Normanby Stye Batts–Miller's Nab (Robin Hood's Bay), North Yorkshire

[NZ 972 025]–[NZ 952 075]

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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 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.

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 (Figure 6.5) and (Figure 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 6.7)a,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 ed.,* 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 KN. 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 para-stratotype (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

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 sinuostforme* 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* vacs heterogenesand *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, Pagophylloceras* 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 *Uptonta 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

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, 810) 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 Jameson 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: *Leptebioceras 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, Ophiomorpba* 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
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 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 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 sub-zones 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, p1. 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 Johnston 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.

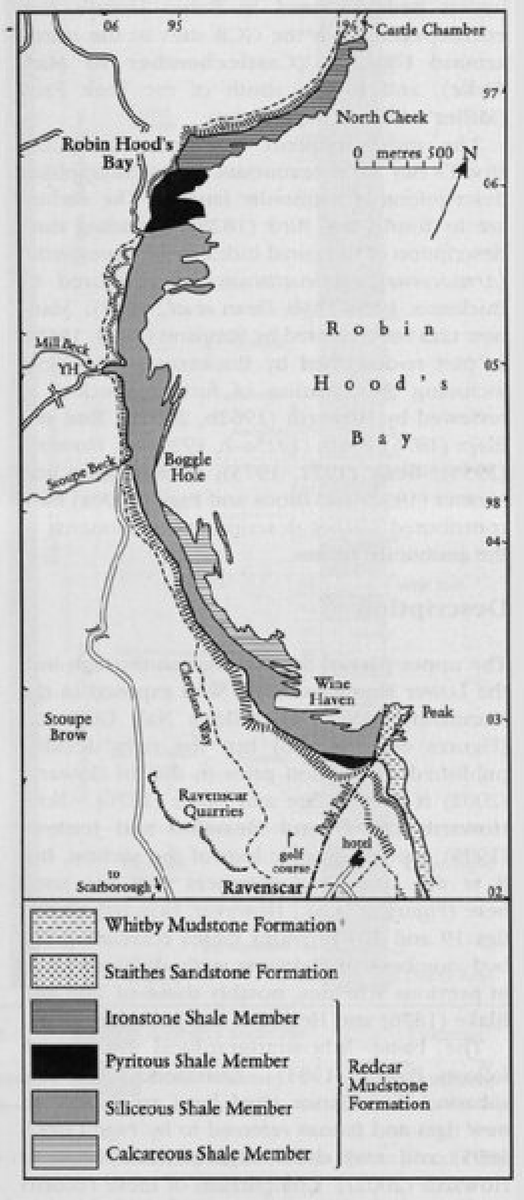
The Yorkshire succession is lithologically similar in part to that of the Hebrides Basin. However, although broad-scale correlations between the facies units have been made on the basis of sequence stratigraphy (Hesselbo and Jenkyns, 1998), stratigraphical refinement of the Hebridean succession is not 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

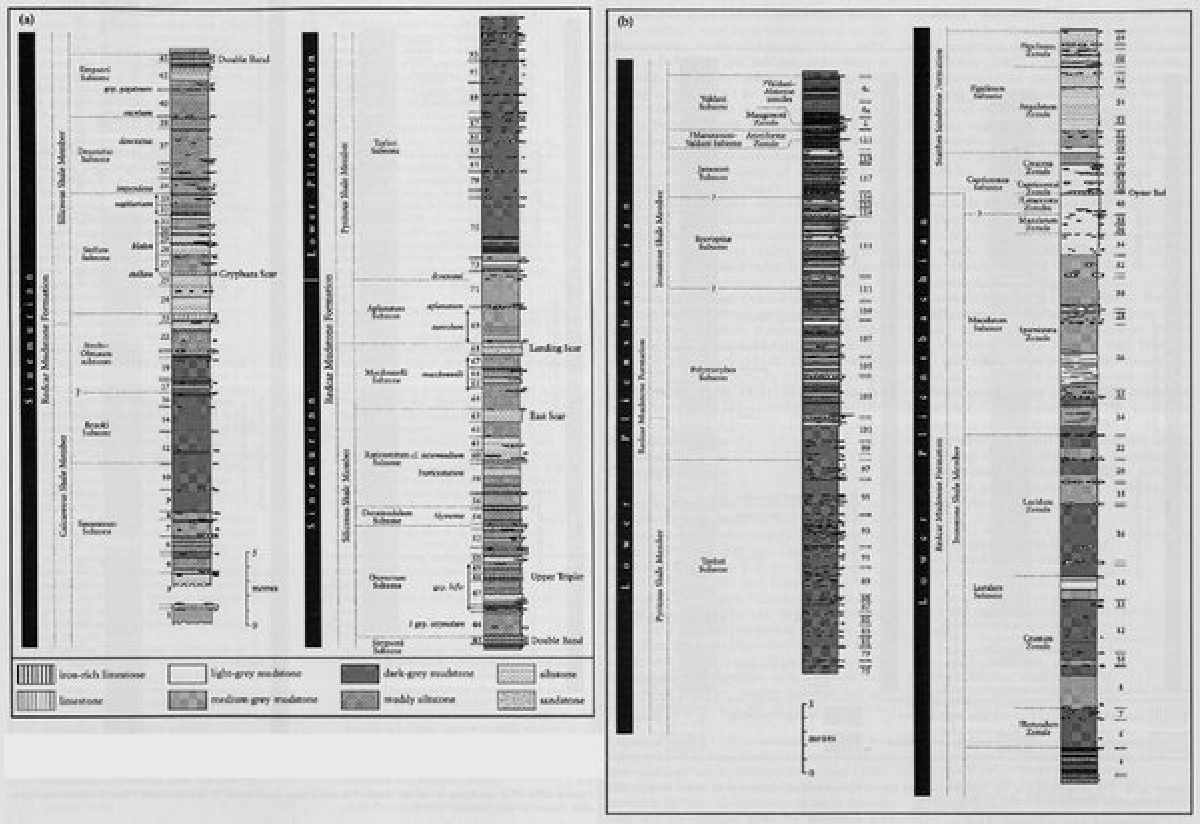
The sections exposing the Redcar Mudstone Formation in the Normanby Stye Batts–Miller's Nab (Robin Hood's Bay) GCR site provide the most complete Sinemurian and Pliensbachian sequence in Britain. The fauna at this site has been little investigated compared with its Dorset counterpart but, nonetheless 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.

References

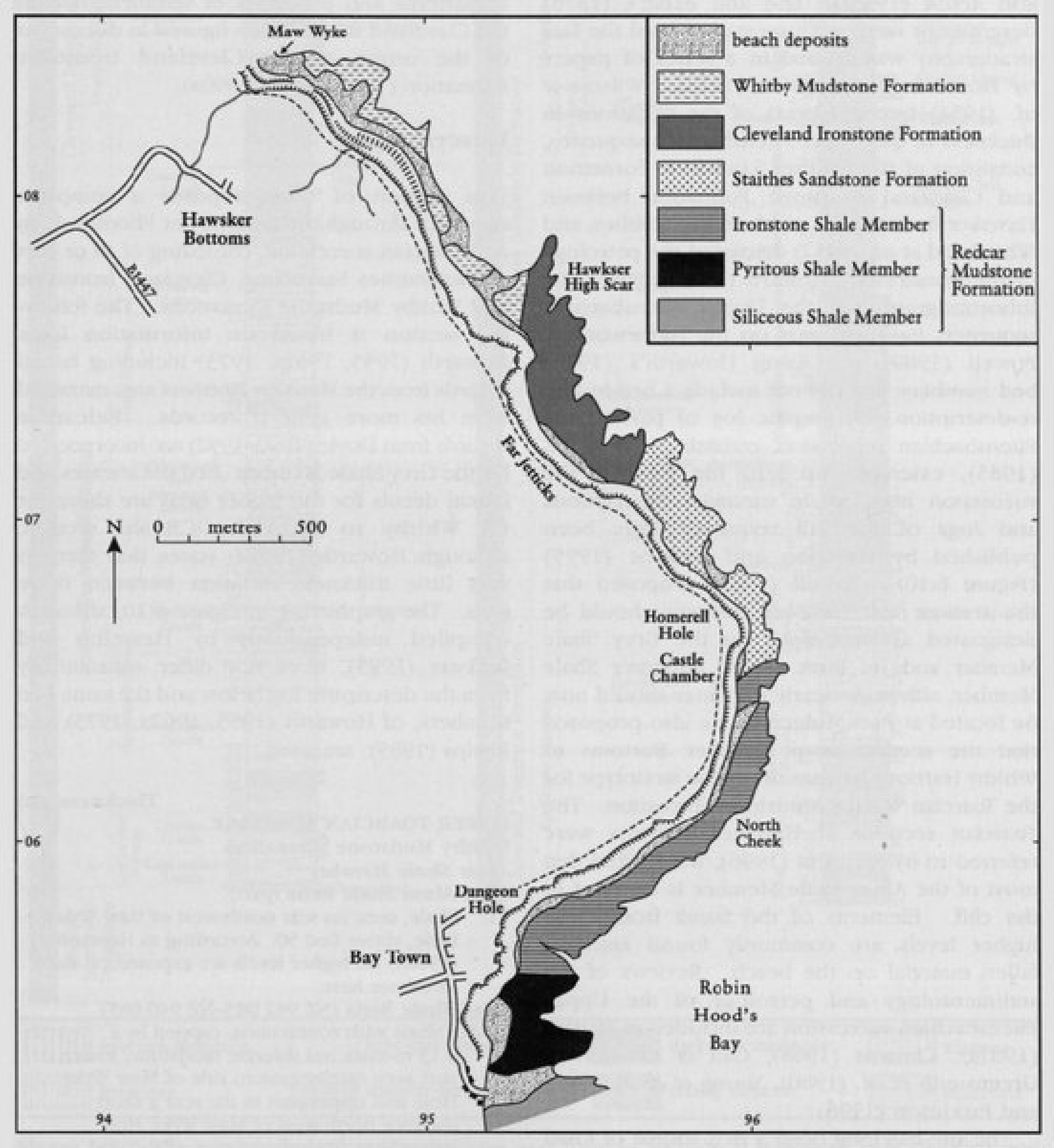
(Figure 6.5) Extensive foreshore exposures of the Redcar Mudstone Formation in Robin Hood's Bay at low tide, viewed from Ravenscar. The concentric disposition of the 'reefs' demonstrates the domed structure of the outcrop here. (Photo: M.J. Simms.)



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



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



(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).

(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.)