Chapter 6 The Cleveland Basin

Introduction

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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 (Gateliff *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'.

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 Capricomus, 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 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 southeast, 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 provinciAllty 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 provinciAllty. 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

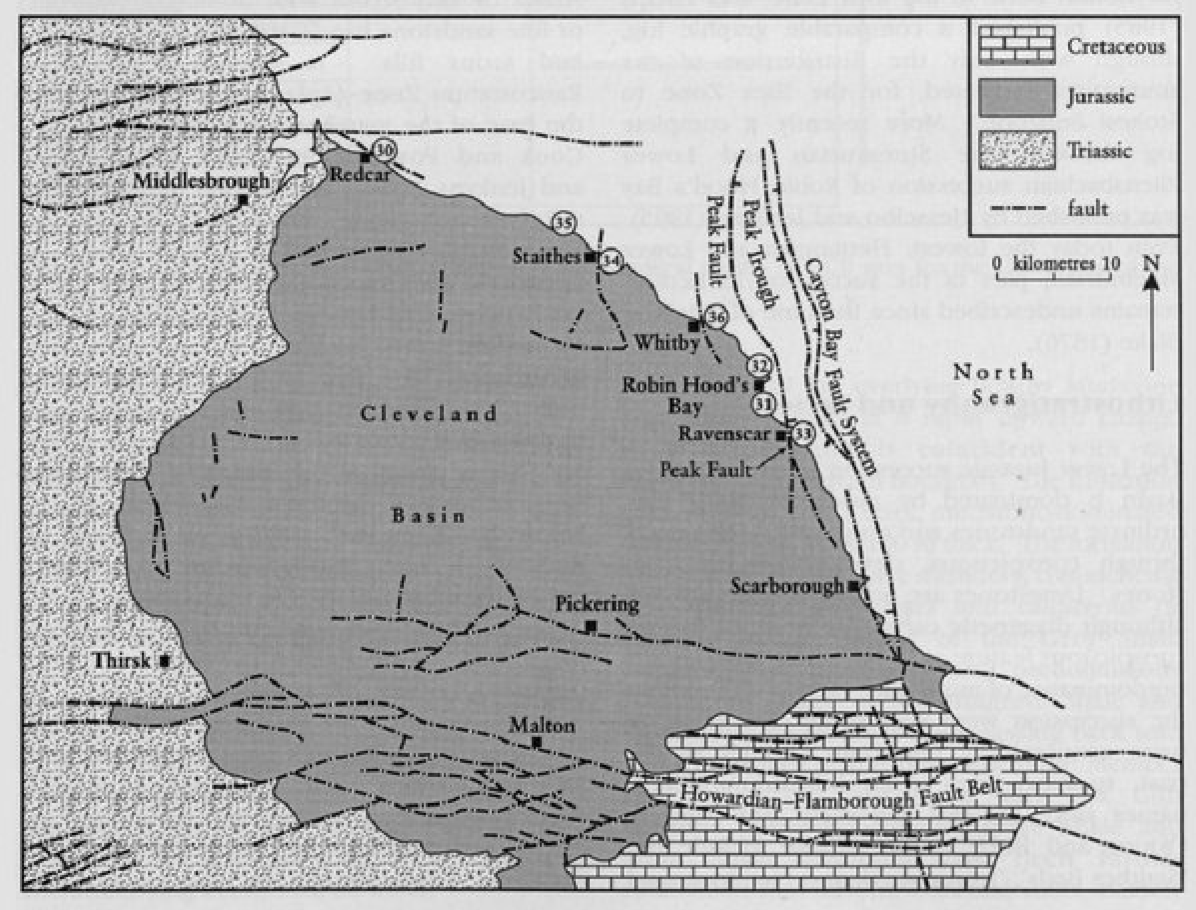
Kettleness members of the Cleveland Ironstone Formation. Nonetheless, the southward increase in magnitude of this hiatus does suggest that, like the larger hiatuses in Humberside, this too may be attributable to movement on the Market Weighton High.

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).

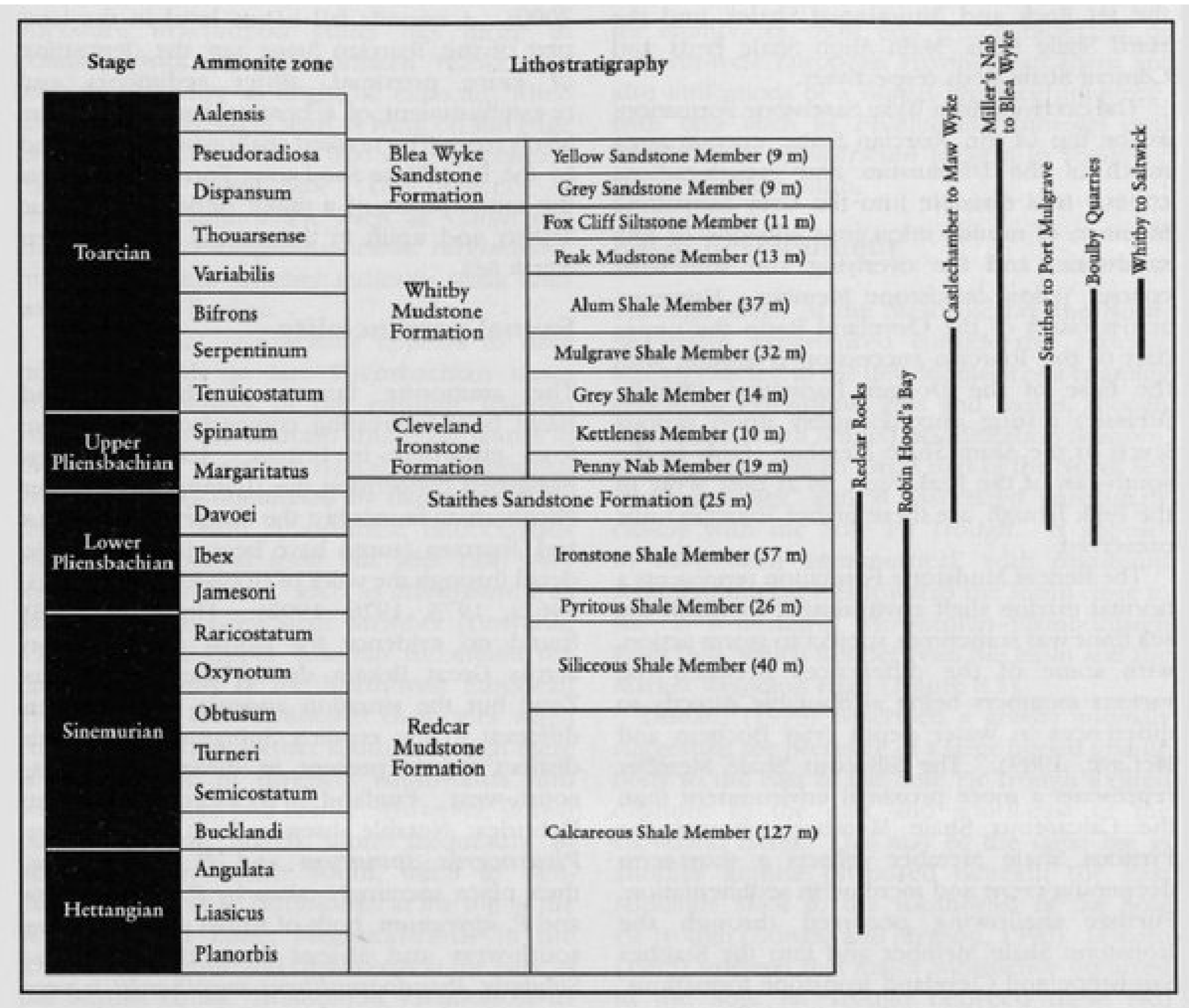
In the Wessex Basin, Hesselbo and Jenkyns (1995) drew comparison between the Yorkshire and Dorset coast successions. On a coarse scale they mostly found close agreement between the facies sequences seen in the two basins, with differences between the two reflecting the more proximal, and generally shallower-water, 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 Oenkyns 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.

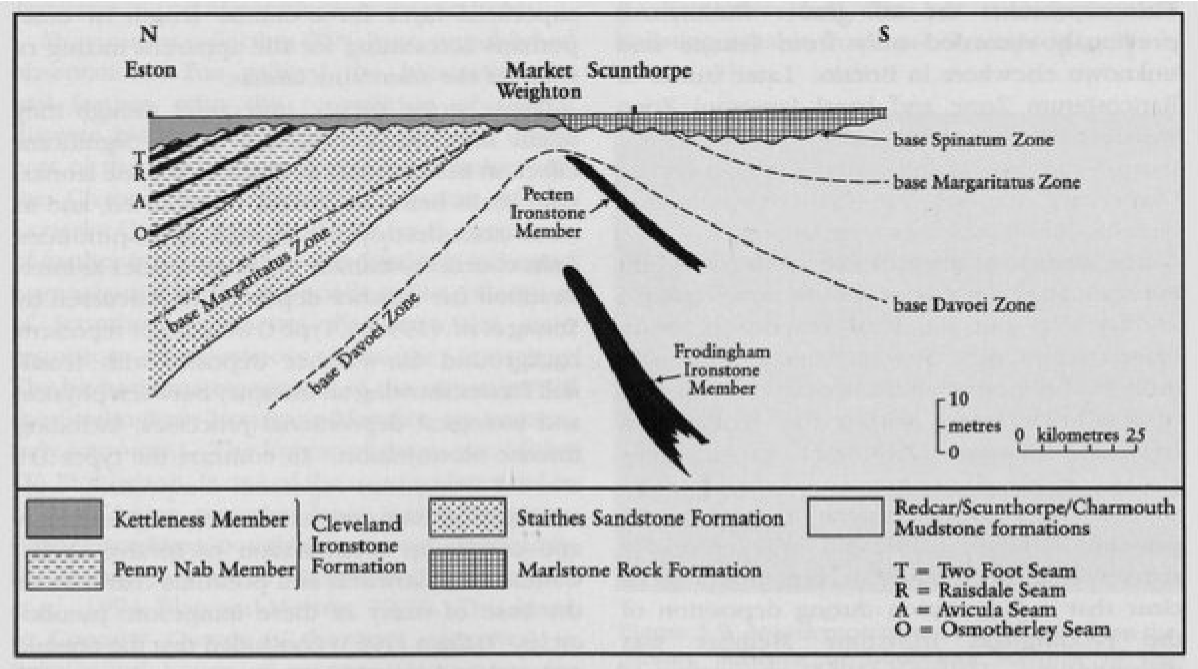
References



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



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



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