the top of the Cleveland Ironstone Formation and the bituminous Sulphur Band at the base of the Whitby Mudstone Formation. The lower part of the Grey Shale Member is a 'normal shale', as indicated by burrows, benthic invertebrates and the gamma-ray spectrometry (Morris, 1979; Myers and Wignall, 1987). It passes up into a 'restricted shale' facies towards the top of the member and then, fairly abruptly, into laminated bituminous shales of the Mulgrave Shale Member, in which benthic activity is limited or absent and the fauna is dominated by nektonic and pelagic organisms. The lower part of the Mulgrave Shale Member was termed an 'anoxic event' by Jenkyns (1988) and can be traced across much of Europe. It represents a significant extinction event for many benthic organisms (Little, 1996). It shows evidence of considerable stability by comparison with some other organic-rich mudrock sequences (Myers and Wignall, 1987), which has been taken as evidence of greater water depth than the mudrocks above and below. Hallam (1997) suggested a water depth of 50–100 m for the Mulgrave Shale Member, compared with no more than 20 m depth for the Staithes Sandstone and Cleveland Ironstone formations. He estimated that sea level rose at between 0.8 cm and 2.5 cm per ka in early Toarcian times, a figure equivalent to the growth rate of mid-oceanic ridges. This rapid eustatic rise might explain the onset of anoxic conditions at this time throughout much of Europe. The foraminiferan ***Reinholdia macfadyeni*** occurs in abundance in the Grey Shale Member at Port Mulgrove (Hylton and Hart, 2000), an indicator of deep water (Broumer, 1969) and implying a transgressive event. It disappears at the onset of the low-oxygen conditions of the Jet Rock.

Total organic carbon content of the mudrocks of the Mulgrave Shale Member ranges between 5% and 15% (Küspert, 1982; Raiswell and Berner, 1985). The organic material in the mudrocks is mainly structureless but includes various microplankton, pollen and spores (Wall, 1965; Hallam, 1967a). Under laboratory distillation these mudrocks yield from 54 to 86 litres of sulphurous oil per tonne (Hemingway, 1974). Calcareous concretions often emit a strong odour of mineral oil when broken open (Arkell, 1933) and cavities, such as ammonite chambers, may also occasionally contain an oil-like hydrocarbon. The development of microbial mats has been invoked to explain certain levels with wavy laminations (O'Brien, 1990) and a similar process may be responsible for peculiar patches of very finely and wavy banded micritic limestone, occasionally found within some of the calcareous concretions. A wide range of different shapes and sizes of concretions are developed within the Jet Rock, and at some levels have a characteristic outer pyritic skin or zoning (Hallam, 1962a; Coleman and Raiswell, 1981). These nodules, which form such a conspicuous element of parts of the Whitby Mudstone Formation, have been the subject of various papers. Hallam (1967b) found a correlation between sediment grain-size and the relative abundance of sideritic and calcitic early diagenetic nodules. Siderite nodules are more abundant in sandier sediment, such as the Grey Shale Member, whereas calcitic nodules predominate in the mudrocks, particularly the Mulgrave Shale Member. Raiswell and White (1978) concluded that the areal distribution of nodules at a particular horizon was random, implying that adjacent nodules had no influence on the growth of each other and did not compete for limited resources during growth. The discovery that some 30% had a long-axis orientation, with a prevailing NNE–SSW trend, indicated that there might be a preferred direction of water transport along bedding planes during compaction. Raiswell (1976) and Coleman and Raiswell (1981) showed that most of the calcite cement in these nodules originated from organic matter in the sulphate reduction zone and that the nodules formed at shallow depth beneath the sediment surface. They also demonstrated two phases of pyrite growth, with sulphate reduction during the second phase providing the carbonate source for nodule growth. The pyrite-skinned nodules (Hallam, 1962a; Coleman and Raiswell, 1981) may be analogous to the pyrite-skinned Coinstone and the Eype Nodule Bed of the Dorset coast (Ensom, 1985b; Hesselbo and Jenkyns, 1995; Hesselbo and Palmer, 1992). Development of the pyritic skin in the Dorset examples has been attributed to diagenesis associated with exhumation and re-burial of the carbonate concretions, although there is no evidence for any hiatus surfaces associated with pyrite-skinned nodules in the Mulgrave Shale Member.

Hemingway's (1974) observations of jet in the Mulgrave Shale Member suggest that rather than being simple compressions of intact logs, many pieces were formed from tree trunks split longitudinally, with these planks then being mechanically rounded prior to burial and compaction. Silicification of the cores of some pieces must have occurred early in diagenesis since these are largely uncompacted. The presence within some pieces of jet of detrital clastic grains suggests that many pieces of wood had already experienced a long period floating at the surface, and occasionally being washed ashore, before they entered this area and sank to the sea floor.

The Toarcian succession seen at this site differs only in very minor respects from correlative sections farther along the Yorkshire coast. Howarth (1962a) recorded total thickness variations for the Mulgrave Shale Member of less than 1 m over a distance of almost 18 km along the coast and was able to correlate individual units over this distance. Similar constancy of thickness was also seen in the Grey Shale Member (Howarth, 1973). The region was tectonically stable throughout this period. In contrast, the Cleveland Ironstone Formation shows marked lateral changes (Figure 6.11), particularly in the thickness of the ironstone seams which thicken to the north-west of Staithes but thin to the south-east at the expense of the intervening clastics (Young *et al.*, 1990a). In addition, the Kettleness Member onlaps unconformably onto the northward dipping Penny Nab Member. The thickening of the ironstone seams to the north-west has been attributed to increasingly low subsidence rates towards the margins of the basin while the southward onlap of the Kettleness Member may relate to movement on the Market Weighton Block (Figure 5.10, Chapter 5).

Conclusions

The cliffs and foreshore between Staithes and Port Mulgrave, North Yorkshire expose one of the most complete and accessible Upper Pliensbachian to Toarcian successions in Britain. The Pliensbachian sequence between Staithes and Port Mulgrave, includes the type sections of the Staithes Sandstone and the Cleveland Ironstone formations, and of the Penny Nab Member of the latter formation. Because of the extensive foreshore exposures, accessibility of the site, and often fossiliferous nature of the succession, this site has been the focus of much research into a diverse range of topics covering many aspects of the palaeoecology, sedimentology and diagenesis of the sequence. The results of much of this research have had considerable bearing on the interpretation of other successions elsewhere in the geological record and makes it one of the most important Lower Jurassic reference sections in Britain.

BOULBY QUARRIES, REDCAR AND CLEVELAND (NZ 735 200–NZ 757 194)

K.N. Page and M.J. Simms

Introduction

The Boulby Quarries GCR site, also known as 'Boulby and Loftus Alum Shale Quarries', comprises a series of large pits excavated into the highest cliffs in England, which rise to 215 m above sea level. The quarries and the cliffs below expose a virtually complete, but largely inaccessible, succession through the Redcar Mudstone, Staithes Sandstone, Cleveland Ironstone and Whitby Mudstone formations, thereby providing an almost unbroken sequence through the Pliensbachian and Toarcian stages in the Cleveland Basin. The term 'Alum Rock' was coined at this site by Young (1817) in reference to the whole Lower Jurassic succession exposed on Boulby Cliff, but the name has subsequently been refined to 'Alum Shale Member', representing just part of the (Toarcian) Whitby Mudstone Formation. The Toarcian sequence in the alum shale quarries is now weathered and overgrown in places (Figure 6.18). The Lower Jurassic succession is capped by the Middle Jurassic (Aalenian–Bajocian) Dogger Formation and Ravenscar Group.

During their working life the quarries were an important source of marine reptiles, including plesiosaurs, ichthyosaurs and a single pterosaur (Benton and Taylor, 1984; Benton and Spencer, 1995). The first record of vertebrate remains from the area, was that of a plesiosaur vertebra from Loftus Quarry (Young and Bird, 1828). Most of this fauna is likely to have been collected prior to closure of the Loftus quarries in 1863, two years after the Boulby works had ceased operating (Fox-Strangways, 1892). The Alum Shale Member in particular has been a rich source of marine reptiles, while the Pliensbachian succession below has yielded some of the only intact asteroids known from the Yorkshire Lias.

Despite the remarkable nature of the exposure at Boulby Quarries, little has been published on the stratigraphy of the quarries or of the main cliff, commonly known in early accounts as 'Rockcliff', for well over a century. Hence only general comparison can be made with better-known exposures, particularly that at

Figure 6.18 The long-abandoned alum shale workings on Boulby Cliff, with the Middle Jurassic sandstones of the Dogger Formation rising behind them. (Photo: K.N. Page.)

the **Staithes to Port Mulgrave** GCR site only a few kilometres farther east along the coast. The most complete and detailed section yet published of the site, and still the most useful today, was by Hunton (1836). His graphic depiction of the section exposed in the cliff enables the main modern lithostratigraphical units to be recognized (Figure 6.19). His account also documented the stratigraphical distribution of the main fossils present and a separate list of taxa and their occurrence. The site was mentioned by Phillips (1829, 1835, 1875) and Herries (1906a,b), who also provided sketches of the cliff face and its stratigraphy. Wright (1862–1880) reproduced part of Hunton's (1836) description, from the 'Lower Lias Shales' to the 'Jet Rock', but added little additional information. Rastall (1905) discussed the site briefly in connection with the relationship of the Middle Jurassic beds to the Lias beneath. The area is also included in the descriptions of the Yorkshire Lias of Tate and Blake (1876) Taken together these accounts formed the basis for the brief description provided by Fox-Strangways (1892). Other than the lists of fossils published by Hunton (1836) and Phillips (1829, 1835, 1875), only two taxonomic groups have been investigated in any detail here. The reptile fauna from the Toarcian strata has been described and much discussed over the past 150 years in publications by Carte and Bailey (1863), Seeley (1865), Tate and Blake (1876), Newton (1888), Watson (1911), Melmore (1930), Wellnhofer (1978), Benton and Taylor (1984), Taylor (1992), Benton and Spencer (1995). Wright (1862–1880) described and figured two species of asteroid from here.

Description

The cliff and quarries form a vertical exposure through most of the Pliensbachian to Toarcian succession of North Yorkshire and Cleveland (Figure 6.19). Phillips (1829, 1835, 1875) and Herries (1906a) showed that the site lies on the axis of a broad gentle anticline that stretches from east of Staithes westwards to Skinningrove Bay. Phillips (1829, 1835, 1875) noted that this stretch of cliffs is unbroken by faults and stated that it was possible to measure almost every bed and collect its contained fauna, except from the inaccessible middle part of the Middle Lias.

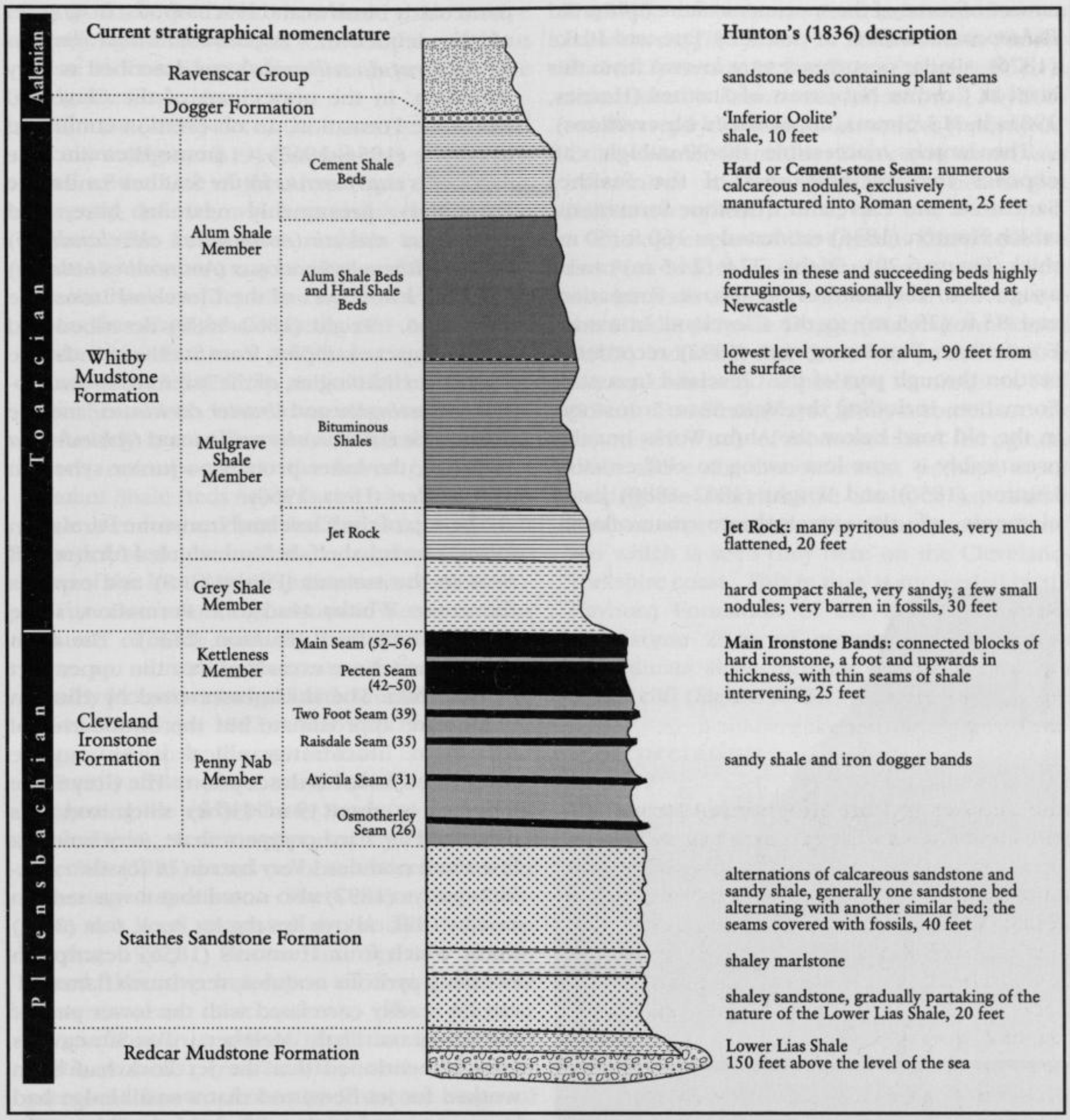

Figure 6.19 Sketch section of Boulby Cliff. After Hunton (1836). Bed numbers are those of Howarth (1955) for the Staithes section. Hunton's original lithological notes are on the right-hand side of the column; the modern interpretation of the lithostratigraphy is on the left.

About 45 m (150 ft) of shales and siltstones of the upper part of the Ironstone Shale Member of the Redcar Mudstone Formation are exposed on the foreshore and in the lower part of the cliff. Towards the base, grey shales with bands of concretionary iron-rich (?sideritic) carbonate nodules contain ammonite faunas, in part pyritized, indicating at least three of the four subzones of the Jamesoni Zone; taxa include *Polymorphites* (Polymorphus Subzone), *Platypleuroceras* (Brevispina Subzone) and *Uptonia* (Jamesoni Subzone). It is unlikely that any lower strata are represented, although because of the lack of any other detailed studies north of Staithes, this cannot be ruled out entirely. Higher parts of this member were described by Hunton (1836) including an upward transition to the Staithes Sandstone Formation. At the top of the Redcar Mudstone Formation, shell beds with *Aegoceras maculatum* may have been the source of some of the specimens of the ophiuroid *Palaeocoma milleri* as noted by Tate and Blake (1876); similar occurrences are known from this level at Cowbar Nab, west of Staithes (Herries, 1906a,b; M.J. Simms, unpublished observations).

The largely inaccessible 80–90 m-high cliff exposes the full thickness of the Staithes Sandstone and Cleveland Ironstone formations, which Hunton (1836) estimated as 160 ft (50 m) thick (Figure 6.20). Of this, 77 ft (24.5 m) can be assigned to the Staithes Sandstone Formation, and 83 ft (25.5 m) to the Cleveland Ironstone Formation. Fox-Strangways (1892) recorded a section through part of the Cleveland Ironstone Formation, including the Main Seam ironstone, in the old road below the Alum Works but this presumably is now lost owing to cliff erosion. Hunton (1836) and Wright (1862–1880) listed elements of the invertebrate macrofauna, particularly bivalves and brachiopods, from parts of the sequence. *Rhynchonelloidea lineata* (= *Terebratula trilineata*) was described as 'very abundant' in the upper part of the Cleveland Ironstone Formation, an observation confirmed by Ager (1956–1967). Ammonites include *Aegoceras capricornus* in the Staithes Sandstone Formation, presumably near its base, and *Amaltheus stokesi* (*Ammonites clevelandicus*) and *Amaltheus subnodosus* (*Ammonites vittatus*) from the lower part of the Cleveland Ironstone Formation. Wright (1862–1880) described and figured intact examples, from Staithes Sandstone Formation lithologies, of the asteroids *Archastropecten hastingiae* and *Uraster carinatus*, and the ophiuroids *Palaeocoma milleri* and *Ophioderma carinata*, the latter probably a junior synonym of *P. milleri* (Hess, 1960).

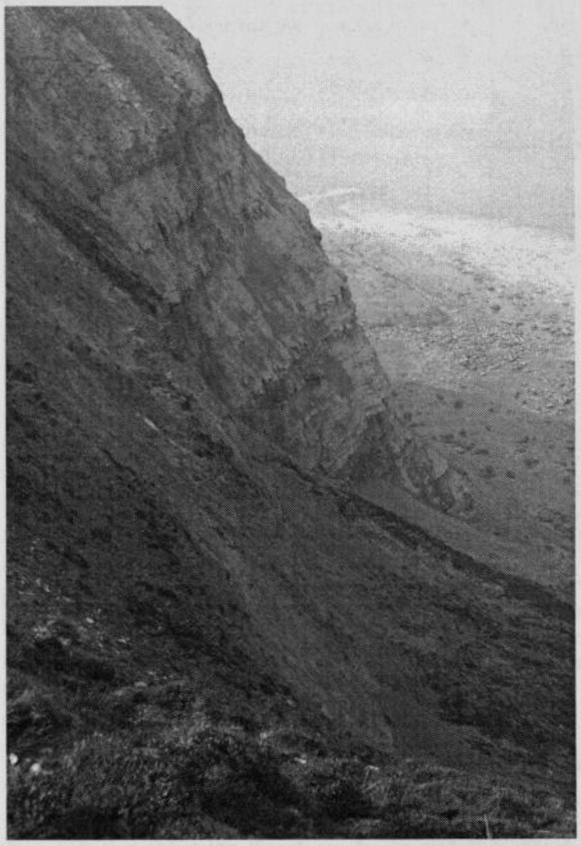

Figure 6.20 The Pliensbachian succession on the lower face of Boulby Cliff, viewed from the abandoned alum workings. The ironstone bands of the Cleveland Ironstone Formation are visible in the upper part of the face. Foreshore reefs are formed by the upper beds of the Redcar Mudstone Formation, Ironstone Shale Member. (Photo: K.N. Page.)

The top of the Cleveland Ironstone Formation forms a broad shelf, behind which a further cliff rises to the summit (Figure 6.18) and exposes the entire Whitby Mudstone Formation, some 72 m (235 ft) thick (Hunton, 1836). The alum shale quarries are excavated into the upper part of this cliff. The thicknesses cited by Hunton (1836) are approximate but the boundaries of the main lithostratigraphical units can be recognized from his description. The Grey Shale Member is about 9 m (30 ft) thick and was described as 'hard compact shale, very sandy; a few small nodules. Very barren in fossils'. Fox-Strangways (1892) also noted that it was seen in Boulby Cliff. Above lies the Jet Rock, 6 m (20 ft) thick, which from Hunton's (1836) description of 'many pyritous nodules, very much flattened' can be readily correlated with the lower part of the Mulgrave Shale Member. Fox-Strangways (1892) mentioned that the Jet Rock had been worked for jet here, and that a small ledge had been excavated in the cliff at this level between the Boulby Alum Works and the west end of Loftus Alum Works. From the Jet Rock and the lower part of the Bituminous Shales Hunton (1836) recorded *Harpoceras exaratum*, *H. falciferum* (= *Ammonites mulgravius*), *Elegantuliceras elegantulum*, *Ovaticeras ovatum*, *Pseudolioceras lythense* (= *Ammonites concavus*), *Phylloceras heterophyllum* and a small lytoceratid that he identified as '*Ammonites fimbriatus*'. He also noted remains of *Ichthyosaurus*, *Plesiosaurus* and the crocodilian *Pelagosaurus brongniarti* (= *Teleosaurus chapmanni*), preserved 'generally in pyritous nodules', and the fish *Lepidotes gigas* which he described as being 'rarely met with elsewhere'. The bivalve *Pseudomytiloides dubius* was found throughout what is considered here to represent the Mulgrave Shale Member.

Hunton (1836) noted the lowest level worked for alum (Figure 6.19) but this may not correspond to the base of the Alum Shale Member as currently defined, which probably lies a little higher. The ferruginous nodules in the Alum Shale Member here may be similar to the nodular siderite horizons described by Howarth (1962a) from the Hard Shale Beds and Main Alum Shale Beds. Hunton's (1836) description of the succeeding 25 ft (7.7 m), as the 'Hard or Cement-stone Seam' with 'numerous calcareous nodules, exclusively manufactured into Roman cement', clearly corresponds to the lower part of the Cement Shale Beds towards the top of the Alum Shale Member, as does the the remaining 10 ft (3 m) of 'shale' beneath the unconformity at the base of the local Middle Jurassic succession.

The alum workings removed an enormous volume of rock and the vertebrate remains were so numerous that one of the walks at Boulby House was edged with saurian vertebrae (Fox-Strangways, 1892). Tate and Blake (1876) suggested that the vertebrate fauna came primarily from their zone of *A. communis*, suggesting the early Bifrons Zone (= Main Alum Shale Beds), a view supported by Benton and Spencer (1995) based on observations of matrix adhering to specimens. The Cement Shale Beds have also been suggested as a source for some (Taylor, 1992). Benton and Spencer (1995) noted that the holotypes of the plesiosaur *Eretmosaurus macropterus*, the pliosaur *Rhomaleosaurus zetlandicus*, the ichthyosaur *Ichthyosaurus crassimanus* and the only pterosaur known from the Toarcian Stage of Britain, *Parasicephalus purdoni* came from this locality. The ichthyosaur *Temnodontosaurus platyodon* was recorded by Simpson (1884): this species and *Ichthyosaurus communis* were noted by Hunton (1836), but without indicating the level within the Whitby Mudstone Formation that they occurred. The bivalve *Nuculana ovum* was stated by Hunton (1836) as very abundant in the Cement Shale Beds and present throughout much of the Alum Shale Member. He commented that the species was used to indicate which part of the shale succession was suitable for alum extraction. Among the fauna cited from the Alum Shale Member were *Dactylioceras commune*, *Hildoceras bifrons* (*Ammonites walcotti*), *Frechiella subcarinata*, *Catacoeloceras crassum*, *Peronoceras fibulatum*, *P. subarmatum*, *Pseudolioceras lythense*, *Ps. boulbiense*, *Nodicoeloceras crassoides* (= *Ammonites annulatus*), *Phylloceras heterophyllum* and '*Ammonites fimbriatus*'. Other elements include *Cenoceras astacoides*, belemnites and the inarticulate brachiopod *Discinisca reflexa*.

The upper part of the Cement Shale Beds and the Peak Mudstone Member are missing at this site beneath the unconformity at the base of the Middle Jurassic Dogger Formation. Rastall (1905) indicated that there was palaeorelief on the unconformity of perhaps as much as 50 ft (15 m). Fox-Strangways (1892) recorded around 1.4 m (4 ft 6 in.) of ironstone and ferruginous shale above the unconformity, perhaps representing the Murchisonae Shale, a key marker horizon of proven Aalenian (Murchisonae Zone) age which is seen only here on the Cleveland–Yorkshire coast. This in turn is succeeded by the Hayburn Formation of the Ravenscar Group, with some 25 m of massive sandstone and subordinate shale forming the top part of the upper cliff (Figure 6.18).

Interpretation

The succession at the Boulby Quarries GCR site is similar to that at the **Staithes to Port Mulgrave** GCR site. Bed-by-bed correlation is possible for parts of the succession (Figure 6.19). The ironstones of the Cleveland Ironstone Formation are thicker here than east of Staithes, a reflection of the north-westerly thickening towards Eston (Young *et al.*, 1990a) (Figure 6.11).

Some aspects of the biostratigraphy of the site are still unresolved. Hunton (1836) correctly cited *Amaltheus subnodosus* (= *Ammonites vittatus*) as occurring in the Osmortherley Seam (Bed 26 of Howarth, 1955) at the base of the Subnodosus Subzone. However, his notes imply that he found *Amaltheus stokesi* (= *Ammonites clevelandicus*), indicative of the Stokesi Subzone, in beds equivalent to beds 29 to 38 of the Penny Nab Member at Staithes (Howarth, 1955), whereas these beds actually lie within the succeeding Subnodosus and Gibbosus subzones. *Pseudolioceras lythense* was said to occur in the Mulgrave Shale Member, corresponding to the Serpentinum Zone, but this species is known to be restricted to the succeeding Commune Subzone (Howarth, 1992). Hunton (1836) cited *Pseudolioceras boulbiense* from the Alum Shale

Member at this site but this species is confined to the Cement Shale Beds, and higher parts of the Toarcian succession not preserved at Boulby Quarries. Simpson (1855) described a large slab from the Jet Rock, containing some 80 specimens of *Cleviceras exaratum* and the holotype and paratype of *Phylloceras easingtonense* (= *P. heterophyllum*), the latter being re-figured by Howarth (1962b).

Some elements of the Pliensbachian and Toarcian fauna listed by Hunton (1836) cannot now be interpreted, including most of the belemnites and certain of the ammonites and brachiopods. His identification of *Lytoceras* ('*Ammonites*') *fimbriatum* from the Mulgrave Shale and Alum Shale members is questionable because this is a Pliensbachian species. The Mulgrave Shale Member specimen may represent *Trachylytoceras nitidum*, a small species with periodic raised annular ribs rather like those of *Lytoceras fimbriatum* (Howarth, 1962a), while the Alum Shale Member record may refer to *Lytoceras cornucopia*, said to occur sporadically in the Bituminous Shales and in the Alum Shale Member (Howarth, 1962a). Among the vertebrates, records of the ichthyosaurs *Temnodontosaurus platyodon* and *Ichthyosaurus communis* (Hunton, 1836; Simpson, 1884) need to be confirmed since these are characteristically Hettangian and Sinemurian taxa.

This site was an important source of intact echinoderms, from the Upper Pliensbachian sequence, and marine reptiles, from the Toarcian Stage, during the 19th century. The preservation of the echinoderms is typical of obrution deposits (Seilacher *et al.*, 1985) and suggests a similar general palaeoenvironment to that of the Staithes Sandstone Formation at its type locality, with frequent storm re-suspension of sediment bringing about the burial and death of many elements of the benthos. However, although ophiuroids have been found at Staithes (M.J. Simms, unpublished observations) at a level comparable to that at which they are recorded here by Wright (1862–1880), asteroids have not been reported from the former site though this may reflect collection failure.

The Toarcian vertebrate remains have received more attention than other elements of the fauna at this site, though there is little documentation of the stratigraphical levels from which they were obtained. Early records suggest that more specimens were found in the Loftus Alum Quarries than at Boulby Quarries (Tate and Blake, 1876; Fox-Strangways, 1892). However, this could reflect collector bias rather than a genuine difference in distribution, particularly if all of the bones from Boulby were used to line pathways rather than ending up in collections! Benton and Spencer (1995) noted that the Loftus quarries appeared to have yielded a reptile fauna distinct from those from sites around Whitby. Only six specimens from the Boulby–Loftus area can now be positively traced but it is likely that a greater variety of taxa was collected. The preservation of these animals in laminated, organic-rich, mudstones is typical of stagnation deposits (Seilacher *et al.*, 1985). Taylor's (1992) investigation of a large plesiosaur skeleton, *Rhomaleosaurus zetlandicus*, suggested that it had drifted and decayed before sinking to the sea floor. He found no evidence for post-mortem scavenging but the decay of soft tissues continued on the sea floor and, in early diagenesis, probably caused the growth of pyritous nodules around the axial skeleton.

Conclusions

The Boulby and Loftus alum quarries, and the cliffs and foreshore below, constitute the thickest vertical exposure of the Lower Jurassic Series in Britain, representing levels from the Lower Pliensbachian Substage up to the Aalenian Stage, and including the base of the Redcar Mudstone Formation and the Staithes Sandstone, Cleveland Ironstone and Whitby Mudstone formations. Despite the main description of the site having been published more than 160 years ago, all of the main lithostratigraphical units were recognized. Hunton's (1836) attempt at an ammonite biostratigraphy of the section is one of the earliest known; its wider significance has perhaps been overlooked on account of his premature death. The stratigraphy of the site has been little studied since that time and has great potential for further investigation. The site has yielded important faunas of Toarcian reptiles, including plesiosaurs, ichthyosaurs and a pterosaur, and of Upper Pliensbachian asterozoan echinoderms. The Toarcian reptile fauna appears distinct from those known from correlative sections farther south. More precise data on thicknesses or facies of individual sedimentary units will prove invaluable in understanding regional patterns within the Lower Jurassic succession of the Cleveland Basin.

WHITBY TO SALTWICK, NORTH YORKSHIRE (NZ 901 115–NZ 916 109)

K.N. Page

Introduction

The town of Whitby is one of the best-known Lower Jurassic sites in Britain, and the Whitby to Saltwick coast section is of international importance for its classic Lower Toarcian exposures, unconformably overlain by the Middle Jurassic Dogger Formation. The location gives its name to the Whitby Mudstone Formation, with part of its type section, and the type section of the Alum Shale Member, falling within the boundaries of this site (Powell, 1984). The term 'Whitbian' was also coined by Buckman (1910) for the lower part of the Toarcian Stage. It was re-defined by Dean *et al.* (1961) as the Whitbian Substage, encompassing only the Lower Toarcian Tenuicostatum to Bifrons zones. Although the term is seldom now used, the section is the type locality for this substage. In addition, there are superb, and readily accessible, exposures of the Alum Shale Member and underlying Mulgrave Shale Member, which have yielded a rich fauna of vertebrates and invertebrates, including the type fossils of many species. On the basis of its ammonite faunas the site includes stratotypes, or at least parastratotypes for several zones and subzones.

The coastal exposures of the Whitby Mudstone Formation (Toarcian) here have featured extensively in geological descriptions of the Yorkshire coast, including Young and Bird (1822, 1828), Phillips (1829, 1835, 1875), Simpson (1868, 1884), Tate and Blake (1876), Fox-Strangways (1892) and Herries (1906a,b), and Howarth (1962a). This last provides the best description of the succession at this site. The vertebrate palaeontology of the Whitby to Saltwick GCR site is included in the *Fossil Reptiles of Great Britain* (Benton and Spencer, 1995) and *Fossil Fishes of Great Britain* (Dineley and Metcalf, 1999) GCR volumes. Excursion details for the site are included in Rawson and Wright (1992) and Scrutton (1996). The Toarcian of the Whitby district has long been an important source of fossils, including many type specimens. However, published accounts and museum labels are often vague about the original source locality. In many instances 'Whitby' is just as likely to include specimens from Ravenscar or Port Mulgrave as from close to the town itself, and only taxa confined to strata above the Alum Shale Member or below the Mulgrave Shale Member can definitely be eliminated from any list of 'Whitby' fossils. Skeletons of large marine reptiles were among the first fossils to be described from here and, in contrast to so many other fossils, were sometimes associated with quite precise location details (Chapman, 1758; Wooller, 1758; Benton and Spencer, 1995). The ammonite faunas are particularly well-known, although old descriptions and material are often poorly localized. Many species were figured and described by Simpson (1855, 1884), Buckman (1909–1930) and Howarth (1962b, 1992). The belemnite faunas are similarly well-documented, with descriptions in Young and Bird (1822, 1828), Phillips (1835, 1875, 1865–1909), Simpson (1855, 1866, 1884), Tate and Blake (1876) and Doyle (1985, 1990–1992). The vertebrate fauna is also well-documented as a result of three reviews (Benton and Taylor, 1984; Benton and Spencer, 1995; Dineley and Metcalf, 1999). However, other than some of the 19th century texts there has been little systematic recording of other elements of the fauna at this site. Simms (1989) cited some poorly localized crinoid remains from the Whitby district while Watson (1982) collected almost 300 specimens of *Dacromya ovum* with a few adherent specimens of the brachiopod *Discinisca reflexa*.

Some of the fossils for which Whitby is so well known have formed the basis for folklore. The best known of these is the legend of the Whitby snakestones. When St Hilda (614–680), founder of one of the first churches in England, arrived in Whitby she found the area infested with snakes. To eradicate this supposed evil she cut off the serpents' heads and cast them into the sea, the legend thereby conveniently explaining why ammonites are common on the beaches of the district (Scrutton, 1996). This event is commemorated by the three coiled 'snakes' (ammonites) on the town's coat of arms and it spawned a souvenir trade in the mid- to late-19th century, with snakes' heads being carved on fossil ammonites (usually *Dactylioceras*). Legend meets science in the lectotype of *Dactylioceras commune*, which bears just such a carved snake's head at the end of its last whorl (Dean *et al.*, 1961). St Hilda's association with the town is further celebrated in the ammonite genus *Hildoceras*, the type species of which, *H. bifrons*, came from the area. Jet was another geological product that was sold extensively, mostly as jewellery or small carvings, in Whitby during the 19th century, although most material was obtained from sites elsewhere on the coast since the main jet-bearing beds are exposed here only in small patches at low tide.

Description

Only the middle part of the Whitby Mudstone Formation, comprising some 55 m of strata, is exposed in the cliffs and foreshore between Whitby East Pier and Saltwick Nab (Figure 6.21). The strata are folded into a broad, asymmetric syncline, so that from Whitby to Saltwick the gentle dip swings from south, to south-east and then south-west. The lowest strata seen are at about the level of the Whalestones (Bed 35 of Howarth, 1962a), towards the middle of the Jet Rock. They are exposed only around low-water mark along the seaward edge of the shore north-east of Saltwick Nab. Higher parts of the Mulgrave Shale Member and the full thickness of the Alum Shale Member are exposed on the foreshore to the north-east of Whitby East Pier as far as Long Bight, where the core of the syncline brings the base of the Dogger Formation down to beach level. Between there and towards Whitby East Pier the foreshore exposures pass down through the sequence to the base of the Alum Shale Member.

Howarth's (1962a) description of the Bituminous Shales was based on the exposures around Saltwick Nab. This is the only location where the complete Bituminous Shales succession can be examined on the foreshore: it effectively forms the type locality for this bed. Lamination is less well-developed, and the organic content lower, in the Bituminous Shales than in the Jet Rock below. The Alum Shale Member section was recorded between Saltwick Nab and Whitby by Howarth (1962a) and this forms its type section. The Main Alum Shale Beds have a calcium carbonate content sufficiently low that formerly they were used in the manufacture of Alum. The vast scars of this former industry litter the coast from Whitby to Boulby. The removal of many thousands of tonnes of shale led to the reduction

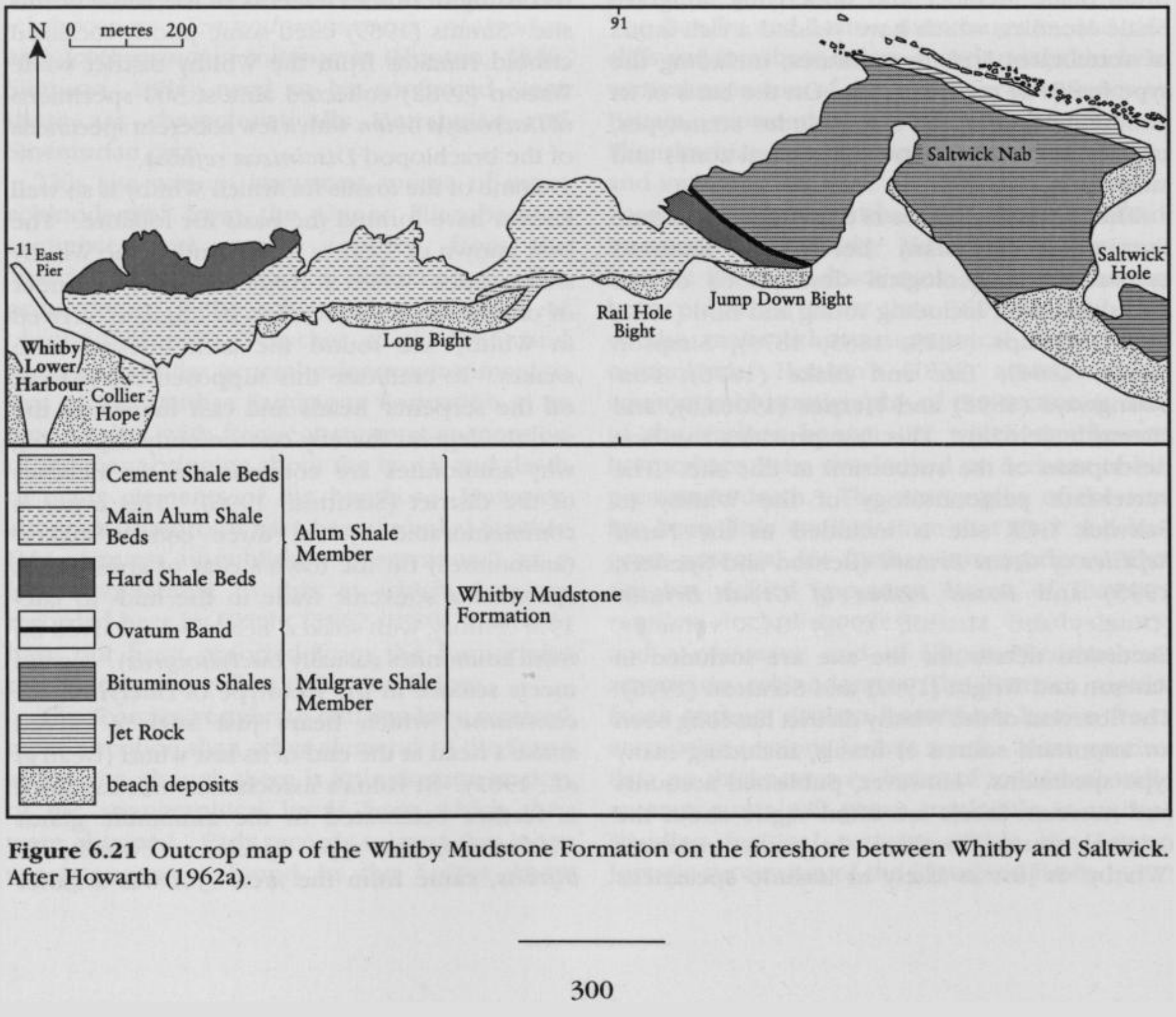

Figure 6.21 Outcrop map of the Whitby Mudstone Formation on the foreshore between Whitby and Saltwick. After Howarth (1962a).

of formerly grand headlands and cliffs to little more than stumps, such as at Saltwick Nab (Figure 6.22) and Kettleness. The Hard Shale Beds and Cement Shale Beds have slightly higher carbonate contents: concretions in the latter were once worked for cement manufacture. Thicknesses and lithological description of the Jet Rock are based on the section near Port Mulgrave, as recorded by Howarth (1962a). With minor revisions (Howarth, 1992), these form the basis of the following section.

Thickness (m)

AALENIAN STAGE
Dogger Formation
Sandstone, grey, at base, lying unconformably on Whitby Mudstone Formation.
LOWER TOARCIAN SUBSTAGE
Whitby Mudstone Formation
Alum Shale Member
Cement Shale Beds
Bifrons Zone, Crassum Subzone
72 (part): Shale, grey, with calcareous nodules. *Catacoeloceras crassum*, *Hildoceras semipolitum*, *H.* ex grp *bifrons*. Belemnites include *Acrocoelites levidensis*, *A. tricissus*, *A. subtricissus*, *Simpsonibelus expansus*, *S. dorsalis*, *S. lentus* and *Dactyloteuthis crossotela*. This horizon corresponds to the *crassum–bifrons* and *crassum–semipolitum* biohorizons, while the base of the unit at Whitby is a parastratotype for defining the Crassum Subzone of Howarth (1992). 2.5

Fibulatum Subzone
72 (part): Shale, grey, with calcareous nodules. *Porpoceras* cf. *vortex*, *P. verticosum*, *Hildoceras* ex grp. *bifrons*, *Acrocoelites levidensis*, *A. tricissus*, *A. subtricissus*, *Simpsonibelus expansus*, *S. dorsalis*, *S. lentus* and *Dactyloteuthis crossotela*. This corresponds to the *vortex* Biohorizon. 1.5
65–71: Shale with several rows of calcareous concretions. *Hildoceras* ex grp. *bifrons*, occasional *Phylloceras heterophyllum* and rare *Lytoceras cornucopia* at base. *Acrocoelites levidensis*, *A. subtricissus*, *A. inequistriatus*, *Simpsonibelus expansus*, *S. dorsalis* and *S. lentus* present. 1.85 (6 ft)
Main Alum Shale Beds
63 (part)–64: Shale with bands of calcareous nodules. *Peronoceras fibulatum*, *P. turriculatum*, *Zugodactylites braunianus*, *Pseudolioceras lythense*, *Hildoceras* ex grp. *bifrons*, *Phylloceras heterophyllum* and *Lytoceras cornucopia* with *Acrocoelites vulgaris*, *Simpsonibelus expansus* and *S. dorsalis*. Corresponds to the *braunianus* Biohorizon. 1.9
60–63 (part): Shale with bands of calcareous nodules. The fauna is reported to be in the lower approximately 1 m and includes *Peronoceras fibulatum*, *P. turriculatum*, *P. perarmatum*, *P. subarmatum*, *Pseudolioceras lythense*, *Hildoceras* ex grp. *bifrons* and *Phylloceras*. Belemnites include *Acrocoelites vulgaris*, *A. tricissus*, *A. inequistriatus*, *Simpsonibelus expansus*, *S. dorsalis and S. lentus*. These beds correspond to the *turriculatum* Biohorizon, while the base of Bed 60 at Whitby corresponds to the base of the Fibulatum Subzone as defined by Howarth (1992). 1.33

Figure 6.22 The Whitby Mudstone Formation in the cliffs at its type location. (Photo: K.N. Page.)

Thickness (m)

Commune Subzone

55–59: Shale with bands of calcareous nodules. *Dactylioceras athleticum* and *D.* spp., *Hildoceras* ex grp. *lusitanicum*, *Pseudolioceras lythense*, *Phylloceras heterophyllum* and *Lytoceras cornucopia*. Also *Acrocoelites oxyconus*, *A. subtenuis*, *A. subgracilis*, *A. pyramidalis*, *A. vulgaris*, *A. tricissus*, *A. subtricissus*, *A. inequistriatus*, *Simpsonibelus expansus*, *S. dorsalis* and *S. lentus*. Corresponds to the *athleticum* Biohorizon. 2.8 (9 ft 2 in)

51–54: Shale with bands of calcareous nodules. *D. commune* and *D.* spp., *Hildoceras* ex grp. *lusitanicum*, *Phylloceras heterophyllum* and rare *Frechiella subcarinata*. Belemnites include *Acrocoelites oxyconus*, *A. subtenuis*, *A. longiconus*, *A. subgracilis*, *A. pyramidalis*, *A. vulgaris*, *A. tricissus*, *A. subtricissus*, *A. inequistriatus*, *Simpsonibelus expansus* and *S. dorsalis*. Corresponds to part of the *commune* Biohorizon. 9.5 (31 ft)

Hard Shale Beds

49–50: Shale with concretions and pyritic masses, capped by a 0.13 m-thick red sideritic mudstone band. *Dactylioceras commune*, *D. temperatum* in upper part, also *Hildoceras* ex grp. *lusitanicum*, *Parapassaloteuthis polita*, *Acrocoelites subtenuis* and *Simpsonibelus dorsalis*. This corresponds to the lower part of the *commune* Biohorizon, while the base of Bed 49 here marks the base of the Commune Subzone as defined by Howarth (1992). 6.4 (20 ft 9 in.)

Mulgrave Shale Member

Bituminous Shales

48: **Ovatum Bed**: Double row of large sideritic concretions in grey shale, with irregular masses of pyrite and occasional 'belemnite battlefields' with abundant *Acrocoelites subtenuis* and *A. vulgaris*. *Ovaticeras ovatum* formerly common, probably including the holotype, with *Dactylioceras* cf. *consimile* and occasional *Phylloceras heterophyllum*. Corresponds to part of the *ovatum* Biohorizon. 0.25 (10 in.)

47 (part): Shale, grey bituminous with occasional *Ovaticeras ovatum*, also *Parapassaloteuthis polita*, *Acrocoelites subtenuis*, *A. vulgaris* and *Simpsonibelus dorsalis*. Corresponds to part of the *ovatum* Biohorizon. 0.75

Serpentinum Zone, Falciferum Subzone

46–47 (part): Shale, grey, bituminous, with a 0.13 m-thick sideritic mudstone at base. *Dactylioceras* sp., *Parapassaloteuthis polita*, *Acrocoelites subtenuis*, *A. vulgaris* and *Simpsonibelus dorsalis*. 4.98

44–45: Shale, grey, bituminous, with a row of scattered concretions at base. *Harpoceras* ex grp *falciferum* (J. Sowerby), *D.* cf. *consimile* and *P. heterophyllum*, also *Parapassaloteuthis polita*, *Acrocoelites* (*A.*) *subtenuis*, *A.* (*O.*) *subtricissus* and *Simpsonibelus dorsalis*. The *falciferum* Biohorizon lies within these two beds. 3.5 (11 ft 6 in.)

41–43: Shale, grey, bituminous, with a row of scattered, pyrite-skinned concretions, containing abundant *Pseudomytiloides*, near the middle. *Harpoceras* ex grp. *falciferum*, including *Harpoceras mulgravium*, *Dactylioceras* spp. and *Nodicoeloceras incrassatum*, *Parapassaloteuthis robusta*, *P. polita*, *Acrocoelites subtricissus*, *A. inequistriatus*, *Simpsonibelus dorsalis*, *Youngibelus tubularis* and *Y. simpsoni*; the last two species are restricted to Bed 43 of Howarth (1962a), which was termed the '*tubularis* Bed' in unpublished notes by Phillips (Doyle, 1985). These beds probably include the *mulgravium* Biohorizon. The base of Bed 41 at Saltwick is effectively a parastratotype for the base of the Falciferum Subzone (Howarth, 1992). 13.8 (44 ft 10 in.)

Jet Rock

Exaratum Subzone

40: **Millstones**: Giant, flattened lenticular calcareous concretions, reaching more than 4.5 m in diameter, in grey bituminous shale. They are exposed near low-water mark to the north of Saltwick Nab, extending south-eastwards in the direction of Whitestone Point. Corresponds to part of the *elegans* Biohorizon. 0.3 (1 ft)

39: **Top Jet Dogger**: Continuous band of argillaceous limestone. *Acrocoelites trisulcolosus*. Corresponds to part of the *elegans* Biohorizon. 0.23 (9 in)

38: Shale, grey, bituminous, with occasional calcareous concretions. *Acrocoelites trisulcolosus* and *A. ilminsterensis* present. 1.5 (5 ft)

37: **Curling Stones**: Calcareous concretions up to 0.45 m in diameter, with pyritic skins and almost perfect spheroidal shape, set in grey bituminous shale. *Acrocoelites trisulcolosus* and *A. ilminsterensis* present. Corresponds to part of the *elegans* Biohorizon. 0.3 (1 ft)

36: Shale, grey, bituminous. *Acrocoelites trisulcolosus* and *A. ilminsterensis*. 1.08 (3 ft 6 in)

35: **Whalestones**: Large ovoid calcareous concretions up to 3 m long and 1 m thick, with many smaller concretions, in grey bituminous shale. They form a conspicuous feature at low tide, beyond the outcrop of the Millstones, capping pillars of the underlying shale (Bed 34). Between Black Nab and Whitestone Point their position is often marked by a line of breaking waves. *Cleviceras exaratum*, with less frequent *Harpoceras serpentinum*, *Lytoceras crenatum* and probably also *Dactylioceras* sp.. This may be the type locality and horizon for *Hildaites forte* and *H. murleyi* (Howarth, 1992). *Acrocoelites trisulcolosus* and *A. ilminsterensis*. Corresponds to part of the *exaratum* Biohorizon. 0.92 (3 ft)

The invertebrate macrofossil fauna of the Whitby Mudstone Formation at this site is dominated by cephalopods, mostly dactylioceratid and hildoceratid ammonites and belemnites, but including the nautiloid *Cenoceras astacoides* from the Alum Shale Member (Howarth, 1962b). Belemnites are especially abundant and the Whitby district has yielded many type specimens; those definitely known to be from this site include *Acrocoelites inequistriatus*, *A. trisulculosus*, *Simpsonibelus dorsalis*, *Youngibelus tubularis* and *Y. simpsoni*. The type specimens of several other species are said to be from Whitby (Doyle, 1990–1992) but, as with many other old records, such labels may encompass several other sites along the coast. Specimens of *Youngibelus tubularis* and *Y. simpsoni* from Bed 43 at Saltwick Nab were used by Doyle (1985) to argue that these two nominal species were sexual dimorphs of a single species. Lenticular concentrations of belemnites at the level of the Ovatum Bed were termed 'belemnite battlefields' by Doyle and McDonald (1993). The remainder of the invertebrate fauna is of low diversity, as is typical of the Mulgrave Shale and Alum Shale members at other sites. In the Mulgrave Shale Member *Pseudomytiloides dubius* is one of the few common non-cephalopod macrofossils, while in the succeeding Alum Shale Member *Dacromya ovum* may be abundant at certain levels, sometimes associated with commensalistic examples of the brachiopod *Discinisca reflexa* (Watson, 1982). Morris (1979) provides a more complete list of bivalve taxa found in the two members. Rare examples of the crinoids *Pentacrinites dichotomus* and *Seirocrinus subangularis* have been recorded from the Bituminous Shales (Simms, 1989), with at least some probably recovered from this site. Small pyritic burrows occur at some levels in the Alum Shale Member.

The vertebrate fauna of this site is well documented through the work of Benton and Taylor (1984), Benton and Spencer (1995) and Dineley and Metcalf (1999). Among the reptile fauna plesiosaurs, ichthyosaurs, crocodiles and possibly a dinosaur are represented and include many nominal type species (Benton and Taylor, 1984). However, although detailed locality data is available for some specimens, even from more than two centuries ago (e.g. Chapman, 1758; Wooller, 1758), for many others a Whitby label is not necessarily proof that the specimen was obtained from this site. It is clear from Benton and Taylor's (1984) study that Saltwick was an exceptionally rich source of fossil marine reptiles with most of the better-recorded specimens obtained from the Main Alum Shale Beds (Benton and Spencer, 1995), the only level which was extensively quarried in the region, with a few from the Bituminous Shales. Fish remains have an almost equally long history of study, with eight type species described from here in papers by Agassiz (1833–1845), Egerton (1852), Simpson (1855) and especially by Woodward (1896, 1897, 1898, 1899). However, some taxa listed as from here have since been deemed indeterminate or are thought to have originated from localities outside of Yorkshire (Dineley and Metcalf, 1999). Many of the earlier collections were made from the Bituminous Shales but in later times material was also obtained from industrial workings of the Alum Shale Member. Many of the fish described from this site, particularly those within carbonate nodules, are beautifully preserved in a high degree of articulation although others typically occur as disarticulated remains. Among these are remains of the giant chondrostean *Gyrosteus mirabilis*, thought to reach lengths of 5–6 m. The fish fauna as a whole is dominated by osteichthyans, such as *Gyrosteus*, *Lepidotes*, *Pachycormus*, *Pholidophorus* and *Leptolepis*. Chondrichthyans appear to be absent, or at least have not been recorded from here.

Interpretation

The ammonite faunas of the Bituminous Shales and the Alum Shale Member at Whitby have formed the basis of many stratigraphical reviews and include the stratotypes, or parastratotypes, of the Commune, Fibulatum and Crassum subzones of the Bifrons Zone (Howarth, 1992). Cox (1990) suggested that the area could provide reference sections for the Serpentinum (= Falciferum) and Bifrons zones. The Whitby area is the type locality for many ammonite species (Howarth, 1962b, 1992) some of which may not have come from the near the town. For example, the types of *Elegantuliceras elegantulum* and *Dactylioceras semicelatum* are both from levels stratigraphically lower than any beds currently exposed between Whitby and Saltwick (Howarth, 1973, 1992). They could have come from Hawsker Bottoms to the south or beyond Sandsend to the north. Type specimens of some species, used as zonal indices, are more likely to have come from the Whitby to Saltwick area.

These include *Cleviceras exaratum*, *Dactylioceras commune*, *Hildoceras bifrons* and *Peronoceras fibulatum*. Unusual elements in the ammonite faunas include the Tethyan giant *Phylloceras heterophyllum*, which occurs sporadically throughout the succession here, and the rarer *Lytoceras* ex grp. *cornucopia*. Both appear to have greatly expanded their range northwards at this time, perhaps due to more open seaways associated with the mid-Toarcian eustatic highstand (Hesselbo and Jenkyns, 1998). This may also account for the presence of the Mediterranean Bouleiceratine *Frechiella subcarinata*, of which the holotype is probably from Whitby, which reached the area in small numbers during the Commune Subzone (Donovan, 1967).

Throughout the Whitby Mudstone Formation succession exposed here the fauna is dominated by nektonic, planktonic and pseudoplanktonic taxa, with few unequivocally benthic forms. Morris (1979) used these and other observations to interpret the Mulgrave Shale Member as a 'bituminous-shale facies' and the succeeding Alum Shale Member as a 'restricted-shale facies'. The presence of finely preserved, commonly articulated vertebrates indicates that scavenging benthos was largely absent from the Mulgrave Shale and Alum Shale members. O'Brien (1990) noted that the organic content and the development of lamination was weaker in the Bituminous Shales than in the Jet Rock. He interpreted these as indicators of increasing water depth. They might also indicate a decline in biological productivity in near-surface waters, perhaps reflecting changes in marine circulation or climatic conditions (Hesselbo and Jenkyns, 1995).

The absence of chondrichthyan fish at this site, a common element of many other early Jurassic fish faunas (Dineley and Metcalf, 1999) seems significant. However, this observation appears to hold largely true also for the German correlative of these strata, the Posidonienschiefer. Only *Hybodus hauffianus* occurs in equivalent strata in Posidonienschiefer, where it has been reported from the Serpentinum Zone, but even there it occurs only rarely among a fish fauna comprising many thousands of specimens. Perhaps the rarity of chondrichthyans in these anoxic mudstone facies reflects an at least intermittently benthic habit for these fish which lack a swim bladder, and hence must swim actively to remain at the bottom.

The lithostratigraphy of the Mulgrave Shale and Alum Shale members at this site is similar to that at others north-west of the Peak Fault. Many of the marker bands can be recognized along this whole stretch of coast. The succession differs markedly from the correlative succession south-east of the Peak Fault. There is little difference in the thickness of the Mulgrave Shale Member on either side of the fault (Howarth, 1962a), but the nodule horizons in the Jet Rock at Whitby are largely absent south of the fault. In the Bituminous Shales and Alum Shale Member there are again significant differences between the succession recorded here and that at Blea Wyke. Lithostratigraphical correlation between the two sites of Whitby–Saltwick and Blea Wyke is difficult, with only the Ovatum Bed at the top of the Bituminous Shales common to both sections. The ammonite faunas allowed Howarth (1962a) to make tentative correlation of various horizons and to establish that the unconformity at the base of the Dogger Formation cuts out approximately the top 2 m of the Alum Shale Member at Whitby. The most significant difference between the two sections is the expansion of the succession at Blea Wyke compared to that at Whitby, with most of this occurring in the Cement Shale Beds. There is no evidence of a non-sequence at this level in the Whitby section so presumably this represents a brief increase in subsidence rate within the Peak Trough.

Conclusions

The cliffs and foreshore between Whitby and Saltwick expose a classic Toarcian section which has been a rich source of type and figured fossils, particularly ammonites and vertebrates. The section exposes the higher part of the Mulgrave Shale Member and an almost complete Alum Shale Member succession: it is the only site where the Alum Shale Member is extensively exposed and accessible on the foreshore. At other sites this part of the succession is exposed only in relatively inaccessible cliff sections or in old quarry workings now degraded by weathering. The section includes stratotypes, or at least parastratotypes for several lithostratigraphical and chronostratigraphical units, and it is the type locality for the Toarcian Whitbian Substage. The ammonites have inspired legends of serpents and are commemorated on the Whitby coat of arms.