British Middle Jurassic Stratigraphy

B.M. Cox*

and

M.G. Sumbler*

*** formerly of the British Geological Survey, Keyworth, Nottingham**

GCR Editor:

D. Skevington

JOINT NATURE CONSERVATION COMMITTEE

Chapter 5

The Middle Jurassic stratigraphy of North Yorkshire

B.M. Cox and K.N. Page

INTRODUCTION

B.M. Cox

The coastal exposures of Middle Jurassic rocks in Yorkshire have a long history of investigation dating back to the early part of the 19th century when Young (1817), Young and Bird (1822) and Phillips (1829) produced their pioneer geological accounts. William Smith was also active here; in 1821, his geological map of Yorkshire was published and, from 1828 to 1834, he was employed as land agent on the Hackness estate, a little inland, during which time he mapped the Hackness Hills (Rayner, 1974). At various times during his life he lodged in Scarborough and remained there from 1835 until his death in August 1839 (Cox, 1942). In 1845, the [British] Geological Survey began its systematic mapping of the county and its work on the Jurassic rocks culminated in the memoir by Fox-Strangways (1892) based on earlier district memoirs by Fox-Strangways (1880), Fox-Strangways and Barrow (1882) and Fox-Strangways *et al.* (1885). During this period, John Leckenby, a bank manager in Scarborough and local fossil collector, made an important early contribution to the palaeontology and stratigraphy of the Callovian strata exposed on the coast (Leckenby, 1859).

By this time, it was already well understood that the Aalenian–Bathonian rocks in Yorkshire were quite unlike their correlatives in southern England (see Chapters 2, 3 and 4), being mainly deltaic, estuarine, fluvial or alluvial, but including four, relatively thin, discrete marine units. Debate and discussion about the depositional environments has continued for over 100 years (see below). A number of the early investigators, for example Wright (1860), Hudleston (1874) and later Richardson (1911c), were particularly concerned with the differences between this part of the Yorkshire succession and that in southern England. The Callovian succession is likewise different, being predominantly marine sandstones in Yorkshire and marine mudrocks in southern England. The geological events and structural setting that led to these contrasting facies are now understood. Tectonic activity in the British area early in the Jurassic Period led to the development of a local extensional basin over North Yorkshire that became separated from the shallower shelf to the south (East Midlands Shelf) by a hinge (Market Weighton High) bounded on the north side by a fault zone (Howardian–Flamborough Fault Belt) (Figure 5.1). The western limit of this so-called 'Cleveland Basin' was probably defined by the Pennine High. Throughout the Early Jurassic Epoch, marine, predominantly argillaceous, sediments (Lias Group) accumulated in the rapidly subsiding Cleveland Basin but, in the very latest part of the Toarcian Age, regional uplift was initiated, associated with thermal doming and accompanying volcanic activity in the central North Sea (Bradshaw and Cripps, 1992; Underhill and Partington, 1993). During the Aalenian and Bajocian ages, sediments were eroded from the newly emergent Mid North Sea High, transported southwards by rivers and deposited as a fluvio-deltaic succession over Yorkshire and the adjacent Sole Pit Trough, whilst the East Midlands Shelf remained covered by a warm, shallow shelf-sea. Overall, the evidence suggests small prograding deltas that ultimately coalesced into a large, coastal alluvial-plain rather than a large single river-system feeding a large delta (Rawson and Wright, 1992, 1995). The thin marine strata that are intercalated with the fluvio-deltaic succession bear witness to times when seawater encroached into the basin from the south and possibly east (Holloway, 1985). Movement along the margins (Peak and Red Cliff faults) of the narrow graben known as the 'Peak Trough' (Milsom and Rawson, 1989), which cuts obliquely across the present coastline, also took place at this time. Early in the Callovian Age, the sea again transgressed into the Cleveland Basin, and marine sandstones were deposited. Apart from Richardson's (1911c) account, other published work dating from the early part of this century includes that on the fossil floras of the non-marine beds by Seward (1900), the basal beds by Rastall (1905), the Callovian succession by S.S. Buckman (1913), fossil footprints by Hargreaves (1913) and a second edition of Fox-Strangways and Barrow's memoir (1915). Later, Black (1928, 1929, 1934) elucidated sedimentological aspects of the 'deltaic' succession, including a description of channelling phenomena, and also discovered new palaeobotanical localities. Another significant newcomer on the scene at this time was John Edwin Hemingway (1906–1997) who joined Rastall in a series of largely petrographical studies (Rastall and Hemingway, 1935, 1939, 1940a,b, 1941, 1943, 1949), a topic on which Smithson (for example, 1934, 1937, 1942) also published. The fossil

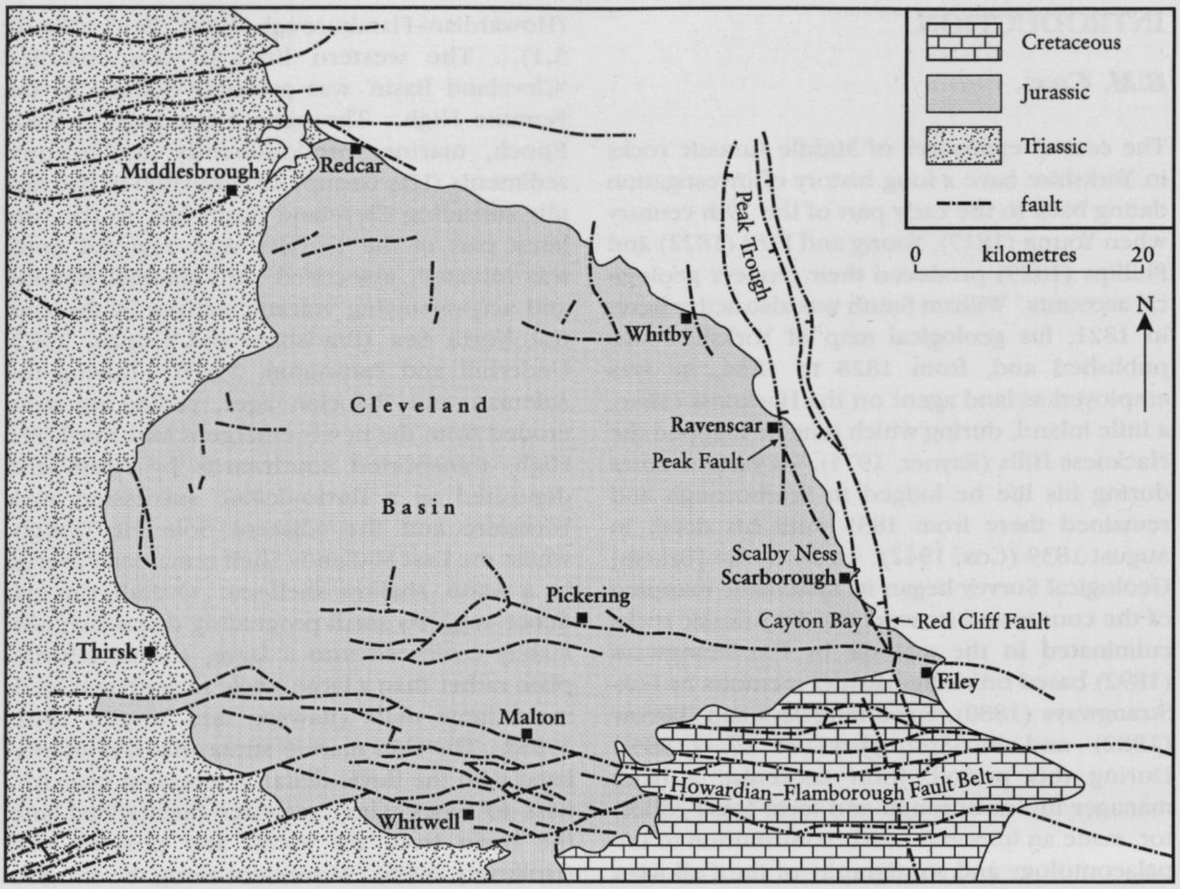


Figure 5.1 Structural setting of the Cleveland Basin. (After Rawson and Wright, 1995, fig. 2.)

floras were described in a series of papers by Harris (1942–1953, 1953, 1961–1979), trace fossils by Farrow (1966) and fossil footprints by Sarjeant (1970). Many sections, both coastal and inland, in the predominantly non-marine Middle Jurassic beds were recorded by Bate (1959, 1964, 1965, 1967b) during his investigation of the fossil ostracod faunas.

From the 1970s onwards, interest in the Middle Jurassic rocks of Yorkshire has been heightened because of their value as facies analogues of oil-producing horizons in the North Sea Basin. Detailed sedimentological, palynological and palaeoenvironmental research, and sequence-stratigraphical studies have been undertaken on the coastal exposures, leading to a continuing output of publications including Knox (1973), Nami (1976), Parsons (1977b), Nami and Leeder (1978), Leeder and Nami (1979), Hancock and Fisher (1981), Livera and Leeder (1981), Whyte and Romano (1981, 1993), Riding (1984), Kantorowicz (1984, 1985, 1990), Fisher and Hancock (1985), Alexander (1986, 1987, 1989, 1992a,b), Romano and Whyte (1987), Milsom and Rawson (1989), Riding and Wright (1989), Knox *et al*. (1991), Eschard *et al*. (1991), Gowland and Riding (1991), Lott and Humphreys (1992), and Alexander and Gawthorpe (1993). Much unpublished work has also been undertaken by and for commercial oil companies and consultancies. The coastal exposures also feature in three recently published field guides (Rawson and Wright, 1992, 1995; Scrutton, 1994) that supersede earlier ones (e.g. Hemingway *et al*., 1968), as well as van Konijnenburg-van Cittert and Morgans' (1999) field guide to the fossil flora.

After his early work with Rastall (see above), Hemingway, who had a lifelong association with the Yorkshire Jurassic rocks (see, for example, Hemingway (1974) and references therein), initiated the development of a modern lithostratigraphical scheme for the predominantly non-marine beds that eventually led to the current scheme shown in Figure 5.2 (Hemingway, 1949; Sylvester-Bradley, 1949; Hemingway and Knox,

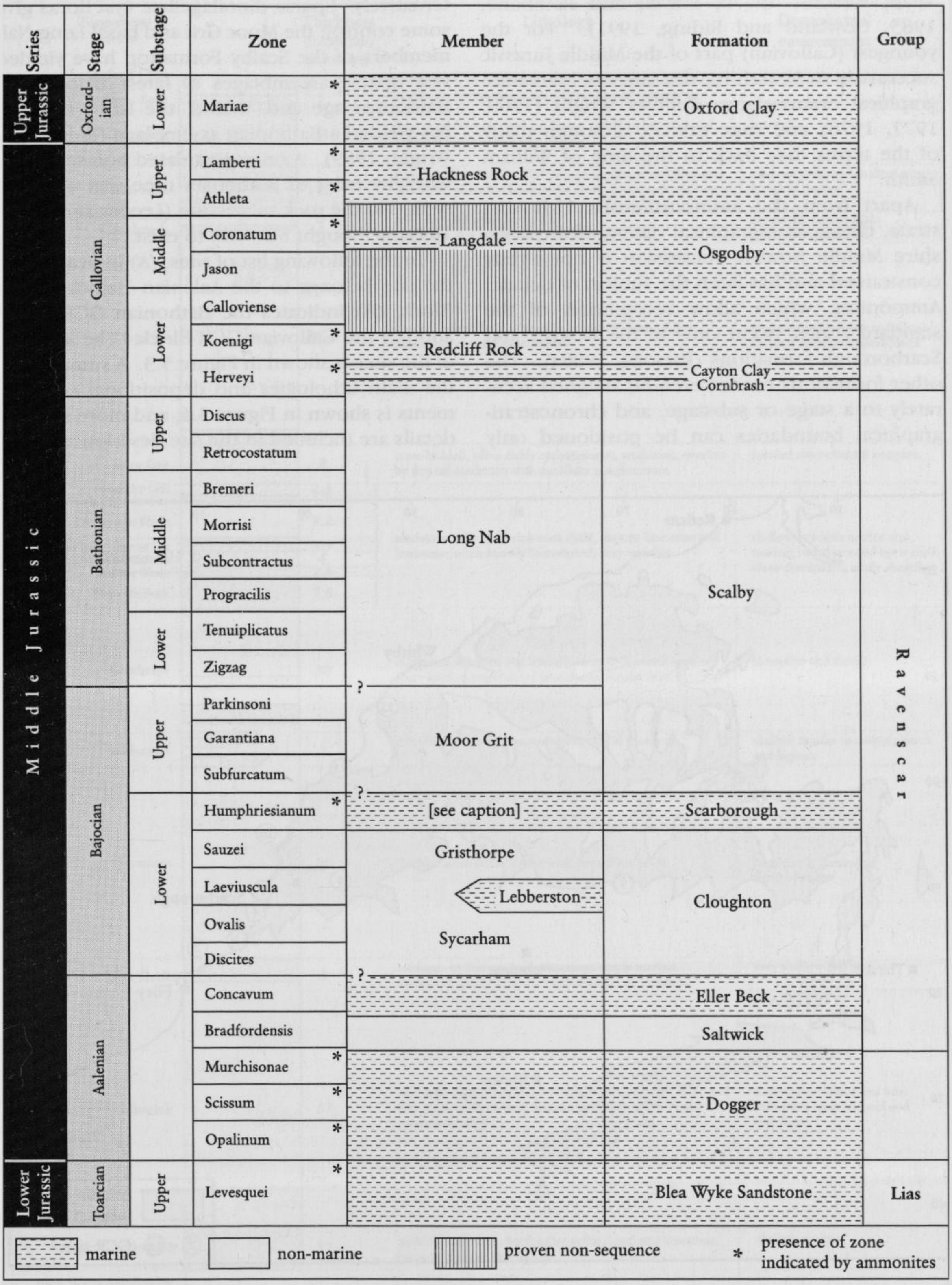


Figure 5.2 Lithostratigraphy of the Middle Jurassic rocks of Yorkshire. At its type locality, the Scarborough Formation has been divided into seven members (Parsons, 1977b; Gowland and Riding, 1991). From below, these are named Helwath Beck, Hundale Shale, Hundale Sandstone, Spindle Thorn Limestone, Ravenscar Shale, White Nab Ironstone and Bogmire Gill. Not to scale.

1973; Parsons, 1977b; Powell and Rathbone, 1983; Gowland and Riding, 1991). For the youngest (Callovian) part of the Middle Jurassic succession in Yorkshire, the current lithostratigraphical nomenclature follows Wright (1968, 1977, 1978) and Page (1989), although many of the terms date back to the time of William Smith.

Apart from the ammonitiferous Callovian strata, chronostratigraphical dating of the Yorkshire Middle Jurassic succession is not tightly constrained and has been the subject of debate. Ammonites, which allow recognition of the standard zones, occur only in the Dogger and Scarborough formations (Parsons, 1980a). The other formations cannot even be assigned accurately to a stage or substage, and chronostratigraphical boundaries can be positioned only tentatively. Sparse dinoflagellate cyst floras give some control; the Moor Grit and basal Long Nab members of the Scalby Formation have yielded very sparse assemblages of latest Bajocian to Bathonian age and, inland, the latter member has yielded a Bathonian assemblage (Riding and Wright, 1989). A once-postulated non-sequence whereby most of Bathonian time was unrepresented in the rock succession (Leeder and Nami, 1979) is thought now not to exist.

In the following list of sites, (A) indicates that the site belongs to the Aalenian–Bajocian GCR Block, (B) indicates the Bathonian GCR Block and (C) the Callovian GCR Block. The location of the sites is shown in Figure 5.3. A summary of the main lithologies and depositional environments is shown in Figure 5.4, and more specific details are included in the site descriptions.

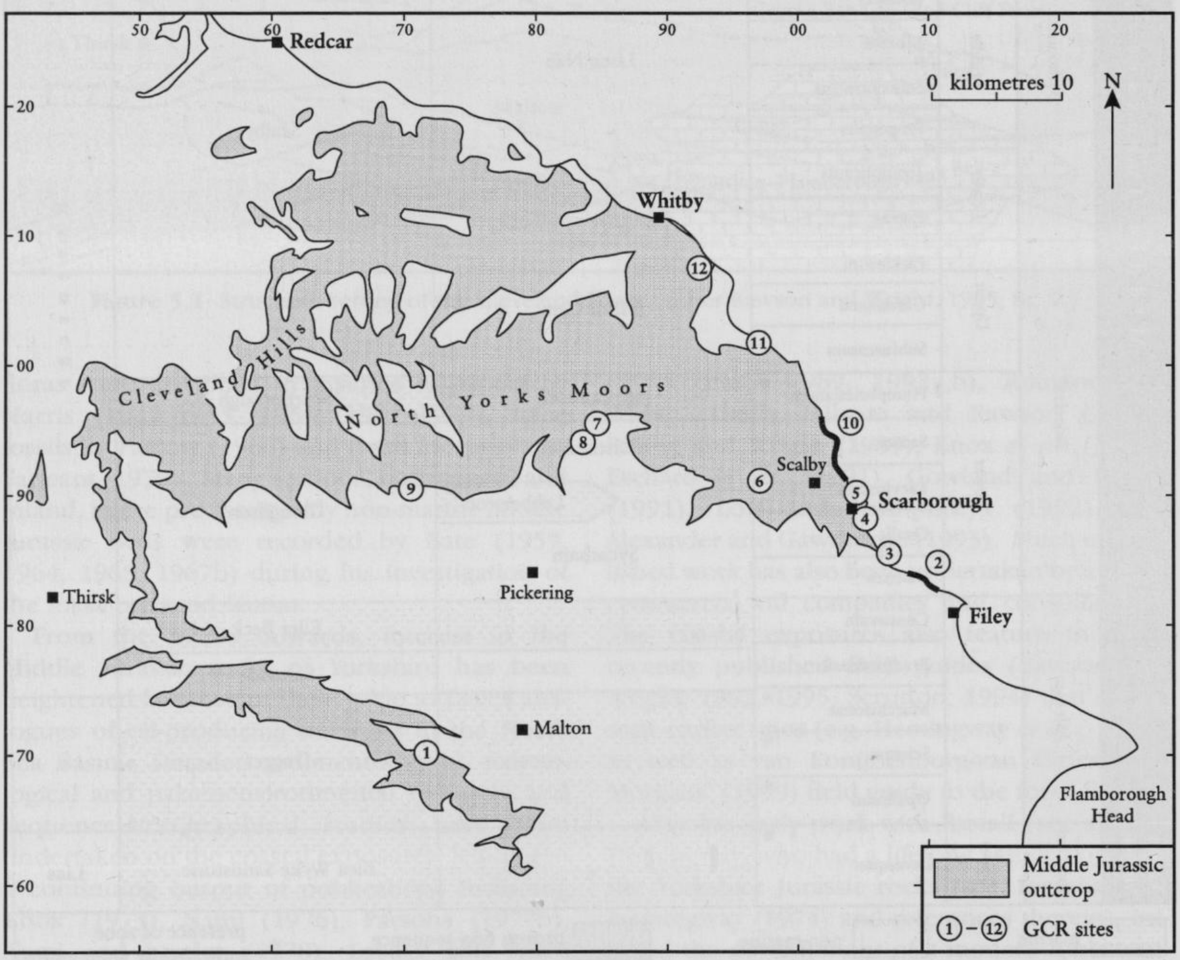
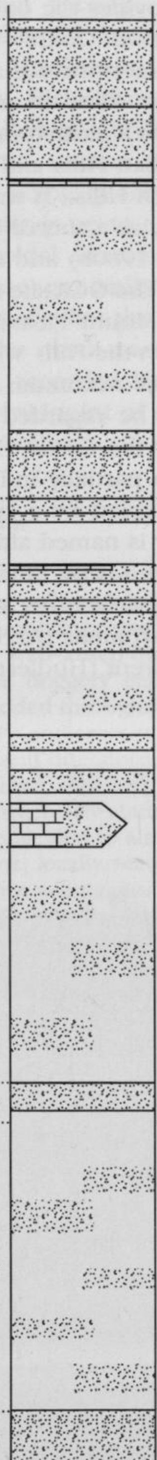


Figure 5.3 Geological sketch map showing the location of the GCR sites described in Chapter 5. (1) Whitwell Quarry; (2) Gristhorpe Bay, Yons Nab and Red Cliff–Cunstone Nab; (3) Osgodby Point; (4) South Toll House Cliff; (5) North Bay, Scarborough; (6) Hackness Rock Pit; (7) Havern Beck, Saltergate; (8) Hudson's Cross Crags, Newton Dale; (9) Fairy Call Beck; (10) Iron Scar–Hundale and Hundale Point–Scalby Ness; (11) Blea Wyke; (12) Hawsker Bottoms.



Formation/member		Thickness (maximum in metres)	Lithology	Depositional environment
Oxford Clay				
Osgodby	Hackness Rock	2	fine-grained, poorly sorted sandy limestone and calcareous sandstone; berthierine ooids well developed towards top	fully marine, shallow water
	Langdale	15	fine- to medium-grained sandstone and siltstone; scattered berthierine ooids; thin clay partings	pro-delta
	Redcliff Rock	11.5	fine-grained sandstone with beds of sandstone and limestone containing abundant berthierine ooids; occasional calcareous concretions	offshore shelf, and shallow water marginal marine
Cayton Clay		3	grey, shaly, silty and sandy clay	deepening marine basin
Cornbrash		1	limestones and sandy marl; ooidal in part	shallow water marine
Scalby	Long Nab	52+	clay and silt with thin, laterally extensive sheets of fine sandstone; channel sandstones	meandering channels and alluvial marshes and floodbasins/plains
	Moor Grit	8	cross-bedded, often richly carbonaceous, sandstone, overlain by rippled sandstone with mudflake conglomerate	braided river-channel complex
Scarborough	Bogmire Gill	2.5	sandstone, silty and calcareous shale, impure limestone and ironstone; often heavily bioturbated; very variable	shallow brackish-marine and marine; nearshore and open shelf; wave-dominated, sandy shoreface
	White Nab Ironstone	1.3		
	Ravenscar Shale	8.2		
	Spindle Thorne Lst	3.7		
	Hundale Sandstone	4		
	Hundale Shale	2.6		
	Helwath Beck	7.6		
Cloughton	Gristhorpe	30	mudstone, siltstone and laterally extensive, planar-bedded sheet sandstones; channel sandstones; rootlet beds	lacustrine and fluvial
	Lebberston	9	cross-bedded sandstone and shale; ooidal limestone	shallow marine to coastal; beach and lagoon
	Sycarham	50	'coal measure facies' as Saltwick Formation below	dominantly freshwater fluvio-deltaic
Eller Beck		8	medium- to fine-grained, sometimes ripple-marked sandstone, overlying shale with subordinate ironstone	very shallow marine
Saltwick		57	rhythmic units of argillaceous sandstone, siltstone, shale and low-grade coal; channel sandstones; plant debris ('coal measure facies')	non-marine with some tidal influence; river channel and overbank
Dogger		12	sideritic sandstone, berthierine oolite, bioclastic limestone, laminated shale; pebble beds	shallow marine
Blea Wyke Sandstone				

Figure 5.4 Summary of main lithologies and depositional environments of the North Yorkshire coast Middle Jurassic succession. (Compiled from various sources; see text.)

Whitwell Quarry, North Yorkshire (A)
Gristhorpe Bay (A), Yons Nab (B) and Red Cliff–Cunstone Nab (C), North Yorkshire
Osgodby Point, North Yorkshire (C)
South Toll House Cliff, North Yorkshire (C)
North Bay, Scarborough, North Yorkshire (C)
Hackness Rock Pit, North Yorkshire (C)
Havern Beck, Saltergate, North Yorkshire (C)
Hudson's Cross Crags, Newton Dale, North Yorkshire (C)
Fairy Call Beck, North Yorkshire (C)
Iron Scar–Hundale (A) and Hundale Point–Scalby Ness, North Yorkshire (B)
Blea Wyke, North Yorkshire (A)
Hawsker Bottoms, North Yorkshire (A)

WHITWELL QUARRY, NORTH YORKSHIRE (SE 734 670)

B.M. Cox and M.G. Sumbler

Introduction

The GCR site known as 'Whitwell Quarry' comprises a face in a disused quarry, *c.* 7 km south-west of Malton, North Yorkshire (Figure 5.5). It coincides with the Site of Special Scientific Interest (SSSI) known as 'Mount Pleasant Quarry' and provides the only significant exposure of the Whitwell Oolite. The overlying beds of the Upper Limestone are also exposed. The Whitwell Oolite (first named by Hudleston (1874) as 'Whitwell Limestone') occurs throughout the Howardian Hills and the southern part of the Hambleton Hills. It was once extensively quarried, mainly as a source of lime for agricultural use (Kent, 1980b) and its lower beds also for road metal. The GCR site is representative of the quarries at Mount Pleasant and Crambeck, near Whitwell-on-the-Hill, where the Whitwell Oolite reaches its maximum thickness (*c.* 9 m) and which may be regarded as the type area. Once owned by the Castle Howard Estate, the quarry has been partially infilled and restored, and is now occupied by a landscaped caravan park. The latter is named after a topographical feature (Jamie's Crags) that has developed where quarrying over many years has modified the angular escarpment overlooking the valley of the River Derwent (Hudleston, 1874).

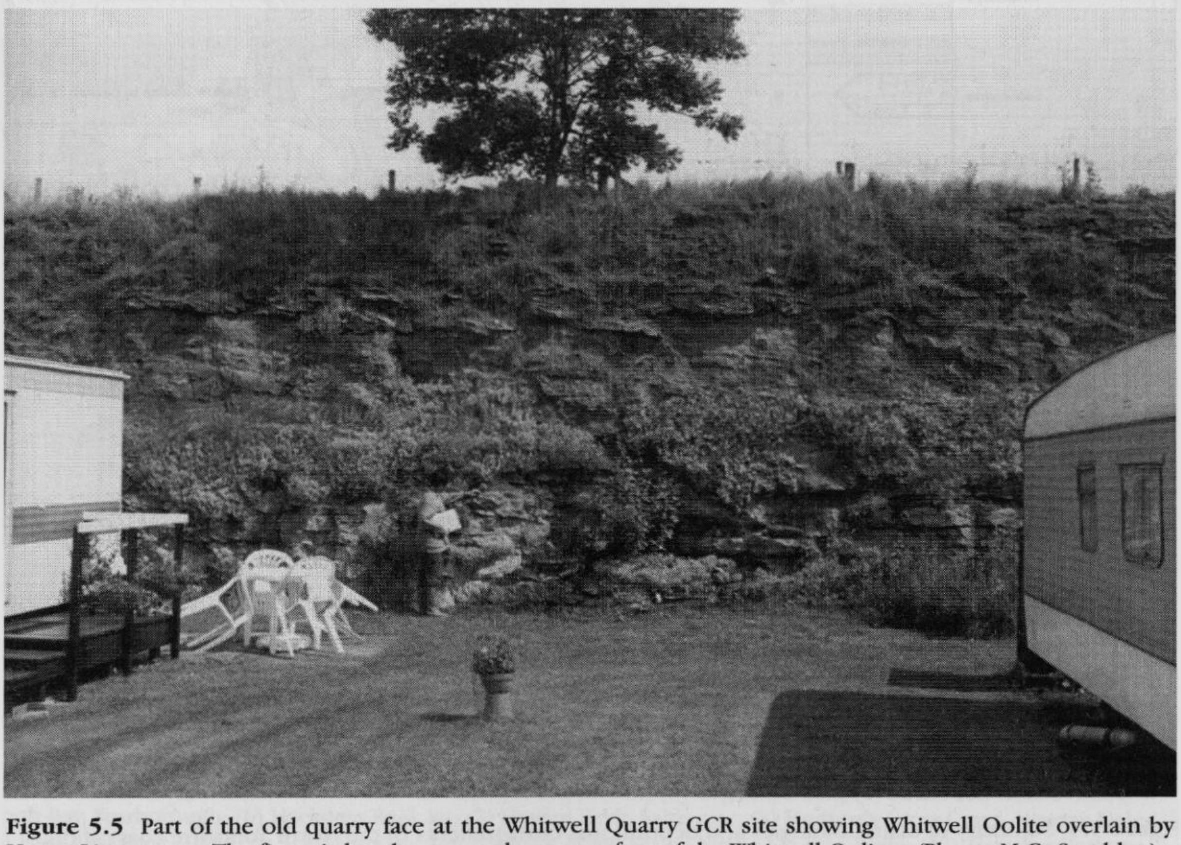


Figure 5.5 Part of the old quarry face at the Whitwell Quarry GCR site showing Whitwell Oolite overlain by Upper Limestone. The figure's hand rests on the top surface of the Whitwell Oolite. (Photo: M.G. Sumbler.)

Description

The succession exposed within the quarry complexes at Mount Pleasant and Crambeck, near Whitwell-on-the-Hill, have been cited by Wright (1860), Hudleston (1873), Fox-Strangways (1892), Richardson (1911c), Bate (1967b) and Hemingway (1974) but the only published measured section is that of Bate (1967b). The SW-facing quarry face (*c.* 200 m long) at the GCR site is up to *c.* 5 m high. The exposed strata (ooidal limestone overlain by calcareous sandstone) generally dip gently in an easterly direction such that the oldest beds are exposed only in the north-western part of the quarry. A section, recorded by the authors at approximately the midpoint of the main face in July 1997, is given below.

	Thickness (m)
Cloughton Formation	
Upper Limestone	
Limestone, very sandy, to weakly calcareous sandstone; grey to yellowish-brown with ferruginous mottling; essentially medium-grained, well-sorted quartz sand with variable 'doggery' cementation; strongly cross-bedded throughout in small-scale troughs and cross-sets with variable current directions; sporadic fine-grained, silty and clayey laminae particularly abundant in upper part; decalcified to almost loose sand in parts; locally, secondary, limonitic, ironstone segregations at sharp, probably slightly channelled, base	*c.* 3.5
Whitwell Oolite	
Limestone, greyish-brown, poorly sorted, medium- to coarse-grained, peloidal and ooidal packstone to grainstone with scattered shell-debris; hard, well cemented, markedly cross-bedded in topmost 0.6 m, becoming less strongly cemented and more massive downwards; sporadic laminae of quartz silt	*c.* 1.4

The maximum thickness of the Upper Limestone (*c.* 4 m) is seen in the eastern part of the quarry face. The maximum thickness of the Whitwell Oolite (*c.* 1.8 m) is seen in the western part of the face.

The fauna of the Whitwell Oolite includes the echinoids *Pygaster semisulcatus* Phillips and *Stomechinus germinans* Phillips; the bivalves *Ceratomya bajociana* (d'Orbigny), *Gervillella*, '*Lima*', *Modiolus imbricatus* J. Sowerby, pectinids and trigoniids; crinoid columnals; the brachiopod *Acanthothiris*; the bryozoan *Collapora straminea* (Phillips); and the serpulids *Galeolaria socialis* (Goldfuss) and *Vermicularia nodus* Phillips. Early fossil collectors appear to have made no distinction between the Whitwell Oolite and the overlying sandy beds of the Upper Limestone; the extensive faunal list given by Fox-Strangways (1892) does not differentiate between these two units.

Interpretation

The Whitwell Oolite is now included in the Lebberston Member of the Cloughton Formation. This member comprises a 'wedge' of calcareous sandstone and ooidal limestone that was deposited during a marine transgression that advanced northwards from the East Midlands Shelf (see Chapter 4) into the Cleveland Basin, thinning out against the fluvio-deltaic area to the north (Kent, 1980a). In the Whitwell-on-the-Hill area, and in the Howardian Hills generally, the Whitwell Oolite comprises a basal, poorly fossiliferous, calcareous sandstone that passes up into an ooidal grainstone with abundant fragments of bivalves, crinoids, corals and gastropods. The cross-bedding that is seen in places, such as at the GCR site, suggests a high-energy depositional environment, most probably an offshore carbonate sand-bank (Hemingway, 1974) or shoreface zone (Powell *et al.*, 1992). Where the bedding is more massive and apparently lacking in bedding structures, the limestones may contain plano-convex lenses of quartz sand up to 5 m long and 0.6 m thick; these may well represent advancing sand-dunes suggesting a depositional environment of comparable energy (Hemingway, 1974). Many of the individual ooids, particularly in the lower part, are little more than quartz grains with a thin carbonate coating.

Elements of the faunal assemblage, notably the bryozoan *Collapora* (formerly *Entalophora*, *Haploecia*, *Millepora* or *Spiropora*) *straminea*, also occur in the Millepore Bed of the Yorkshire coastal exposures (see **Gristhorpe Bay, Yons Nab and Red Cliff–Cunstone Nab** GCR site report, this volume), which, on that basis, has long been recognized as a correlative of the Whitwell Oolite (Wright, 1860) (Figure 5.6). Indeed, some authors (e.g. Powell *et al.*, 1992) have described these two stratal terms as synonymous and their usage has certainly overlapped (e.g. Fox-Strangways, 1892). The

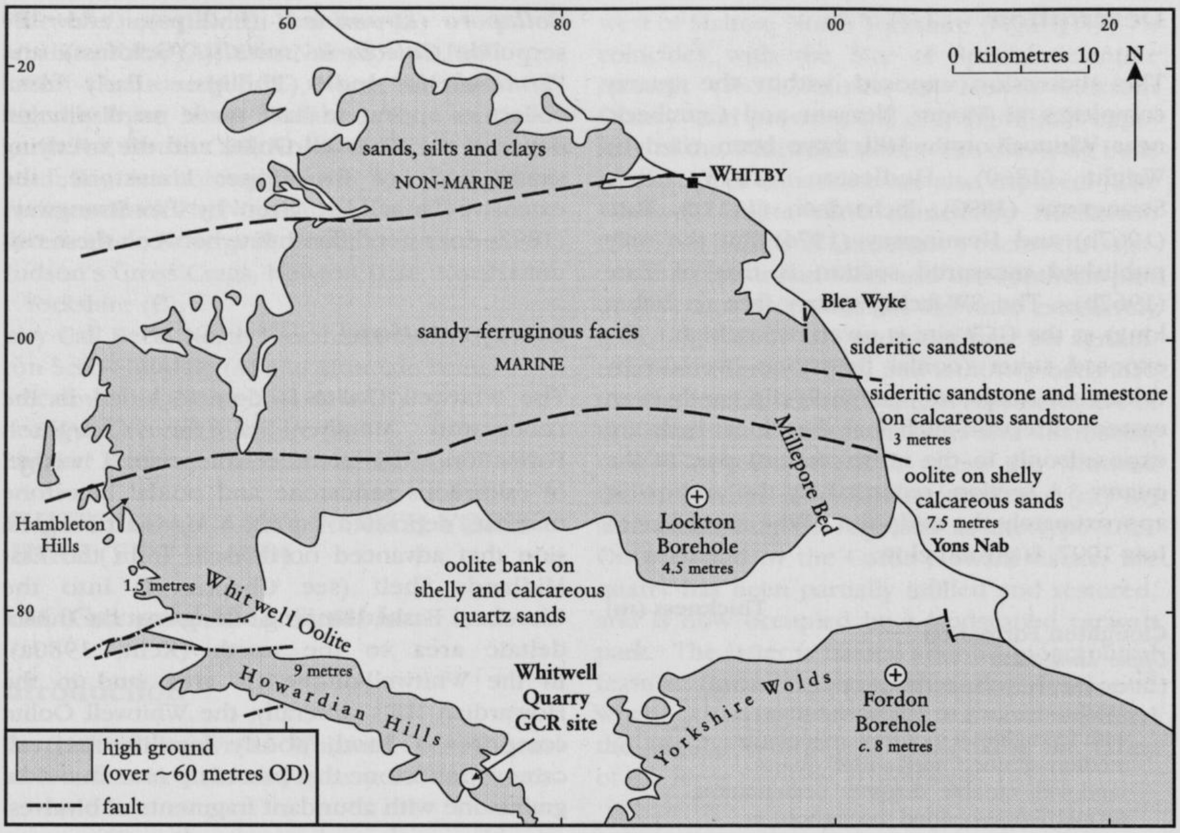


Figure 5.6 Facies distribution sketch map of the Whitwell Oolite and the Millepore Bed which together form the transgressive leaf of the Lebberston Member. (After Hemingway, 1974, fig. 51.)

Upper Limestone is correlated with the Yons Nab Beds of the coastal sections. The latter were previously included, with the Millepore Bed, in the Lebberston Member but, following a suggestion by R.W.O'B. Knox (in Rawson and Wright, 1995), they are now included in the overlying Gristhorpe Member because, in places, they are scarcely marine (see **Gristhorpe Bay**, **Yons Nab and Red Cliff–Cunstone Nab** GCR site report, this volume). Ammonites are unknown in the Whitwell Oolite but its ostracod fauna has been assessed by Bate (1967b) who found it to be basically similar to that of the Lower Lincolnshire Limestone and thereby deduced that the Whitwell Oolite belonged to the Lower Bajocian Discites Zone. Stratigraphical position and macrofaunal assemblages identify the Cave Oolite Member of the Market Weighton area (see **Eastfield Quarry** GCR site report, this volume) as a correlative of both the Whitwell Oolite and Millepore Bed and a product of the same Early Bajocian marine transgression (Kent, 1980a).

Conclusions

Whitwell Quarry exposes the once extensively quarried Whitwell Oolite and overlying Upper Limestone. The Whitwell Oolite, together with the Millepore Bed of the coastal sections (see **Gristhorpe Bay**, **Yons Nab and Red Cliff–Cunstone Nab** GCR site report, this volume), bear witness to a marine incursion from the south that resulted in a 'wedge' of marine rocks (Lebberston Member) in an otherwise non-marine succession (Cloughton Formation). Stratigraphical position and macrofaunal content show that the Cave Oolite Member, which occurs south of Market Weighton (see **Eastfield Quarry** GCR site report, this volume), is also associated with this event. The present site is thus an important one for understanding the relationship between the different facies that occur within the Middle Jurassic succession of the Cleveland Basin and East Midlands Shelf, as well as the Early Bajocian palaeogeography.

GRISTHORPE BAY, YONS NAB AND RED CLIFF–CUNSTONE NAB, NORTH YORKSHIRE (TA 079 841–TA 093 835, TA 085 842, TA 076 840–TA 100 830)

B.M. Cox and K.N. Page

Introduction

The GCR sites on the North Yorkshire coast known as 'Gristhorpe Bay', 'Yons Nab' and 'Red Cliff–Cunstone Nab', which are assigned respectively to the Aalenian–Bajocian, Bathonian and Callovian GCR blocks, overlap in their geographical extent and stratigraphy, and are therefore considered together (Figure 5.7). The sites comprise cliff and foreshore exposures, now included in the Gristhorpe Bay and Red Cliff Site of Special Scientific Interest (SSSI), which have been known since the early days of geological investigation (Phillips, 1829; Leckenby, 1859; Wright, 1860; Hudleston, 1876; Fox-Strangways, 1892, 1904). Together they display the greater part of a classic Cleveland Basin Middle Jurassic succession comprising the Cloughton, Scarborough, Scalby, Cornbrash, Cayton Clay and Osgodby formations. Localities contained within these sites give their names to the Lebberston and Gristhorpe members of the Cloughton Formation, the Yons Nab Beds, which form the basal part of the latter member, the Cayton Clay Formation and the Redcliff Rock Member of the Osgodby Formation. The sites show a range of features of stratigraphical and sedimentological importance, and include the best Callovian–Oxfordian stage boundary sequence in the Cleveland Basin.

Description

The following notes are based mainly on Rawson and Wright (1992, 1995), Whyte and Romano (1994), Wright (1968, 1977) and Page (1988).

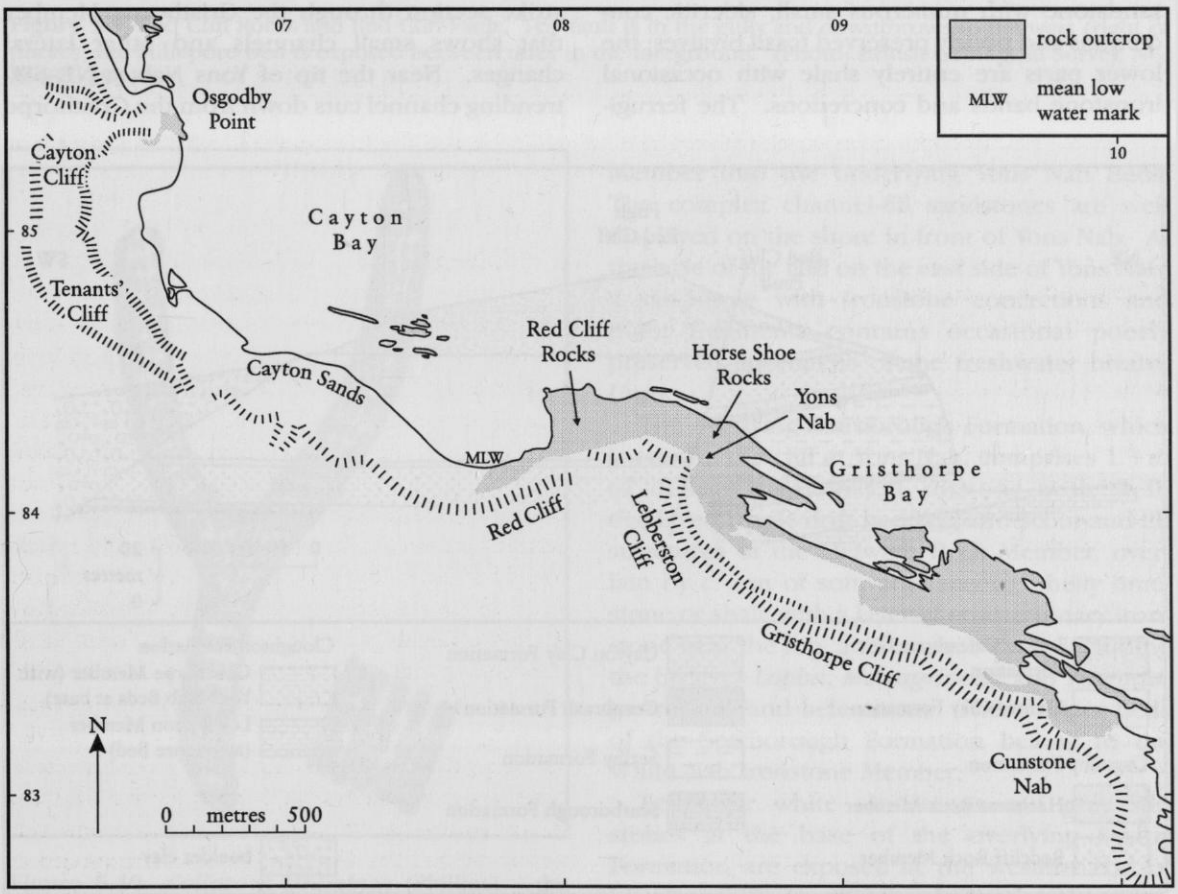


Figure 5.7 Locality map for Gristhorpe Bay, Yons Nab and Red Cliff–Cunstone Nab.

The oldest beds are exposed at, and immediately north of, Yons Nab where, at very low tides, sandstone of the lower part of the Cloughton Formation (Sycarham Member) can be seen at the seaward end of the rock platform beneath the massive rampart and natural breakwater formed by the Millepore Bed (Lebberston Member). The Millepore Bed and overlying Yons Nab Beds (Gristhorpe Member) run straight across the rock platform (Red Cliff Rocks and Horse Shoe Rocks) to meet the Red Cliff Fault as it runs out northwards into the sea (see Bate, 1959, pl. 3). In the cliff, this fault runs down a small gully at the eastern end of Red Cliff (Figures 5.8 and 5.9). The Millepore Bed consists of *c.* 7 m of cross-bedded calcareous sandstone (seen only at very low tides) overlain by *c.* 2 m of ooidal limestone with cross-bedding detectable beneath the barnacle-encrusted surface. Fragments of the bryozoan from which the bed takes its name are not common here (Figure 5.10). The Yons Nab Beds consist of *c.* 5 m of flaggy alternations of shale and siltstone–sandstone with numerous small, sideritic concretions and poorly preserved fossil bivalves; the lower parts are entirely shale with occasional ironstone bands and concretions. The ferruginous upper surface of the Yons Nab Beds shows internal moulds of bivalves including *Pholadomya*, *Pteroperna* and *Trigonia*, some in life position, together with some large vertical U-shaped burrows. Iron-rich concretions containing poorly preserved bivalves occur near the base of the overlying 4.5 m of tough sandstone; the middle part of this unit is strongly bioturbated and the upper part irregularly bioturbated. The succeeding Gristhorpe Plant Bed comprises thinly laminated, friable clays that have yielded a well-preserved fossil flora of stems and leaves of Bennetitales, Ginkgoales, conifers, ferns, Pteridophytes and Caytoniales (Figure 5.11). When first recorded by Wright (1860), the thickness of this bed was given as 2 ft (0.6 m); it probably ranges up to 1 m but Rawson and Wright's (1992, 1995) figure of 2.5 m seems excessive unless they were including in it some part of the overlying *c.* 5 m of largely rootletted beds that form the upper part of the Gristhorpe Member in the lower part of Low Red Cliff and the cliff at Yons Nab. These cliffs expose a strike section through the Gristhorpe Member that shows small channels and other lateral changes. Near the tip of Yons Nab, a NE–SW-trending channel cuts down from the Gristhorpe

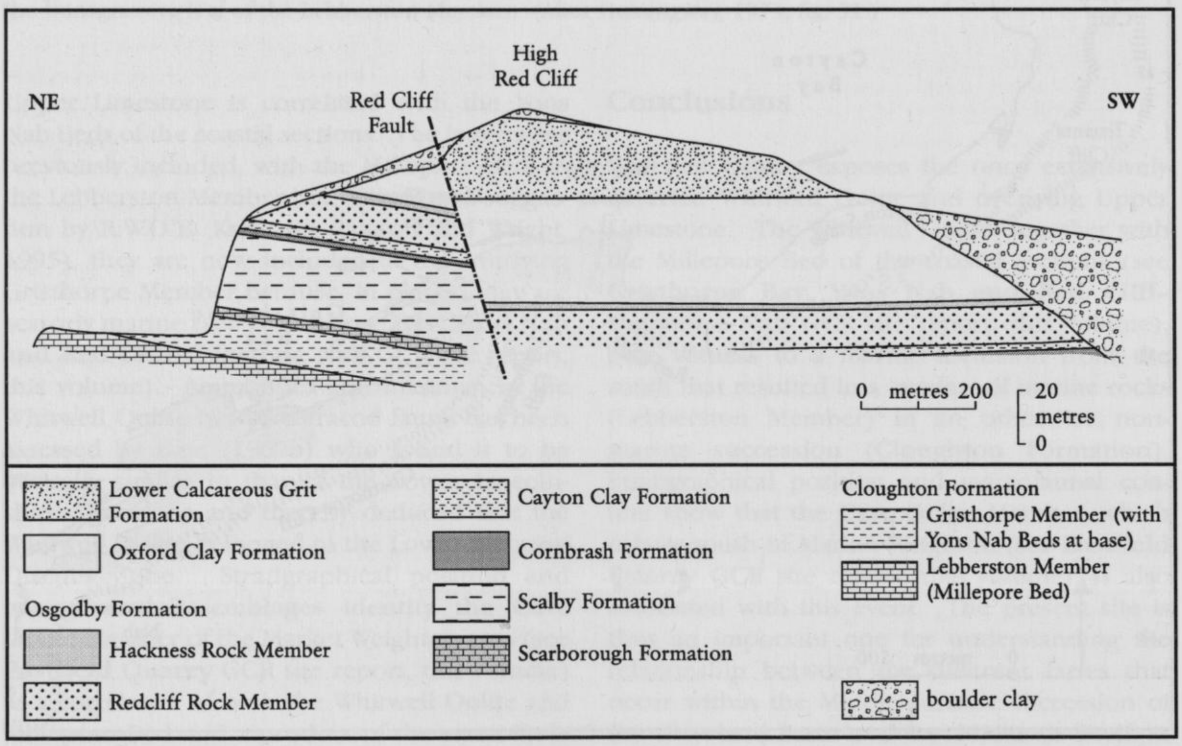


Figure 5.8 Diagrammatic cross-section of the cliffs at the south-eastern end of Cayton Bay. (After Rawson and Wright, 1992, fig. 24.)

Figure 5.9 Red Cliff Rocks and Red Cliff Fault. The fault is in the gully and downthrows to the west (right of photo); the Millepore Bed is exposed between tides in the foreground. (Photo: British Geological Survey, No. A5487, 1931.)

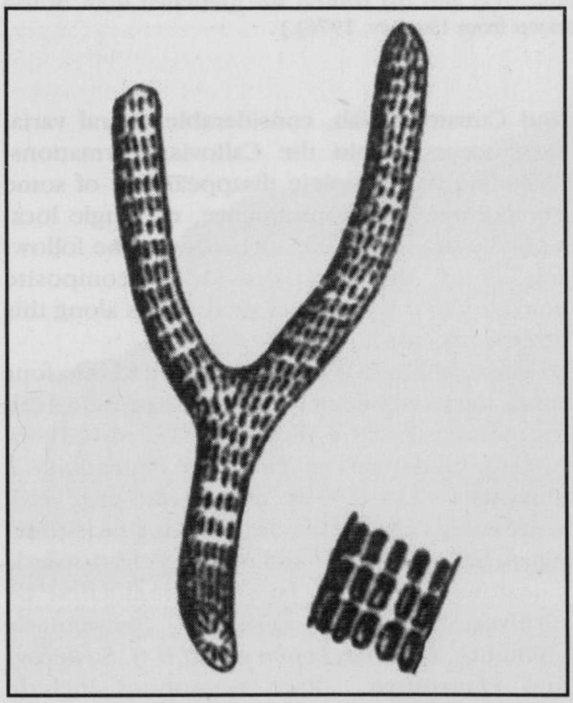


Figure 5.10 *Collapora straminea* (Phillips) – the bryozoan, originally called *Millepora straminea*, that gives its name to the Millepore Bed. (Reproduced (×4) from Phillips, 1835, pl. 9, fig. 1.)

Member into the underlying Yons Nab Beds. The complex channel-fill sandstones are well displayed on the shore in front of Yons Nab. At the base of the cliff on the east side of Yons Nab, a sandstone with ironstone concretions and plant fragments contains occasional poorly preserved specimens of the freshwater bivalve *Unio*.

The overlying Scarborough Formation, which is seen in the cliff at Yons Nab, comprises 1.3 m of delicately laminated siltstone with well-displayed ripple-drift bedding and scour-and-fill structures of the Helwath Beck Member, overlain by *c.* 2 m of soft, argillaceous, shelly limestone or shale with a layer of concretionary ironstone near the top, and crushed shells including the bivalves *Lopha*, *Meleagrinella* and *Trigonia*, gastropods and belemnites. These upper beds of the Scarborough Formation belong to the White Nab Ironstone Member.

Lenticular white sandstones and grey siltstones at the base of the overlying Scalby Formation are exposed at the western end of Low Red Cliff. These may contain abundant, fine or coarse, coalified plant-debris. Pyritization and subsequent weathering of some of the plant

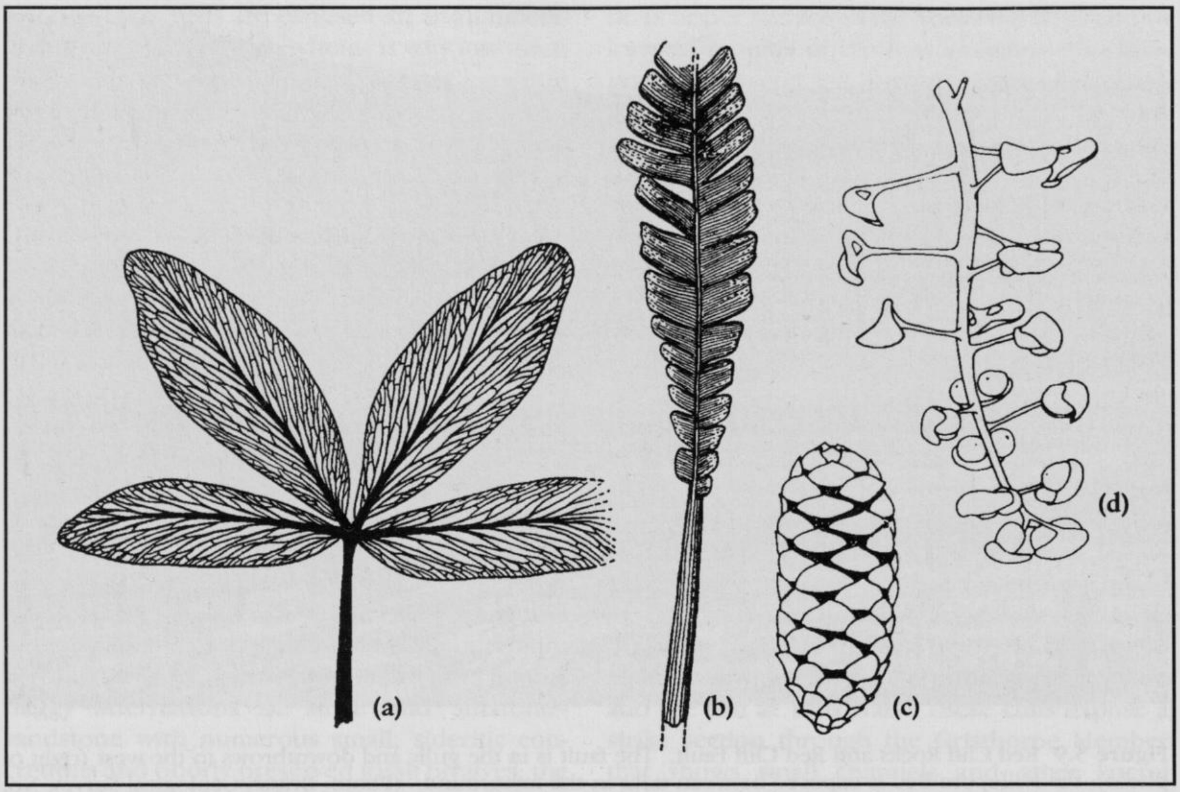


Figure 5.11 Examples of fossil plants from the Gristhorpe Plant Bed. (a) Leaf *Sagenopteris phillipsi* (Brongniart); (b) leaf *Nilssonia compta* (Phillips); (c) restoration of male cone *Androstrobus manis* Harris; (d) restoration of female cone *Beania gracilis* Carruthers. ((a) and (b) natural size (redrawn from British Museum (Natural History), 1975), (c) and (d) × 0.5 (redrawn from Hughes, 1976).)

material has given the cliff face a bright yellow sulphurous coating. In places, the basal beds of the Scalby Formation cut down into the Scarborough Formation, the top of which is disturbed. The east side of Yons Nab is well known for the large channel within the Scalby Formation that cuts down into the top of the Scarborough Formation; its base is marked by a conglomerate of pyrite nodules. This channel, first described in detail and illustrated by Black (1928), is itself cut through by a smaller channel, the base of which is marked by a bed of shale-conglomerate. The Scalby Formation can be followed into Gristhorpe Bay where it is nearly 40 m thick. The gentle landward dip of the strata is such that, in the cliffs at the centre of the bay, a succession from the Scalby Formation through the overlying Cornbrash, Cayton Clay and Osgodby formations, and into the Oxford Clay Formation can be seen (Figure 5.12). The Callovian formations and Oxford Clay Formation are also well exposed in Red Cliff at the southern end of Cayton Bay (Figure 5.13). Between there and Cunstone Nab, considerable lateral variation occurs within the Callovian formations, including the complete disappearance of some components. In consequence, no single location shows a complete succession. The following notes therefore provide a composite summary of the Callovian successions along this stretch of coast.

The Cornbrash Formation is divided into four units, the basal one of which (α_1) is present at all locations and rests, typically with burrowed contact, on mudstones of the Scalby Formation. It comprises 0.14–0.37 m of greenish-grey, red-weathering, berthierine and sideritic limestone, which becomes softer and more muddy towards Cunstone Nab. Its fauna is dominated by bivalves, including *Entolium* (particularly common), *Liostrea*, *Lopha marshii* (J. Sowerby) and *Pleuromya*. Rare ammonites include *Macrocephalites* ex gr. *terebratus* (Phillips). Unit α_2 is *c.* 0.15 m of pale-grey, shelly, variably ooidal limestone (micrite at Cunstone Nab). Its bivalve fauna is again dominated by *Entolium*,

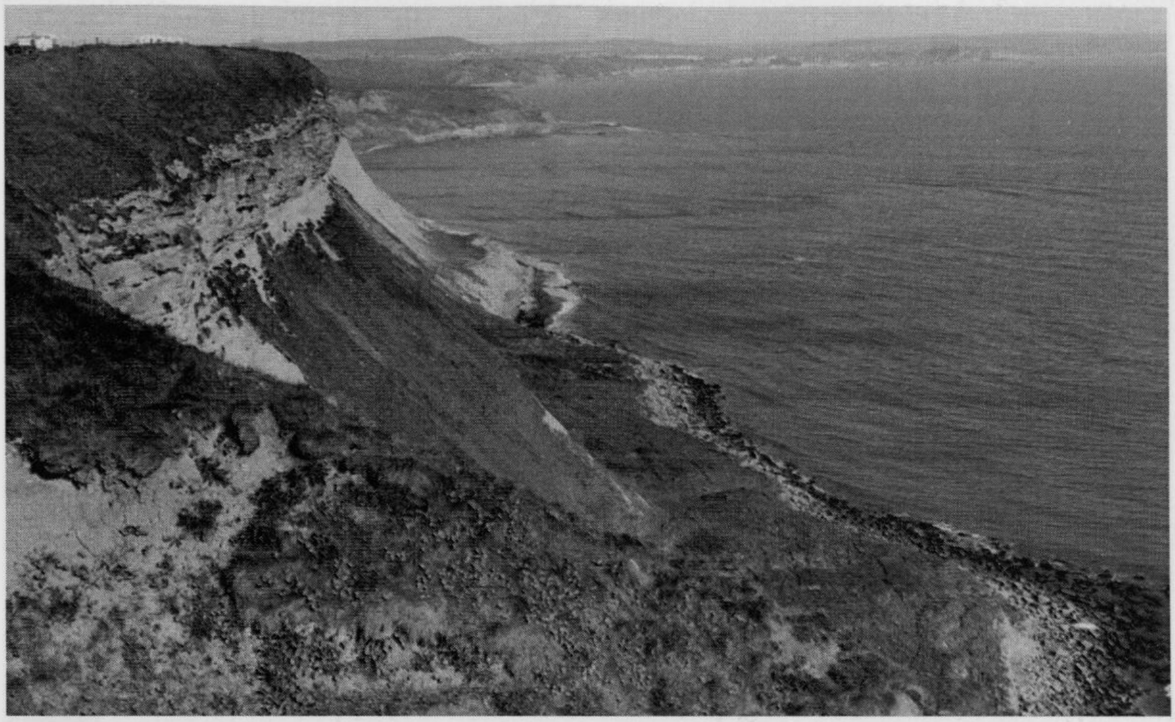


Figure 5.12 Gristhorpe Bay. In the middle distance is the headland Yons Nab and in the far distance Scarborough. (Photo: British Geological Survey, No. L1342; reproduced with the permission of the Director; British Geological Survey, © NERC, 1974.)

Figure 5.13 High Red Cliff, Cayton Bay. (Photo: British Geological Survey, No. A5488, 1931.)

Lopha marshii and *Pleuromya* but also includes *Meleagrinella* and *Trigonia*; the gastropods *'Littorina'*, *Pseudomelania* and *'Trochus'*, and the ammonite *Macrocephalites terebratus* transient β (Callomon and Page in Callomon *et al.*, 1989) are also recorded. Unit α_3 is absent below Red Cliff but well developed in Gristhorpe Bay as a hard, sandy limestone up to 0.18 m thick and with an erosive base. It has yielded bivalves (including *Chlamys*, *Entolium*, *Liostrea* and *Trigonia*) and rare *Macrocephalites kamptus* transient α of Callomon and Page in Callomon *et al.*, 1989). The youngest unit of the Cornbrash Formation (α_4) is a thin silty or sandy shale that forms a lithological transition to the overlying Cayton Clay Formation. It has yielded the bivalves *Entolium* and *Meleagrinella* cf. *braamburiensis* (Phillips) and, locally in Gristhorpe Bay, the brachiopod *Microthyridina lagenalis* Douglas and Arkell *non* Schlotheim.

The base of the overlying Cayton Clay Formation is seen best in cliff exposures at Cunstone Nab. The formation comprises dark-grey shale or silty clay with one or more diffuse bands of small pale-greyish, phosphatic nodules. It yields a low-diversity fauna including *Meleagrinella* aff. *braamburiensis*, *Modiolus bipartitus* (J. Sowerby) and *Nuculana* sp.. This fauna is preserved uncrushed in the phosphatic nodules, which also commonly yield fragmentary small crustaceans. Occasional ammonites, crushed in the clay or with partly phosphatized body chambers, include *Macrocephalites polyptychus* (Spath). The shales typically become sandy in their uppermost part and grade into the basal Osgodby Formation (Redcliff Rock Member) above.

The Osgodby Formation comprises three members, all of which are well developed in Red Cliff and Gristhorpe Bay. The Redcliff Rock Member, at the base, is well developed in Red Cliff (TA 074 841–TA 078 841), which is its type section. The basal part (β_1 of Wright, 1968), passing up from the Cayton Clay Formation below, is pale-yellowish sandstone up to 6.85 m thick with hard calcareous concretions, up to 0.60 m across. The fauna is sparse, except in some concretions, and is dominated by small, often fragmentary, bivalves (including *Meleagrinella*). *Kepplerites* (*Gowericeras*) has been recorded from the top of the unit. In contrast, Unit β_2 (up to 2.35 m thick) is dominated by rusty-weathering, orange to brownish, berthierine ooidal sandstone, the ooids often pale-green in colour. The fauna of β_2 is much richer and more varied than β_1 with many bivalves (including *Entolium*, *Liostrea* and *Modiolus*) and ammonites including *Cadoceras* cf. *tolype* Spath, *Kepplerites* (*Gowericeras*) *indigestus* (S.S. Buckman), *Proplanulites ferruginosus* S.S. Buckman, and rarer *Chamoussetia boreale* (S.S. Buckman). The overlying β_3 (up to 1.98 m thick) is a fossiliferous non-ooidal or very sparsely ooidal sandstone with a similar fauna to the lower units but with a more varied bivalve fauna (including *Chlamys*, *Oxytoma* and *Trautscholdia*), ammonites (*Kepplerites* (*Gowericeras*) and *Proplanulites*) and occasional ?cylindroteuthid belemnites.

A younger unit (β_4), comprising pale-weathering berthierine ooidal sandstone up to 0.55 m thick, is impersistently developed in Red Cliff; it includes shelly concretions full of small bivalves (such as *'Astarte'* and *Entolium*) and rare ammonites (*?Proplanulites*). The youngest unit (β_5) recognized elsewhere may also be present as a soft sandstone, up to 0.65 m thick. Eastwards into Gristhorpe Bay, units β_2–β_5 are rapidly cut out by erosion at the base of the Langdale Member and, before Cunstone Nab is reached, the Redcliff Rock Member is completely removed and the Langdale Member rests directly on an erosively thinned Cayton Clay Formation (Figure 5.14). At Cunstone Nab, the Langdale Member comprises 2.35 m of fine to medium sandstone (γ_1 of Wright, 1968) with clay wisp bedding and small-scale ripple-lamination and scattered belemnites. At *c.* 0.65 m above the base, the ammonites *Erymnoceras* (*Erymnoceratites*) cf. *argoviense* Jeannet and *Kosmoceras* (*Zugokosmokeras*) *grossouvrei* Douvillé are common but poorly preserved. Westwards, the member thins rapidly and is absent at Red Cliff.

The overlying Hackness Rock Member is most thickly developed at Red Cliff where it is dominated by hard, greenish-grey, flaggy, berthierine oolite, which is often heavily oxidized. Bivalves (including *Gryphaea* and *Oxytoma*) are present but age-diagnostic ammonites (*Kosmoceras* and *Quenstedtoceras*) occur relatively rarely; the ammonite *Reineckeia* (*Collotia*) sp. has also been recorded (Rawson and Wright, 1992). Eastwards into Gristhorpe Bay, a tough berthierine ooidal limestone with *Quenstedtoceras* is developed; *Longaeviceras* may also be present (Callomon and Wright, 1989). However, at Cunstone Nab, parts of this succession have been cut out; 0.15 m of calcareous, slightly

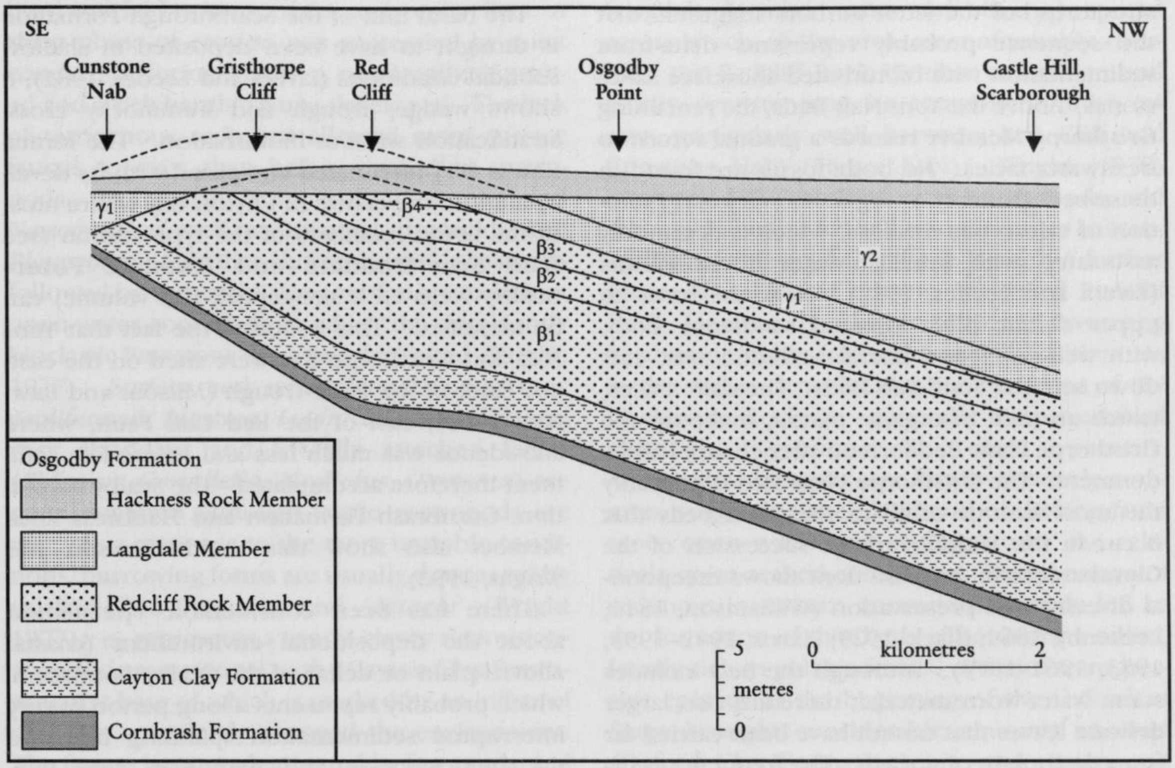


Figure 5.14 Diagrammatic cross-section of the Callovian succession on the coast south of Scarborough. (After Wright, 1968, fig. 3.)

ooidal sandy siltstone (Bed 4 of Wright, 1968) with *Quenstedtoceras* ex gr. *lamberti* (J. Sowerby), *Peltoceras* (*Peltomorphites*) *subtense* (Bean), *Euaspidoceras hirsutum* (Bayle), *Poculisphinctes poculum* (Leckenby), *Alligaticeras alligatum* (Leckenby) and *Kosmoceras* (*K.*) sp. is overlain by 0.15 m of grey sandy clay (Bed 5 of Wright, 1968) with scattered berthierine ooids. The latter unit is best included in the basal Oxford Clay Formation. It yields a crushed, less diverse fauna than the beds below but includes abundant *Quenstedtoceras paucicostatum* (Lange) with *Peltoceras* (*Peltomorphites*) sp.. The overlying 0.15 m of silty clay with berthierine oolite nodules yields *Cardioceras* ex gr. *scarburgense* (Young and Bird) and *Peltoceras* (*Peltomorphites*). At both Red Cliff and Gristhorpe Bay, the Oxford Clay Formation extends for many metres high up in the cliffs.

Interpretation

According to Livera and Leeder (1981), the sandstones of the Sycarham Member seen at Yons Nab represent a large fluvial, channel-sand body that cross-cuts earlier overbank deposits containing thick roots. In the overlying Millepore Bed, cross-stratification has well-preserved bi-polar palaeocurrent directions but the palaeocurrents show no relationship to those demonstrated by wave-ripple sets that are often preserved with ironstone drapes. In the eastern part of the exposure at Yons Nab, there is a strong erosion surface suggesting shallow channel formation. This shallow marine coastal unit is now the sole representative of the Lebberston Member because, following a suggestion of R.W.O'B Knox (in Rawson and Wright, 1995), the Yons Nab Beds, which were previously included therein but which in places are scarcely marine, are now considered to be the basal unit of the overlying Gristhorpe Member. According to Livera and Leeder (1981), the Yons Nab Beds were probably deposited in deeper, quieter water conditions than the Millepore Bed, with little carbonate input, coarsening-upwards on shallowing, allowing complete reworking of the sediment by highly active infauna. Precise environmental analysis is difficult owing to the destruction of all primary sedimentary structures but the latter authors suggested that the sequence probably represents delta-front sedimentation with bioturbated shoreface sandstones. Above the Yons Nab Beds, the remaining Gristhorpe Member records a gradual return to freshwater facies. No body fossils are found in these beds possibly owing to the very early solution of calcareous material, which is commonly associated with brackish-water environments (Livera and Leeder, 1981). Near the base, an upper deltaic plain channel sandstone body, with well-developed lateral accretion sets, cuts down into the Yons Nab Beds. The dark shales, which are rich in organic matter, make up the Gristhorpe Plant Bed formed after channel abandonment. The Gristhorpe Plant Bed is probably the most famous of all of the plant beds that occur in the Middle Jurassic succession of the Cleveland Basin; its fossil flora shows exceptional diversity and preservation (Williamson, 1841; Leckenby, 1864; Black, 1929; Harris, 1942–1953, 1953, 1961–1979). Although the bed includes some water-worn material, there are also larger delicate leaves that cannot have been carried far from their place of growth. The frequent occurrence of leaves with their reproductive organs also suggests that the plant material has been fossilized, probably in sluggish or stagnant river-channels of a fluvio-deltaic environment, close to where the plants grew. Cayton Bay gives its name to the '*Caytonia* plant', which consists of the leaf *Sagenopteris* (Figure 5.11), the megasporophyll (seed) *Caytonia*, the microspherophyll *Caytonanthus* and the stem. It is remarkable for its state of preservation and the amount of detail in which it is known. The Caytoniales do not compare closely with any living primitive flowering plants (angiosperms) although they must be very close to this group. Another famous plant reconstruction is the '*Nilssonia* plant' comprising the leaves *Nilssonia*, the female cone *Beania*, the male cone *Androstrobus* and the scale leaf *Deltolepis* (Figure 5.11). The plant has been reconstructed, with a hypothetical stem, as a small tree with spreading branches and leaves borne in clusters at the end of short shoots; it probably grew very near the edge of the delta or alluvial plain. The succession above the Plant Bed includes a number of sheet sandstones formed by crevasse splays in an overbank environment (Livera and Leeder, 1981). The sandstones show loaded bases, internal convolute-lamination and were colonized by plants leaving thick root-systems.

The basal unit of the Scarborough Formation is thought to have been deposited in shallow subtidal conditions (Livera and Leeder, 1981); it shows wedge, trough and hummocky cross-stratification without bioturbation. The formation is very attenuated compared with its development in the centre of Cayton Bay where most of the seven members of the type section (see **Iron Scar–Hundale and Hundale Point–Scalby Ness** GCR site report, this volume) can be identified. This is due to the fact that Yons Nab and Gristhorpe Bay were sited on the eastern flank of the Peak Trough (Milsom and Rawson, 1989), east of the Red Cliff Fault, where subsidence was much less and where less sediment therefore accumulated. The Scalby Formation, Cornbrash Formation and Hackness Rock Member also show this trend (Rawson and Wright, 1992).

There has been considerable speculation about the depositional environment (coastal alluvial-plain or delta) of the Scalby Formation, which probably represents a long period of very interrupted sedimentation spanning much of the Late Bajocian and Bathonian ages (e.g. Leeder and Nami, 1979; Hancock and Fisher, 1981; Fisher and Hancock, 1985; Alexander, 1989 and references therein). The basal Moor Grit Member, deemed by Livera and Leeder (1981) to be absent at Yons Nab but recognized there by Rawson and Wright (1992, 1995), is thought to have been deposited as an alluvial channel-system over a newly emergent subaerial surface of the Scarborough Formation; the overlying beds of the Scalby Formation are interpreted as predominantly floodplain deposits of the lower coastal plain.

The lowest unit (α_1) of the overlying Cornbrash Formation is widespread, and represents the deposits of a major marine transgression that established quiet marine conditions in the centre and east of the Cleveland Basin. The sediments accumulated in a shallow iron-rich environment with berthierine oolite shoals in the east separated from turbulent areas with bioclastic sediment in the west (Wright, 1977). The quiet conditions of α_1 favoured a predominantly burrowing fauna including the bivalves '*Astarte*', *Goniomya*, *Pleuromya*, *Pseudolimea* and *Trigonia*. Epifaunal, byssally attached forms are virtually absent and infaunal bysally attached forms are rare. Surface faunas were dominated by oysters such as *Liostrea* and *Lopha* although the pectinid *Entolium* is abundant and presumably lived attached to some of the surface dwellers. A short phase of erosion was succeeded by quiet conditions during which α_2 was locally deposited and a rich benthic fauna developed. The lack of terrigenous sediment allowed more surface faunas to exist than before, including gastropods; the bivalve fauna includes *Lopha* and *Nanogyra* as well as infaunal trigoniids and *Pleuromya*. A further shorter erosive phase was followed by the establishment of more turbulent open-water conditions in which the dominantly bioclastic limestone of α_3 was deposited (Wright, 1977). Surface and semi-infaunal faunas now proliferated; *Liostrea*, *Lopha* and serpulids are very abundant and byssally attached forms (*Chlamys*, *Gervillella*, *Modiolus*, *Oxytoma*) are quite common although vagile gastropods are rare. As a response to the more unstable conditions, burrowing forms are usually dominated by thick-shelled *Trigonia* and '*Astarte*' (Wright 1977). α_4 represents a sandy, clayey depositional episode transitional to the Cayton Clay Formation, the base of which is marked by an influx of clay that completely changed the environment. The faunas became dominated by forms adapted to living attached to marine algae or other objects in order to avoid the less favourable seabed conditions. The formation appears to represent a period of relative quiescence over much of England with dark-shale deposition and some phosphate nodule formation.

A major influx of coarse clastic material marks the beginning of Osgodby Formation sedimentation. Wright (1978) interpretated the facies belts and faunal changes he observed regionally in the Redcliff Rock Member as representing a transition from mudflats (possibly brackish-water) and very shallow water (?intertidal sand flats) to more turbulent conditions with sand bars. A reduction in sediment supply and the probable establishment of coastal lagoons in the area led to the development of berthierine ooids (the iron coming from 'tropical' rivers of the northwest and north-east). The benthic fauna of the berthierine ooid-rich sandstones and siltstones is often limited to surface-living oysters, and burrowers are more common where the iron content is less (suggesting to Wright (1968) an ecological effect); younger berthierine-free sands contain richer faunas of surface and burrowing forms thereby supporting this idea.

After a period of uplift, flexuring and erosion later in Early Callovian and early Mid Callovian times (Calloviense and Jason zones), a sheet of Langdale Member sand and silt (γ_1) spread across much of the area, unconformably overlying the Redcliff Rock Member succession and locally over-stepping its component units (as seen particularly well between Red Cliff and Cunstone Nab) (Figure 5.14). Wright (1978) interpreted the sands of γ_1 as beach sands, and the establishment of shallow open-water encouraged the settling of *Gryphaea* larvae. A further phase of uplift and erosion reinstated Redcliff Rock Member β_2-like conditions, favouring berthierine oolite formation and deposition. As in the earlier deposits, the benthic fauna of the Hackness Rock is generally impoverished although *Gryphaea* is often present. Ammonites, however, are locally relatively common, suggesting the likelihood of drifting from more open water and settling under the relatively quiet seabed conditions. The shortage of sediment in eastern areas consequently led to the formation of thin beds of berthierine oolite, locally rich in pelagic fossils. A major transgressive episode at the beginning of the Oxfordian Stage brought considerable amounts of mud (Oxford Clay Formation) into the region and berthierine oolite sedimentation of the Osgodby Formation was brought to an end.

Much of the dating of the succession remains imprecise, but specimens of the ammonite *Teloceras* in the Scarborough Formation at Gristhorpe Bay and Low Red Cliff, including those recorded by Farrow (1966), indicate the (Lower Bajocian) Humphriesianum Zone and Subzone (Parsons, 1977b). Apart from this, only the ammonitiferous Callovian strata can be satisfactorily assigned to chronostratigraphical units. Large, early forms of *Macrocephalites* ex gr. *terebratus* in α_1 of the Cornbrash Formation are suggestive of the *terebratus* α Biohorizon of Callomon and Page in Callomon *et al.* (1989), which was taken by Page (1989) to define the base of the Terebratus Subzone (Lower Callovian, Herveyi Zone). Historically, the overlying α_2 yielded the richest faunas of the Yorkshire Cornbrash Formation, apparently mainly from reefs in Cayton Bay below Red Cliff. The *Macrocephalites terebratus* transient β in that unit indicates the *terebratus* β Biohorizon (Terebratus Subzone), and the *Macrocephalites* in α_3 indicate the *kamptus* α Biohorizon of the early Kamptus Subzone (Herveyi Zone). Callomon *et al.* (1989) defined the base of the latter subzone at this level but Page (1989) subsequently considered that the section at

Thrapston (see GCR site report, this volume) to be more appropriate. The brachiopod *Microthyridina lagenalis*, which occurs in abundance in α_4 at Gristhorpe Bay is a stratigraphically important form also indicative of the *kamptus* α Biohorizon. *Macrocephalites polyptychus*, which occurs in the Cayton Clay Formation, is the index species of the *polyptychus* Biohorizon in the upper part of the Kamptus Subzone. The ammonite faunas of these levels are dominated by Tethyan Macrocephalitinae but at higher levels the ammonite fauna is entirely Boreal with Arctic Province cardioceratids (*Cadoceras* and *Chamoussetia*) together with *Kepplerites* and the Subboreal Province indicator *Proplanulites*. *Kepplerites* (*Gowericeras*) from the upper part of β_1 of the Redcliff Rock Member indicates the Koenigi Zone but the lower 6 m+ of that unit has yielded no age-diagnostic fauna (J.K. Wright, pers. comm., 1996). The ammonite assemblage of β_2 is an internationally important fauna defining the *indigestus* Biohorizon of the Curtilobus Subzone (Lower Callovian, Koenigi Zone). This fauna is better preserved at Red Cliff than elsewhere in the region and the site is the likely type locality of most of the 'Kelloway Rock' ammonite species described from North Yorkshire. The fauna can also be recognized in southern England (Wiltshire) but as no sections now remain in that area, the national and international correlative importance of the Cayton Bay section is increased. Another important correlative ammonite fauna may be present in the Redcliff Rock Member since specimens of the microconch form *Kepplerites distans* Tintant have been recovered, sometimes associated with *Chamoussetia boreale*. The former species has not been found with *K. indigestus* in the main fossiliferous levels in Red Cliff studied by Page (1988), and the preservation of the two forms are commonly distinct. However, the precise biostratigraphy of all but the main fossiliferous horizon of β_2 remains unclear and the possibility that a new correlatively important biohorizon could be established in the Redcliff Rock Member remains open.

The Langdale Member was proposed by Wright (1968) for pale non-ooidal sandstones and silts of Mid Callovian age overlying the Redcliff Rock Member. Its type locality is inland in Langdale but Cunstone Nab provides one of the best available fossiliferous sections. Ammonites there indicate the Grossouvrei Subzone of the Middle Callovian Coronatum Zone. The type locality of the Hackness Rock Member is also inland (see **Hackness Quarry** GCR site report, this volume) but the coastal sections between Castle Hill, Scarborough and Cunstone Nab have yielded most of the well-known fauna of that horizon, including the type specimens of many species. At Red Cliff, the presence of *Quenstedtoceras* indicates the Upper Callovian Lamberti Zone (probably Lamberti Subzone), and *Kosmoceras* (*Lobokosmokeras*) cf. *proniae* Teisseyre indicates the Upper Callovian Athleta Zone (possibly Proniae Subzone). At Gristhorpe Bay, the Lamberti Zone and Subzone are also indicated by the presence of *Quenstedtoceras* and some evidence that the Athleta Zone is present is provided by records of *Kosmoceras* (*Lobokosmokeras*) *compressum* (Quenstedt) from hereabouts (Wright, 1968). Gristhorpe Bay was an important source of Lamberti Zone fossils to early collectors and the type specimens of *Poculisphinctes poculum* and various species of *Quenstedoceras* probably synonymous with *Q.* ex gr. *lamberti*, including *Q. ordinarium* (Bean) and *Q. vertumnus* (Leckenby), probably came from here. At Cunstone Nab, the Athleta Zone is entirely cut out but the succession is otherwise rich in age-diagnostic ammonites and represents the most complete Callovian–Oxfordian stage boundary sequence in the Cleveland Basin. The Lamberti Zone (Lamberti Subzone) is represented by only 0.15 m of strata (Bed 4 of Wright, 1968). The abundant *Quenstedtoceras paucicostatum* with *Peltoceras* (*Peltomorphites*) in the overlying bed (Bed 5 of Wright, 1968) indicate the terminal Callovian *paucicostatum* Biohorizon (Callomon, 1990). This biohorizon was previously considered to represent the basal Oxfordian Stage (e.g. by Marchand, 1979; Wright, 1983) but that horizon is, in fact, indicated by *Cardioceras* ex gr. *scarburgense* in the overlying Bed 6 of Wright (1968). As the best boundary section in the Scarborough district, Cunstone Nab has added international significance because the district is the historical type locality for the basal Oxfordian Scarburgense Subzone of Buckman (1913). The presence of the *paucicostatum* Biohorizon indicates that the boundary section at Cunstone Nab is more complete than that at nearby **Osgodby Point** (see GCR site report, this volume), which was proposed by Callomon (1990) as a candidate Global Stratotype Section and Point (GSSP) for the base of the Oxfordian Stage.

Conclusions

The cliff and foreshore exposures from the southern end of Cayton Bay (Red Cliff) to Cunstone Nab on the North Yorkshire coast display a substantial part of the Cleveland Basin Middle Jurassic succession. The non-marine (deltaic–alluvial) facies of the Ravenscar Group, and two intercalated marine units (Lebberston Member and Scarborough Formation), are exposed at Yons Nab and in the adjoining cliffs. These show a number of interesting sedimentological features including well-developed, complex, channel-fill sandstones, and the internationally famous fossil flora of the Gristhorpe Plant Bed. At Red Cliff and Gristhorpe Bay to Cunstone Nab, cliff and cliff-base exposures provide some of the most impressive and instructive Callovian sequences in Britain. The area includes type sections of the Cayton Clay Formation and the Redcliff Rock Member of the Osgodby Formation. Lower Callovian ammonite faunas of international importance for correlation and the definition of the Terebratus and Kamptus subzones of the Herveyi Zone and the *indigestus* Biohorizon of the Curtilobus Subzone (Koenigi Zone) are present. Type material of several fossil species comes from here. In addition, the site at Cunstone Nab includes the best-developed Callovian–Oxfordian boundary section in the Cleveland Basin. The remarkable lateral variation in terms of erosive loss of different parts of the Callovian succession, provides an important insight into the development of the Cleveland Basin as a whole in late Mid Jurassic times.

OSGODBY POINT, NORTH YORKSHIRE (TA 065 854)

K.N. Page

Introduction

Osgodby Point, perhaps better known as 'Osgodby Nab', is a small headland on the coast, *c*. 4 km south of Scarborough. It separates Cayton Bay to the south from Cornelian Bay to the north. The tip of the headland is formed of upfaulted Cloughton Formation of Bajocian age but Callovian rocks, comprising the Cornbrash, Cayton Clay and Osgodby formations, are exposed on both its sides (at *c*. TA 064 853 and *c*. TA 064 855). Further exposures are visible, depending on the state of the beach, on the foreshore opposite the former Cayton Bay waterworks (TA 067 846). Osgodby Point has long been recognized as an important Callovian site and is now the type locality of the Osgodby Formation (Wright, 1978). The site also includes an internationally important Callovian–Oxfordian stage boundary sequence (Callomon, 1990).

Description

The Callovian sections around Osgodby Point were fully described by Wright (1968, 1977), and the Lower Callovian part reassessed by Page (1988, 1989). The succession is broadly similar to that farther south in Cayton Bay (see **Gristhorpe Bay, Yons Nab and Red Cliff–Cunstone Nab** GCR site report, this volume) but there are differences in detail between the two sites.

The Cornbrash Formation is normally seen only in boulder-covered foreshore exposures (*c*. TA 065 853) on the south side of Osgodby Point. The succession is as follows.

	Thickness (m)
Cornbrash Formation	
α_3: Limestone, sandy, bioclastic with pebbles of berthierine oolite derived from underlying bed; abundant *Lopha marshii* (J. Sowerby); *Macrocephalites* ex gr. *kamptus* (S.S. Buckman)	0.08
α_1: Limestone, red-weathering, berthierine oolite; common bivalves; rare *Macrocephalites*	0.79

Poor exposures of the overlying Cayton Clay Formation are present on either side of Osgodby Point. On the south side, traces can often be seen between boulders above the Cornbrash Formation outcrop recorded above. The basal silty shelly horizon (Bed α_4 of Wright, 1977) is well developed with abundant *Meleagrinella braamburensis* (Phillips), *Lopha marshii* (J. Sowerby) and *Nanogyra nana* (J. Sowerby). Higher levels contain occasional, small, brownish-grey phosphatic nodules, and several (mainly fragmentary) *Macrocephalites polyptychus* (Spath) have been recovered. The formation is also occasionally seen in a disturbed condition on the north side of the point at *c*. TA 063 856 close to the cliff–landslip base where exposures are remarkable for yielding, as well as *Macrocephalites* ex gr. *kamptus* (S.S. Buckman), many fragmentary crustacean (?*Glyphaea*) remains in typical small phosphatic nodules.

In 1996, the overlying Redcliff Rock Member (*c.* 9.6 m thick) of the Osgodby Formation was seen best on the south side of Osgodby Point at *c.* TA 064 853, where units β_1–β_3 of Wright (1968) are well developed. The berthierine ooidal sandstone of β_2 yields the ammonites *Kepplerites* (*Gowericeras*) sp. and *Proplanulites* cf. *ferruginosus* S.S. Buckman.

The Langdale Member (3.8 m thick) is seen overlying the Redcliff Rock Member in the exposure on the south side of Osgodby Point (see above), and again at *c.* TA 064 855 on the north side. It comprises a fine- to medium-grained sandstone with clay wisps and bivalves (*Chlamys* and *Modiolus*) (γ_1 of Wright, 1968) overlain by a flaggy-weathering siltstone with very occasional small bivalves and scattered belemnites (γ_2 of Wright, 1968). *Erymnoceras* has been recorded in γ_2 by J.K. Wright (pers. comm., 1996).

The Hackness Rock Member (*c.* 0.75 m thick) is seen particularly well only on the north side of Osgodby Point, above the Langdale Member. Here it is dominated by a hard, bluish-grey, sandy, berthierine oolite with sporadic ammonites, belemnites and bivalves (Bed 8 of Wright, 1968) overlain by 0.1 m of soft, greenish-grey sand with green berthierine ooids (Bed 9 of Wright, 1968). The base of the member is erosional. The member is overlain by a grey, sandy shale (Bed 10 of Wright, 1968) with scattered berthierine ooids and a line of calcareous nodules *c.* 0.08 m above the base.

On the foreshore opposite the former waterworks (TA 067 846) in Cayton Bay (Wright, 1968, 1983), the Hackness Rock Member comprises *c.* 0.6 m of hard, berthierine ooidal sandstone with *Kosmoceras* and *Binatisphinctes* (Bed 1 of Wright, 1968) overlain by 0.6 m of berthierine oolite and ooidal sandstone with *Quenstedtoceras*, *Peltoceras* (*Peltomorphites*) and *Hecticoceras*. The basal 0.45 m of the overlying Oxford Clay Formation (Bed 5 of Wright, 1968) is a black chamositic silt with calcareous nodules, *Quenstedtoceras paucicostatum* (Lange) and a possible late form of *Longaeviceras* (Wright, 1983, pl. 18, fig. 8).

Interpretation

The presence of *Macrocephalites* in α_1 of the Cornbrash Formation indicates, as elsewhere in the area, the Terebratus Subzone of the Lower Callovian Herveyi Zone; subdivision α_2 is completely absent here. The *Macrocephalites* ex gr. *kamptus* recorded in α_3 is presumed to indicate the *kamptus* α Biohorizon of the Kamptus Subzone (Lower Callovian Herveyi Zone); the *polyptychus* Biohorizon of that subzone is indicated in the Cayton Clay Formation by the presence of its index species (Page, 1988).

Within the Osgodby Formation, *Erymnoceras* in γ_2 of the Langdale Member indicates the Middle Callovian Coronatum Zone but no age-diagnostic fossil has been reported from γ_1. The basal *c.* 0.15 m of the Hackness Rock Member has yielded the ammonites *Kosmoceras* (*Lobokosmokeras*) sp. and rare *Binatisphinctes hamulatus* (S.S. Buckman), *Pachyceras* cf. *crassum* Douvillé and *Peltoceras* (*P.*) *athleta* (Phillips) (Wright, 1968). These are indicative of the upper Phaeinum or lower Proniae subzones of the (Upper Callovian) Athleta Zone. A little higher, but still within Bed 8 of Wright (1968), the ammonite *Quenstedtoceras* ex gr. *lamberti* (J. Sowerby) occurs with the bivalve *Chlamys* and the belemnite *Lagonibelus beaumontiana* (d'Orbigny), and indicates the Lamberti Zone and Subzone (Wright, 1968; K.N. Page, unpublished). Bed 8 therefore appears to include a significant non-sequence as no evidence of the upper Proniae, Spinosum and Henrici subzones is known. The Lamberti Zone and Subzone is also indicated in the overlying Bed 9 by the presence of *Peltoceras* and *Quenstedoceras*.

In the foreshore exposure opposite the former waterworks, the ammonites recorded in the Hackness Rock Member indicate the Athleta Zone overlain by the Lamberti Zone and Subzone. *Quenstedtoceras paucicostatum* here is a terminal Callovian indicator (*paucicostatum* Biohorizon of Marchand, 1979). Although not specifically recorded, the basal Oxfordian Scarburgense Subzone would be expected immediately above this fauna.

On the north side of Osgodby Point, well-preserved *Cardioceras scarburgense* (Young and Bird) are recorded just below the line of calcareous nodules in Bed 10 (figured by Wright, 1983, pl. 18, figs 5–7). This fauna is one of the best-preserved Lower Oxfordian (Mariae Zone, Scarburgense Subzone) faunas in the district. The base of Bed 10 was proposed by Callomon (1990) as the definition of the base of a formalized Scarburgense Subzone, and the site was thereby established as a candidate GSSP (Global Stratotype Section and Point; Salvador, 1994) for the base of the Oxfordian Stage (Figures 5.15 and 5.16). The section certainly forms a valuable

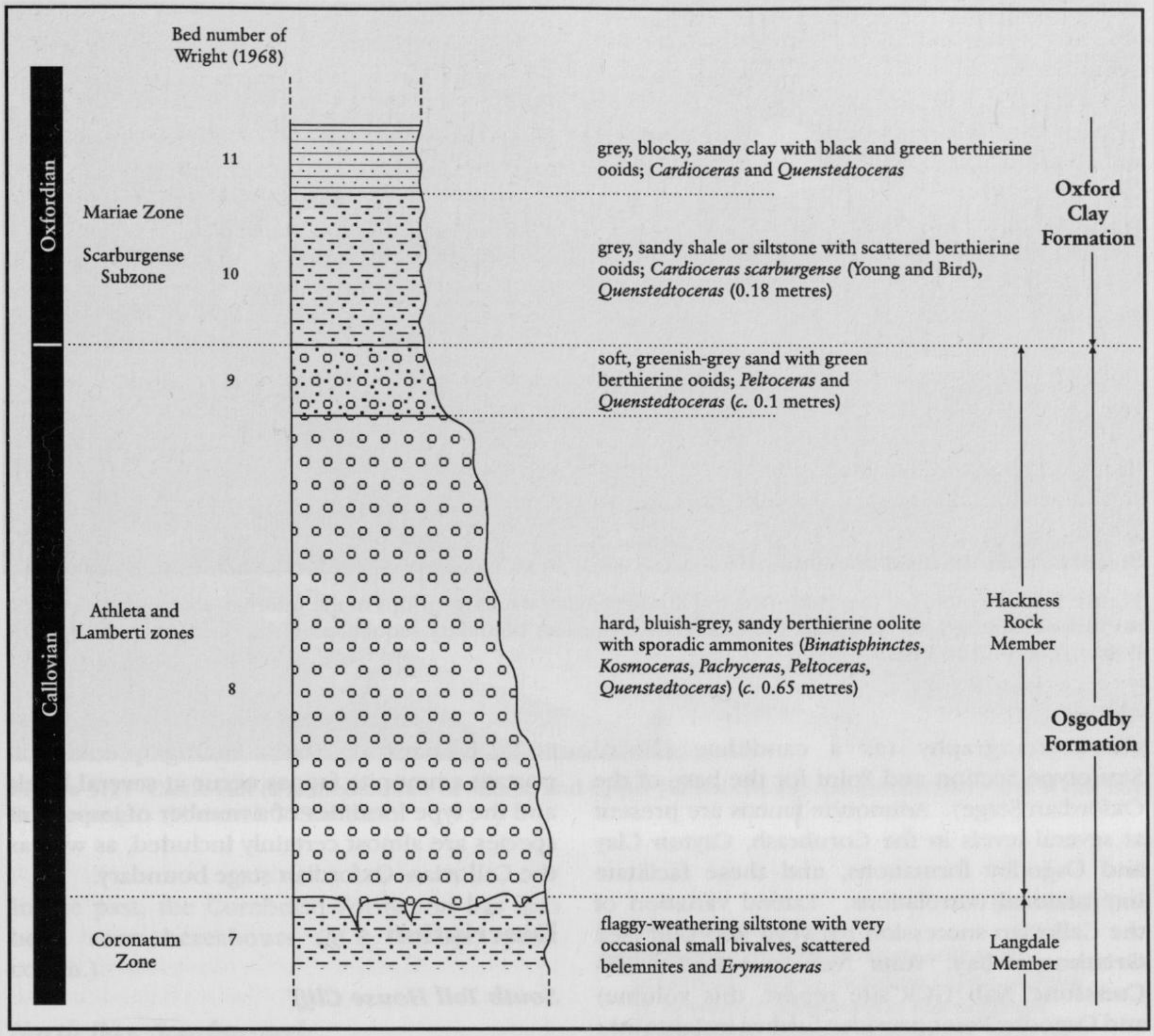


Figure 5.15 Graphic section of Callovian–Oxfordian boundary sequence on the north side of Osgodby Point. (After Wright, 1969, fig. C4.)

reference for a *scarburgense* Biohorizon in the type area of the subzonal index species. According to Callomon (1990), its advantages lie in the fact that it is permanently exposed and accessible, and that the boundary at the base of Bed 10 is readily recognizable. Its disadvantage is that the Scarburgense Subzone is here strongly condensed (total thickness *c.* 0.5 m) compared with 10 m or more elsewhere in Britain. However, the absence of a recognizable terminal Callovian *paucicostatum* Biohorizon (see above) may suggest that a slight stratigraphical gap exists at the proposed boundary, and other sections in the area are more complete (e.g. at Cunstone Nab and on the shore opposite Cayton Bay waterworks; see **Gristhorpe Bay, Yons Nab and Red Cliff–Cunstone Nab** GCR site report, this volume). Even more complete sequences are known in Dorset (see **Ham Cliff** GCR site report, this volume) and in Provence, France (Fortwengler and Marchand, 1994). Although this means that Osgodby Point will not be established as a GSSP, the significance of the site in formulating the GSSP proposals cannot be underestimated.

Conclusions

Osgodby Point (more traditionally known as 'Osgodby Nab') is an important stratigraphical reference site for both lithostratigraphy (as the type locality of the Osgodby Formation) and

Figure 5.16 Members of the Oxfordian and Kimmeridgian working groups of the International Subcommission on Jurassic Stratigraphy sampling the Callovian–Oxfordian boundary sequence on the north side of Osgodby Point. (Photo: K.N. Page.)

chronostratigraphy (as a candidate Global Stratotype Section and Point for the base of the Oxfordian Stage). Ammonite faunas are present at several levels in the Cornbrash, Cayton Clay and Osgodby formations, and these facilitate international correlations. Lateral variation of the Callovian succession between Red Cliff (see **Gristhorpe Bay, Yons Nab and Red Cliff–Cunstone Nab** GCR site report, this volume) and Osgodby Point provides further insights into the structural evolution and depositional history of the Cleveland Basin.

SOUTH TOLL HOUSE CLIFF AND NORTH BAY, SCARBOROUGH, NORTH YORKSHIRE (TA 051 888, TA 045 892–TA 048 893, TA 040 894–TA 051 895)

K.N. Page

Introduction

The GCR sites known as 'South Toll House Cliff' and 'North Bay, Scarborough' represent the surviving remnants of the historically important Callovian exposures on the south and north sides respectively of Castle Hill, Scarborough (Figure 5.17), as described in early literature (e.g. Phillips, 1829; Leckenby, 1859; Hudleston, 1876; Brinkmann, 1926). Stratigraphically important ammonite faunas occur at several levels and the type localities of a number of important species are almost certainly included, as well as the Callovian–Oxfordian stage boundary.

Description

South Toll House Cliff

The site is adjacent to a small storage area (TA 0515 8885), opposite a lighthouse and amusement arcade. The following description is based on Wright (1968) who is the only author to mention the section specifically.

	Thickness (m)
?Oxford Clay Formation	
Soft, ?silty material barely visible beneath soil	–
Osgodby Formation	
Hackness Rock Member	
Sandstone, brown-weathering, with berthierine ooids and soft, flaggy base; *Peltoceras (Peltomorphites) subtense* (Bean) and *Quenstedtoceras* ex gr. *lamberti* (J. Sowerby)	*c.* 0.23
Berthierine oolite, massive, weathering red with pale-green ooids; macroconch and microconch *Quenstedtoceras*; sandstone, pale-coloured, massive; few fossils	*c.* 1.14
Langdale Member	
Sandstone, grey, flaggy, very fine-grained; small burrows	*c.* 9+

Figure 5.17 Castle Hill (a faulted outlier of Middle and Upper Jurassic rocks) (centre distance) and South Bay, Scarborough. (Photo: M.G. Sumbler.)

In the past, the Cornbrash Formation has also been seen hereabouts (M.R. House, pers. comm.).

North Bay, Scarborough

Cliff exposures and other small outcrops around the gardens on the north side of Castle Hill, Scarborough (TA 045 892–TA 048 893), and in landslipped blocks and narrow foreshore platforms below (TA 040 894–TA 051 895), reveal a composite Callovian sequence. The most detailed recent descriptions of the sections are those of Wright (1968, 1977) and Page (1988) on which the following notes are based.

The Cornbrash Formation (*c.* 1.08 m thick) is seen in three places: an exposure (TA 048 893) near the centre of the gardens below Scarborough Castle (Wright, 1977); a small exposure on the edge of the putting green at TA 0470 8925 (J.K. Wright, pers. comm., 1996); and in a ?slipped block on the foreshore close to a tunnel at TA 048 894 (Page, 1988). The succession comprises:

	Thickness (m)
Cornbrash Formation	
α_3: Limestone, bioclastic, sandy with well-preserved bivalves including *Lopha marshii* (J. Sowerby), *Myophorella scarburgense* (Lycett) and *Trigonia elongata* (J. Sowerby), and the brachiopod *Microthyridina*	0.43
α_2: Limestone, rubbly, ooidal, with many pebbles including internal moulds of burrowing bivalves; *Macrocephalites* fragment	0.10
α_1: Limestone, dark greenish-grey, weathering red; bivalves; well-developed *Thalassinoides* burrow-system at base	0.65

The overlying Cayton Clay Formation is not well exposed but the basal 0.10 m (α_4 of Wright, 1977) is seen above the Cornbrash Formation in the foreshore block noted above. Here, dark-grey, silty clay has yielded abundant *Meleagrinella braamburiensis* (Phillips) and *Modiolus bipartitus* (J. Sowerby) (Page, 1988).

The overlying Osgodby Formation is exposed in the cliff exposures below Rutland Terrace (TA 045 892). The Redcliff Rock Member is difficult to access in the sheer cliffs but additional sections are present in foreshore blocks near to that exposing the Cornbrash Formation. The overlying Langdale Member is well developed in the cliffs. Below Rutland Terrace, the Hackness Rock Member is very fossiliferous but the exposures are typically largely covered by soil and grass. The following composite section is based on Wright (1968) and Page (1988); bed numbers follow Wright (1968).

	Thickness (m)
Osgodby Formation	
Hackness Rock Member	
4–6: Limestone, weathering brown, with berthierine ooids	0.6
3: Sandstone with berthierine ooids; fossiliferous with *Camptonectes*, *Gryphaea* and *Kosmoceras* (*Lobokosmokeras*) ex gr. *proniae* (Teisseyre)	0.15
1–2: Sandstone with *Gryphaea lituola* Lamarck and belemnites in upper part	1.12
Langdale Member	
6: Siltstone, soft, and sandstone, fine grained, finely laminated; scattered belemnites, oysters and *Meleagrinella*	est. 9.75
5: Sandstone, fine grained becoming medium grained and well sorted towards base; belemnites 0.08 m above base	c. 1.5
Redcliff Rock Member	
4: Sandstone, clayey with quartz pebbles up to 6 mm diameter	0.2
3: Sandstone, deeply weathered, often deep-orange in colour; ammonites including *Chamoussetia*?, *Kepplerites* (*Gowericeras*) cf. *indigestus* (S.S. Buckman) and *Proplanulites* cf. *ferruginosus* S.S. Buckman	*c.* 2.05
1/2: Sandstone, yellow to orange; shell fragments in upper part	c. 10.4

The upper part of the Hackness Rock Member is also exposed on a narrow wave-cut platform at the bottom of Marine Drive (TA 051 895):

	Thickness (m)
Oxford Clay Formation	
Marl, grey, poorly exposed; scattered berthierine ooids; occasional limestone nodules (up to 0.10 m diameter); *Cardioceras* cf. *scarburgense*	0.15–0.20
Osgodby Formation	
Hackness Rock Member	
Sandstone with berthierine ooids, weathering red; ammonites including *Euaspidoceras* cf. *hirsutum* (Bayle), *Hecticoceras* (*Putealiceras*) *puteale* (Leckenby), *Kosmoceras* (*K.*) ex gr. *spinosum* (J. de C. Sowerby) and *Quenstedtoceras* ex gr. *lamberti* (J. Sowerby); belemnites (*Hibolithes hastatus* (Montfort) and *Lagonibelus beaumontiana* (d'Orbigny)); bivalves (*Chlamys* sp. and *Gryphaea lituola* Lamarck); and the nautiloid *Paracenoceras*	0.3

Interpretation

The once extensive exposures around Scarborough's Castle Hill, and material fallen from them, would have yielded the bulk of the Callovian ammonites collected and described by early workers, often as new species (e.g. Leckenby, 1859; Buckman, 1909–1930). The majority of these exposures were destroyed by the construction of the Marine Drive promenade in the 1860s (Wright, J.K., 1968; Wright, T.,1860); only the sections covered by the South Toll House Cliff and North Bay, Scarborough GCR sites remain.

Old fossil collections suggest that α_2 of the Cornbrash Formation at North Bay is the source of at least some of the large numbers of *Macrocephalus* ex gr. *terebratus* (Phillips) labelled 'Scarborough' in old collections (including the neotype itself (Figure 5.18) and the holotype of the microconch *M. typicus* Blake); the former species gives its name to the Terebratus Subzone of the Lower Callovian Herveyi Zone. T. Wright (1860) noted that most of the then-known fossils from the Cornbrash Formation had come from the north side of Castle Hill, and Fox-Strangways (1892) suggested that many had come from fallen blocks on the shore. He added 'it is probable that nearly all the fossils enumerated from the Yorkshire Cornbrash Formation have come either from these blocks or from the exposure in Cayton Bay at the foot of Red Cliff' (see **Gristhorpe Bay, Yons Nab and Red Cliff–Cunstone Nab** GCR site report, this volume).

In the Osgodby Formation, ammonites reported in the Redcliff Rock Member, which is similarly developed to that in areas farther south around Cayton Bay (see **Gristhorpe Bay, Yons Nab and Red Cliff–Cunstone Nab** GCR site report, this volume), are indicative of the *indigestus* Biohorizon of the Lower Callovian Koenigi Zone, Curtilobus Subzone. The three units into which the member is divided in the above section correspond, from below, to Wright's (1968) subdivisions β_1, β_2 and β_3. Wright (1968) referred the overlying Langdale Member at South Toll House Cliff to his γ_2 subdivision of that member but recognized both γ_1 (Bed 5) and γ_2 (Bed 6) at North Bay. No age-diagnostic ammonite fauna has been recorded but the member probably belongs to the Middle

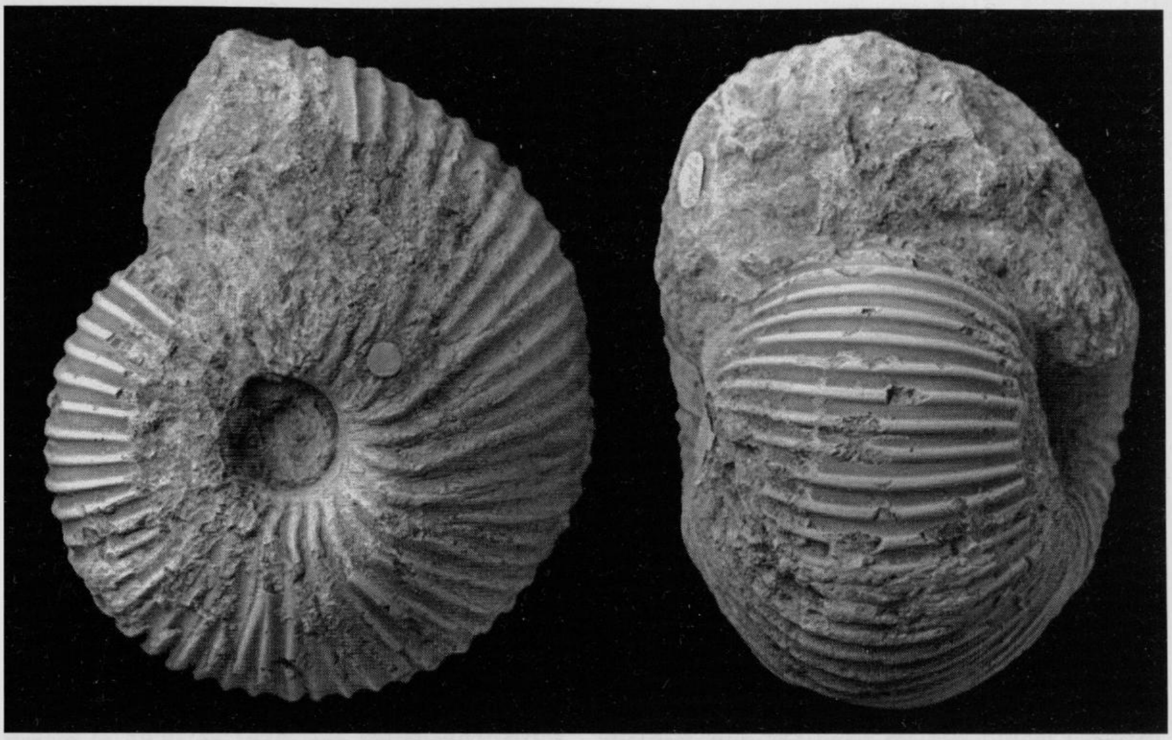


Figure 5.18 Neotype of *Macrocephalites terebratus* (Phillips); The Natural History Museum, London, specimen No. 39566; natural size. (Photo: © The Natural History Museum.)

Callovian Coronatum Zone as at Cunstone Nab (see **Gristhorpe Bay, Yons Nab and Red Cliff–Cunstone Nab** GCR site report, this volume). Bed 3 of the Hackness Rock Member at North Bay is likely to be the source of most of the Upper Callovian Athleta Zone ammonites labelled 'Scarborough', which have been variously figured by Leckenby (1859), Buckman (1909–1930), Cox (1988) and Callomon and Wright (1989). These include *Alligaticeras rotifer* (Brown) (including the holotype), *Binatisphinctes binatus* (Leckenby) (possibly including the holotype), *Binatisphinctes hamulatus* (S.S. Buckman) (including the holotype), *Chamoussetia funifera* (Phillips), *Distichoceras bicostatum* (Stahl), *Hecticoceras* (*Orbignyiceras*) *pseudopunctatus* (Lahusen), *Kosmoceras* (*Lobokosmokeras*) *rowlstonense* Buckman *non* Young and Bird, *Kosmoceras gemmatus* (Phillips), *Longaeviceras placenta* Leckenby (including the holotype), *L. polonicum* Callomon and Wright, *L.* cf. *schumarowi* (Nikitin), *Paralcidia glabellus* (Leckenby) (including the holotype), *Peltoceras* (*P.*) *athleta* (Phillips) (including the neotype (Figure 5.19), and its possible microconch '*Rursiceras*' *reversus* (Leckenby)), *Pseudopeltoceras famulus* Spath (including the holotype), *P. leckenbyi* Spath (including the holotype) and possibly *Reineckeia* (*Collotia*) sp. No trace of this fossiliferous unit of the Athleta Zone can be made out at South Toll House Cliff but it can be seen again farther south at Cayton Bay (see **Gristhorpe Bay, Yons Nab and Red Cliff–Cunstone Nab** GCR site report, this volume).

There can be little doubt that the following comments made by Leckenby (1859) refer to the Athleta Zone fauna detailed above: 'on the North side of Scarborough Castle, numerous blocks of this rock [i.e. Osgodby Formation] ... formerly strewed the base ... A few years ago the surfaces of these blocks were found to consist of cherty calcareous nodules, filled with fossils, and so diligently have these been explored that now hardly a block is to be found to reward the industrious collector'. The cherty calcareous nodules are undoubtedly equivalent to Bed 5 of Wright (1968). The early removal of much of the fossiliferous

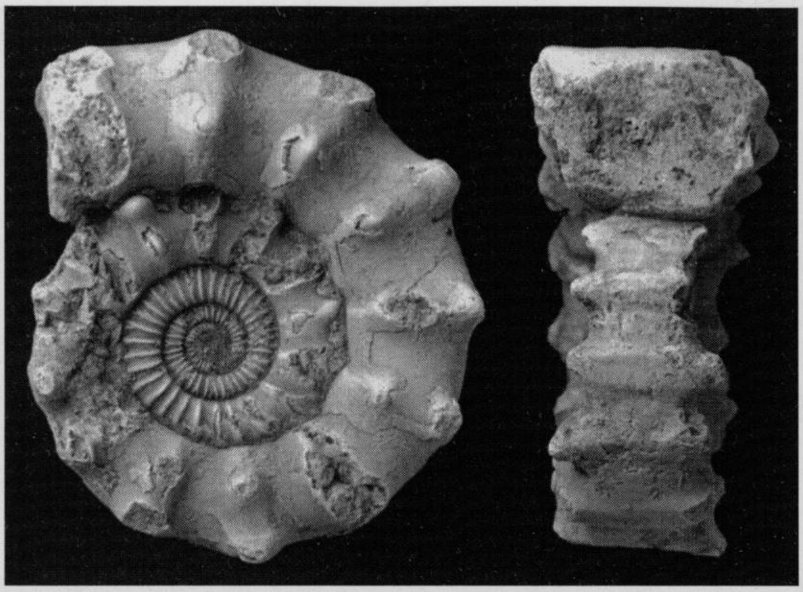


Figure 5.19 Neotype of *Peltoceras athleta* (Phillips); The Natural History Museum, London, specimen No. 89052; approximately natural size. (Photo: © The Natural History Museum.)

material would explain why it is now virtually impossible to re-collect this classic Athleta Zone fauna.

Beds 4–6 of the Hackness Rock Member at North Bay were assumed by Wright (1968) to belong to the Upper Callovian Lamberti Zone but he had no confirmatory ammonite evidence. However, the ammonite fauna recorded from the upper part of the member in the wave-cut platform at the bottom of Marine Drive is characteristic of the Lamberti Zone and Subzone. The Lamberti Zone faunas described in the past from around Castle Hill probably largely come from here and South Toll House Cliff where ammonites recorded from the Hackness Rock Member also indicate the Lamberti Zone and Subzone. They include *Alligaticeras alligatum* (Leckenby), *Euaspidoceras hirsutum* Bayle, *Peltoceras* (*Peltomorphites*) *subtense* (Bean) (possibly including the holotype), and probably *Hecticoceras* (*Putealiceras*) *puteale* (Leckenby) (including the holotype). The grey marl that overlies the Hackness Rock Member at the North Bay site could be the source of the specimen (?holotype) of *Cardioceras scarburgense* figured by Buckman (1924). At South Toll House Cliff, no diagnostic fauna has been recorded from the soft, ?silty material above the Hackness Rock Member but, by analogy with other sections, the Callovian–Oxfordian stage boundary must occur at this level.

Conclusions

The Callovian exposures of South Toll House Cliff and North Bay, Scarborough include historically important and fossiliferous sections of the Cornbrash and Osgodby formations. They are the only surviving parts of the once more extensive exposures of Callovian strata on Castle Hill, Scarborough. Many new species were established on the basis of material collected in the area prior to construction of the Marine Drive promenade and road. Even though opportunities for re-sampling are limited, access to remaining exposures is vital to re-interpretation of the stratigraphy of these early fossil collections. Important ammonite faunas are present at a number of levels and the type localities of several species are almost certainly included. North Bay is the likely source of the type material of at least three stratigraphical index species, *Macrocephalites terebratus* (Phillips) (Terebratus Subzone, Herveyi Zone), *Peltoceras athleta* (Phillips) (Athleta Zone) and the Early Oxfordian *Cardioceras scarburgense* (Young and Bird) (Scarburgense Subzone, Mariae Zone), and together, the two sites yield ammonite assemblages of both the Upper Callovian zones. Lateral variation and facies changes when compared to other localities in the district means that the sites also have a key role to play in palaeogeographical and basin evolution studies.

HACKNESS ROCK PIT, NORTH YORKSHIRE (SE 965 907)

K.N. Page

Introduction

Hackness Rock Pit (sometimes known as 'Hackness Quarry') is a small disused quarry sited on the south side of the road alongside Lowdales Beck, north-west of Hackness Hall, *c.* 7.5 km west of Scarborough, North Yorkshire. It is the type locality of the Hackness Rock Member of the Osgodby Formation and the last significant exposure within the area in which William Smith first recognized and mapped the 'Hackness Rock' (Smith, 1829, 1832; Sheppard, 1917) (Figure 5.20). The underlying Langdale Member is also exposed. William Smith lived and worked in the village of Hackness between 1828 and 1834 (Fox-Strangways, 1892; Cox, 1942), but the quarry is not marked on his geological map of the area dated 1832 (probably drawn in 1829 or 1830; see Sheppard, 1917). This was one of the earliest large-scale geological maps made in Britain and the Hackness area therefore has some significance in the history of geological science. The site, which has yielded Upper Callovian ammonite faunas of importance for international correlation, has been fully described by Wright (1968).

Description

The following description is based on Wright (1968) with additional observations by K.N. Page. The succession in the upper part of the section is now unclear because of deep weathering and vegetation.

	Thickness (m)
Osgodby Formation	
Hackness Rock Member	
6: Limestone with berthierine ooids, flaggy; poorly preserved *Quenstedtoceras*	0.30
5: Sandstone, dark-greenish, somewhat flaggy; berthierine ooids, calcareous in part; band with common *Euaspidoceras hirsutum* (Bayle) associated with *Quenstedtoceras* ex gr. *lamberti* (J. Sowerby) in upper part; otherwise rich fauna dominated by *Q.* ex gr. *lamberti* with rarer *Grossouvria* sp., *Hecticoceras* (*Putealiceras*) cf. *puteale* (Leckenby), *Kosmoceras* (*K.*) ex gr. *spinosum* (J. de C. Sowerby), *Peltoceras* (*Peltomorphites*) *subtense* (Bean) and bivalves including *Chlamys*	0.23
4: Sandstone with berthierine ooids and calcareous concretions; richly fossiliferous with *Kosmoceras* (*Lobokosmokeras*) ex gr. *proniae* Teisseyre and *K.* (*K.*) ex gr. *spinosum* (J. de C. Sowerby), less common *Grossouvria* (*G.*) *sulcifera* (Oppel) and *Hecticoceras* spp., and rare *Binatisphinctes hamulatus* (S.S. Buckman), *Chamoussetia funifera* (Phillips) and *Longaeviceras*; bivalves including *Chlamys*, *Gryphaea lituola* Lamarck and *Pleuromya*; rhynchonellid and terebratulid brachiopods; small corals	0.15
1–3: Sandstone, pale to orange-coloured, calcareous, flaggy in part; few ammonites including *Kosmoceras* (*L.*) *proniae* and *Peltoceras* sp.	1.33
Langdale Member	
Sandstone, massive, fine-grained	*c.* 4.9

Interpretation

The ammonite faunas of beds 1–3, including forms previously described as *Kosmoceras bigoti* (Douvillé) and *K. rimosum* (Quenstedt), indicate the Proniae Subzone of the Upper Callovian Athleta Zone. Most of the ammonites indicative of this zone at Hackness Rock Pit, some of which have been figured by Callomon and Wright (1989) and Cox (1988), have come from the overlying Bed 4. As here understood, *Kosmoceras* (*L.*) ex gr. *proniae* includes macroconch and microconch forms including those previously described as *K.* (*L.*) *duncani* (J. Sowerby), *K. rimosum* and *K. rowlstonense* S.S. Buckman *non* Young and Bird. *K.* (*K.*) ex gr. *spinosum* possibly includes forms previously described as *K.* (*K.*) *bigoti* (Douvillé), *K.* (*K.*) *compressum* (Quenstedt) and *K.* (*K.*) aff. *transitorius* (Nikitin), and the *Hecticoceras* spp. includes macroconch and microconch forms previously ascribed to *H.* (*Sublunuloceras*) and *H.* (*Brightia*) respectively. The *Pseudocadoceras boreale* S.S. Buckman recorded by Wright (1968) is possibly a microconch *Longaeviceras*. According to Callomon and Wright (1989), the holotype of *Chamoussetia funifera* (Phillips) came from the Athleta Zone of either Hackness Rock Pit (i.e. Bed 4 or below) or Scarborough. Many of the ammonites in Bed 4 are fragmentary, which suggests some reworking; a mixture of both Proniae and Spinosum Subzone forms appears to be present. According to Wright (1968), there is no evidence to support Arkell's (1939b) statement that the Hackness Rock extends down into the Coronatum Zone.

The ammonite fauna of Bed 5 is typical of the *lamberti* Biohorizon (Upper Callovian Lamberti

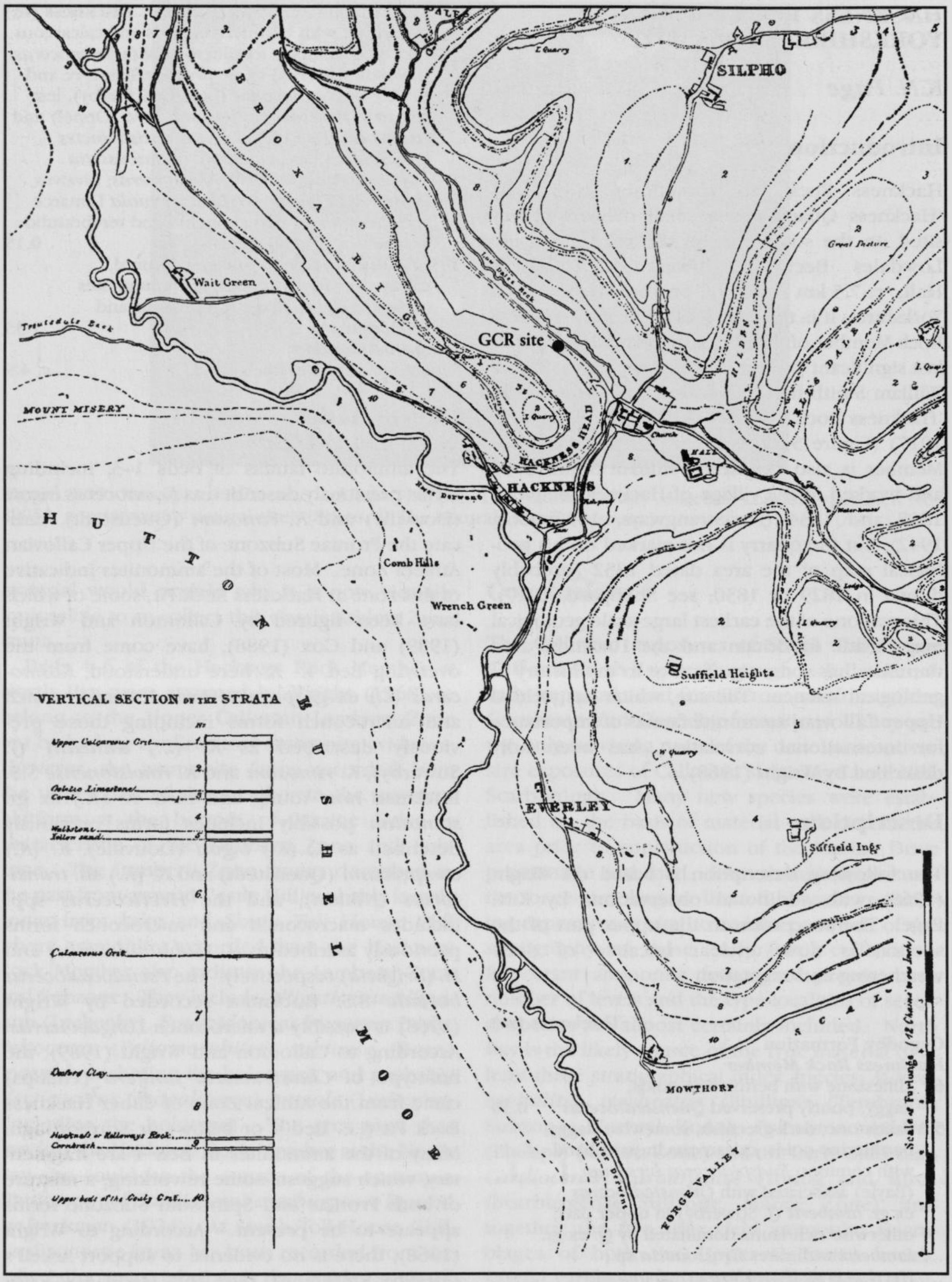


Figure 5.20 Part of the uncoloured lithograph of William Smith's map of Hackness with the location of the Hackness Rock Pit GCR site added. (Modified from Sheppard, 1917, pl. 17.)

Zone and Subzone). Callomon and Wright (1989) indicated that the type locality of *Quenstedtoceras flexicostatum* (Phillips), a microconch of *Q. lamberti*, could be Hackness Rock Pit or Scarborough but, as the preservation of the specimen is good, Hackness Rock Pit is the more likely. However, it should be noted that since the quarry that forms the GCR site is not marked on William Smith's map made in 1829 or 1830 (Sheppard, 1917), there must be some doubt about it being the source of specimens described by Phillips (1829).

Loose specimens of *Cardioceras* (*Scarburgiceras*) aff. *scarburgense* (Young and Bird) indicative of the Lower Oxfordian Mariae Zone, have been found in rubble in Hackness Rock Pit, having been washed down from the Oxford Clay Formation above Bed 6 (Wright, 1968). This suggests that excavations at the site might reveal a good Callovian–Oxfordian stage boundary section (Wright, 1968).

Conclusions

As type locality of the Hackness Rock Member of the Osgodby Formation, Hackness Rock Pit is an important lithostratigraphical reference section. The sequence of ammonite faunas here is also of significance; it is virtually the only remaining site where good Athleta Zone faunas can be collected *in situ* in the region and it also appears to show a sequence of Lamberti Subzone faunas. Indeed, further sampling may well reveal new stratigraphical information of international correlative significance including data on the Callovian–Oxfordian stage boundary.

HAVERN BECK, SALTERGATE, NORTH YORKSHIRE (SE 847 947)

K.N. Page

Introduction

Sections in the small steep-sided valley of Havern Beck, near Saltergate, North Yorkshire, expose the thickest (3.56 m) Cornbrash Formation known in the Cleveland Basin. The formation is seen particularly well in a waterfall section (Figure 5.21). The site has been reported by Fox-Strangways *et al.* (1885), Fox-Strangways (1892), Douglas and Arkell (1932), Wright (1968, 1977, 1978), Page (1988) and Riding and Wright (1989).

Figure 5.21 Havern Beck, Saltergate. The Cornbrash Formation is well exposed behind the waterfall. (Photo: K.N. Page.)

Description

The following notes, including bed notation, are based mainly on Wright (1968, 1977, 1978) and Riding and Wright (1989).

	Thickness (m)
Osgodby Formation	
Langdale Member	
γ_1: Sandstone	seen to 3.8
Redcliff Rock Member	
β_2: Sandstone with berthierine ooids	2
β_1: Sandstone, massive and flaggy; *Macrocephalites* cf. *polyptychus* (Spath) found loose	*c.* 17
Cayton Clay Formation	
Clay, shaly, bituminous; small bivalves (only traces seen)	*c.* 2.4
Cornbrash Formation	
α_3: Limestone, sandy, bioclastic; mudstone-filled burrows; *Entolium*, *Lopha marshii* (J. Sowerby), *Oxytoma*	seen to 0.75
α_2: Limestone, sandy, sideritic; burrows weathering red; bivalves (including *Entolium*, *Liostrea*, *Meleagrinella*, *Modiolus*, *Oxytoma*, *Pinna*) and the brachiopod *Microthyridina* cf. *lagenalis* Douglas and Arkell *non* Schlotheim	0.54
α_1: Limestone, sandy, hard, grey with bivalves (including *Entolium*) and serpulids	1.94
Sandstone, fine-grained, shaly; *Entolium*	0.16
Ironstone, silty, sideritic; *Meleagrinella*, *Modiolus*	0.17
Shale, grey; calcareous and sandy in upper part; brachiopod fragments	*c.* 0.9
Scalby Formation	
Siltstone, grey, sandy, burrowed	

Interpretation

Unlike the Cornbrash Formation of the Yorkshire coastal sections (see **Gristhorpe Bay, Yons Nab and Red Cliff–Cunstone Nab** GCR site report, this volume), marine beds (α_0) occur below α_1; α_2 is missing (Figure 5.22). α_0 rests on a bored erosion-surface at the top of the Scalby Formation into which clay-filled burrows extend 0.05–0.10 m (Riding and Wright, 1989). The presence of thick Cornbrash Formation was not appreciated by Douglas and Arkell (1932) who grouped the beds of α_0, which is present only in this area, with the non-marine Scalby Formation (then called the 'Upper Estuarine Series'). However, Wright (1977) demonstrated their marine character and confirmed that inclusion in the Cornbrash Formation was appropriate; he suggested that, below the main regional marine transgression represented by α_1, at least some of α_0 passed laterally into non-marine sandstones of the Scalby Formation. He concluded that the presence of this lower marine

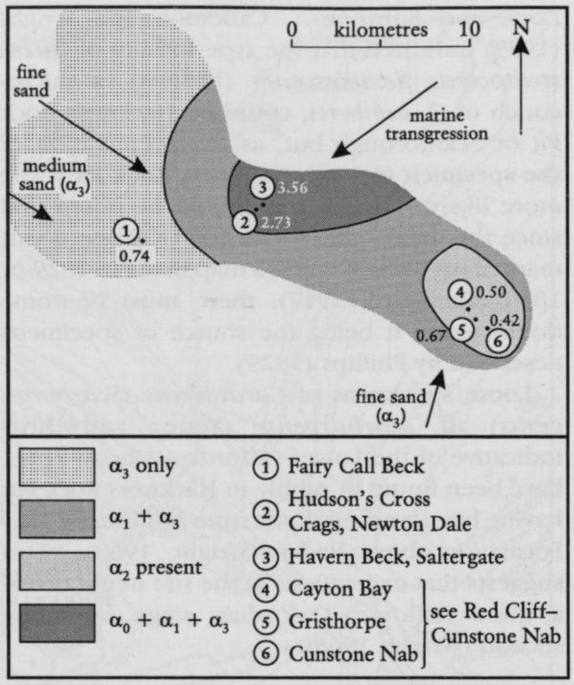


Figure 5.22 Simplified distribution map of the subdivisions of the Cornbrash Formation in the Cleveland Basin showing thicknesses (in metres) at the GCR sites. (After Wright, 1977, fig. 3.)

unit at Havern Beck was due to an earlier marine transgression into a depression in the surface of the Scalby Formation delta in the Langdale–Newton Dale area. Palynological evidence indicates that the Scalby Formation is Bathonian in age (Riding and Wright, 1989); the Cornbrash–Scalby formational boundary is therefore the Bathonian–Callovian stage boundary. The virtual absence of other age-diagnostic fossils at Havern Beck is more problematic, and it can only be assumed that α_1 and α_3 here are contemporaneous with supposed equivalent levels in the Scarborough district, to the east.

The presence of an ammonite comparable with *Macrocephalites* cf. *polyptychus* in the Redcliff Rock Member (possibly β_{1b}; see Figure 5.24, **Fairy Call Beck** GCR site report, this volume) is also problematic since this species is elsewhere typical of the underlying Cayton Clay Formation; its presence here suggests that the lowest part of the Redcliff Rock Member may well still belong to the Kamptus Subzone (Lower Callovian Herveyi Zone), i.e. be older than near Scarborough, unless erosion and redeposition is invoked. No age-diagnostic fossils have been recorded from β_2 here.

Conclusions

The GCR site at Havern Beck exposes the thickest Cornbrash Formation in northern England. The sequence includes a basal marine unit apparently of equivalent age to non-marine deposits of the Scalby Formation elsewhere in the Cleveland Basin and provides clues as to the direction of the Early Callovian marine transgression in the region.

HUDSON'S CROSS CRAGS, NEWTON DALE, NORTH YORKSHIRE (SE 838 947)

K.N. Page

Introduction

Hudson's Cross Crags (or 'Newtondale Crags'), above Talbot Wood in Newton Dale, north of Pickering, North Yorkshire, provide a key section in the Osgodby Formation of the central Cleveland Basin, as well as the underlying Cornbrash and Scalby formations, the latter of Bathonian age. There are differences between the Osgodby Formation, as developed here, and the type succession on the coast to the east (see **Gristhorpe Bay, Yons Nab and Red Cliff–Cunstone Nab** GCR site report, this volume). The GCR site is the gully in which a section representative of the Redcliff Rock Member, which forms the crags lining both sides of the valley over a distance of more than 3.2 km, was recorded by Wright (1968); although these impressive exposures are unrivalled, they are mainly inaccessible.

Description

Exposures of the Cornbrash Formation are relatively good but similar in detail to those at **Havern Beck** (see GCR site report, this volume) including the presence of α_0, which is here reduced to a thickness of 1.08 m. At the base of the Cornbrash Formation, burrows filled with sandy mudstone extend 0.05–0.10 m into the underlying Scalby Formation.

About 21 m of the overlying Osgodby Formation are exposed although the base and top of this formation are not seen in the crags; the section (based on Wright, 1968) is as follows.

	Thickness (m)
Osgodby Formation	
Langdale Member	
γ_1: Sandstone, fine- to medium-grained, flaggy in part	seen to *c.* 4.9
Redcliff Rock Member	
β_2: Sandstone, yellowish-weathering, fine grained; berthierine ooids, nests of small bivalves; *Kepplerites* (*Gowericeras*) and *Proplanulites*	*c.* 2.4
β_1: Sandstone, hard, fine-grained, pale; burrows and ripple marks; bivalves (including *Chlamys*, *Liostrea* and *Meleagrinella braamburiensis* (Phillips)) in upper part	*c.* 13.4

Interpretation

The lower boundary of the Cornbrash Formation with the underlying Scalby Formation has been investigated by Riding and Wright (1989). Their palynological evidence indicates that the Scalby Formation is Bathonian in age; the Cornbrash–Scalby formational boundary is therefore the Bathonian–Callovian stage boundary. Riding and Wright (1989) suggested that the sediments of the Scalby Formation were compacted or lithified, slightly uplifted, eroded and burrowed before the Cornbrash Formation was deposited, and that there was a steady marine transgression across this erosion surface under low-energy conditions. Comparison with the section at **Havern Beck** (see GCR site report this volume) suggests a westward spread of marine influence (see Figure 5.22).

Rare specimens of the ammonites *Kepplerites* (*Gowericeras*) and *Proplanulites* in β_2 of the Redcliff Rock Member are presumed, as elsewhere, to indicate the Curtilobus Subzone of the Lower Callovian Koenigi Zone.

Conclusions

Hudson's Cross Crags include a key inland section in the Osgodby Formation of the Cleveland Basin. The site is of particular importance in geographically linking the more complexly developed β_1 subdivision of western areas of the Cleveland Basin (e.g. **Fairy Call Beck**, see GCR site report, this volume) with the simpler succession of the Scarborough district (see **Gristhorpe Bay, Yons Nab and Red Cliff–Cunstone Nab** GCR site report, this volume). Together with **Havern Beck**, (see GCR site report, this volume), Hudson's Cross Crags provides an important Callovian reference sequence for this intermediate area, and evidence for the palaeogeography of the region at that time.

FAIRY CALL BECK, NORTH YORKSHIRE (SE 712 904)

K.N. Page

Introduction

South-westwards from Fairystones Bridge towards Hutton-le-Hole, near the southern boundary of the North Yorks Moors National Park north of Kirkbymoorside, stream sections in Fairy Call Beck reveal an intermittently exposed but virtually complete Callovian succession including fossiliferous sections in the Cornbrash, Cayton Clay and Osgodby formations. The Redcliff Rock Member of the Osgodby Formation is of particular note here, being distinct from its development in eastern areas of the Cleveland Basin (see **Gristhorpe Bay, Yons Nab and Red Cliff–Cunstone Nab** GCR site report, this volume).

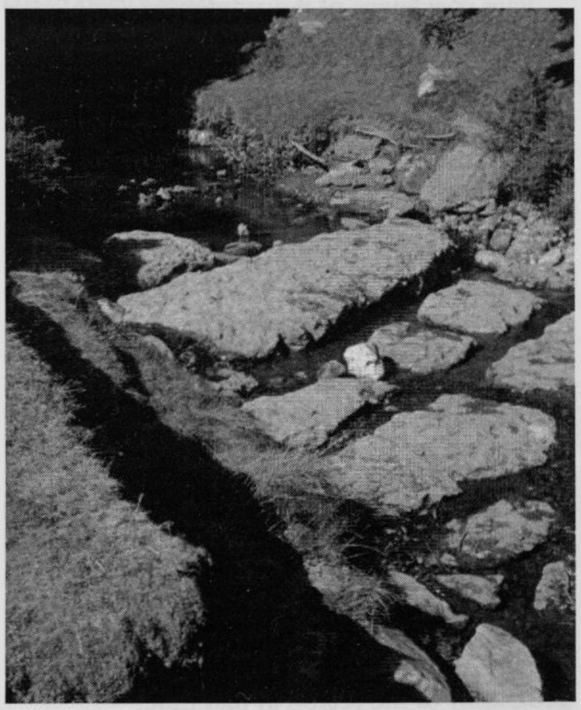
Description

The sections were described by Wright (1977, 1978) on which the following notes are largely based.

The Cornbrash Formation (*c.* 0.70 m thick) is well exposed in the stream bed immediately north of Fairystones Bridge (Figure 5.23). Its basal bed is a thin (0.15 m) flaggy and shelly siltstone resting on white clay of the Scalby Formation and passing upwards into silty limestone. *Meleagrinella* and serpulids are recorded. The overlying 0.55 m of hard limestone with bivalves (including *Lopha marshii* (J. Sowerby)) forms a ledge in the stream bed. It has recently yielded the brachiopod *Microthyridina* cf. *sublagenalis* (Davidson) and the ammonite *Macrocephalites* cf. *terebratus* (Phillips) (macroconch). Immediately above the Cornbrash Formation, traces of grey, silty shale with occasional small, round, calcareous nodules represent the Cayton Clay Formation of which *c.* 0.4 m is seen.

Intermittent exposures of the overlying Osgodby and Oxford Clay formations are present in the banks of Fairy Call Beck south-westwards from Fairystones Bridge. A composite section is given below. Bed notation for the Redcliff Rock and Langdale members follows Wright (1968, 1978).

	Thickness (m)
Oxford Clay Formation	
Shale, grey, silty	'several seen'
Osgodby Formation	
Hackness Rock Member	
Shale, sandy, calcareous; *Quenstedtoceras* aff. *brasili* (Douvillé)	0.6
Sandstone, calcareous and limestone, sandy; bivalves (including *Chlamys*) and belemnites	1.23
Langdale Member	
γ_3: Sandstone, massive, fine grained, bioturbated	*c.* 8.2
γ_2: Sandstone, flaggy, passing down into sandy shale	*c.* 4.2
Redcliff Rock Member	
β_3: Sandstone, fine grained, well bedded; *Camptonectes* and belemnites	*c.* 1.0
β_2: Sandstone, fine- to medium-grained with scattered, or sometimes concentrations of, berthierine ooids; very fossiliferous towards top; *Chlamys*, *Liostrea*, *Meleagrinella*, belemnites and occasional *Kepplerites* (*Gowericeras*)	*c.* 1.6
β_{1d}: Sandstone, mainly massive, fine- to medium-grained, with large calcareous concretions in lower part; fossils in upper part including bivalves ('*Astarte*', *Camptonectes*, *Gervillella*, *Liostrea*, *Meleagrinella*, *Myophorella*) and belemnites	*c.* 6.7
β_{1c}: Sandstone, fine grained with clay laminae and partings	5.0
β_{1b}: Sandstone, tough, laminated, fine- to medium-grained; moulds of large belemnites; *Liostrea*, *Meleagrinella*	0.38
β_{1a}: Sandstone, soft, muddy, fine grained	seen to 0.9



◂**Figure 5.23** Stream-bed exposure of the Cornbrash Formation in Fairy Call Beck near Fairystones Bridge. (Photo: K.N. Page.)

Interpretation

The sections in Fairy Call Beck probably represent the most continuously exposed Callovian succession in the western Cleveland Basin and are important reference sections for regional correlation. The succession shows significant differences from that of the eastern Cleveland Basin, and attempts at correlation between the two areas often remain inconclusive.

Wright (1977) considered that the Cornbrash Formation was not easily proved to be either α_1 or α_3 of the standard subdivisions recognized in the Scarborough district coastal sections (see **Gristhorpe Bay, Yons Nab and Red Cliff–Cunstone Nab** GCR site report, this volume) but he preferred to classify them as α_3, which he believed overlapped α_1 in this area. The more recent ammonite and brachiopod records reported above indicate the Terebratus Subzone of the Lower Callovian Herveyi Zone.

The exposures of the Redcliff Rock Member were taken by Wright (1978) as a standard for the correlation of subdivisions within β_1 in the western Cleveland Basin (Figure 5.24). The presence of common belemnites in β_2 is unusual

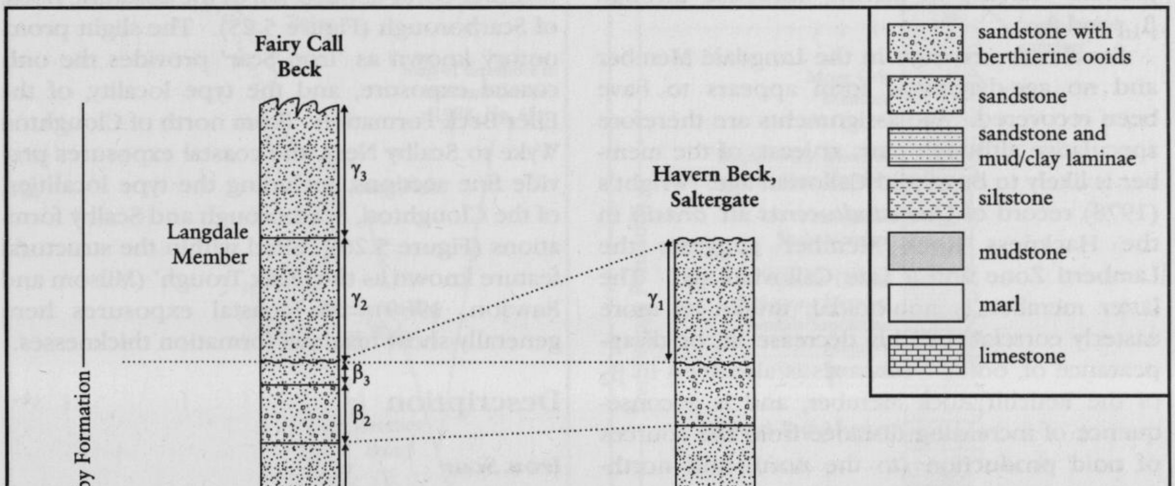


Figure 5.24 Correlation between the sections at Fairy Call Beck and **Havern Beck**. (After Wright, 1978, fig. 2.)

for this stratigraphical level in Britain, as are the large guards in β_{1b}, but these may have been concentrated by sedimentological processes. The record of occasional *Kepplerites* (*Gowericeras*) sp. probably indicates the Curtilobus Subzone of the Lower Callovian Koenigi Zone as in the eastern part of the Cleveland Basin; however, this needs confirmation based on a re-examination of the few recovered ammonites. According to Wright (1978), the overall general pattern of sedimentation in the Redcliff Rock Member consists of the establishment of fully marine conditions early on (β_{1b}) followed by brackish-water marine conditions (β_{1c}) and a gradual increase in marine influence through β_{1d} and β_2.

Fossils are very rare in the Langdale Member and no age-diagnostic form appears to have been recovered. Age assignments are therefore speculative although part, at least, of the member is likely to be of Mid Callovian age. Wright's (1978) record of *Quenstedtoceras* aff. *brasili* in the Hackness Rock Member suggests the Lamberti Zone and a Late Callovian age. The latter member is non-ooidal, unlike its more easterly correlatives; this decrease in, or disappearance of, ooids westwards is also seen in β_2 of the Redcliff Rock Member, and is a consequence of increasing distance from the sources of ooid production (to the north and north-east).

The basal Langdale Member (γ_2) in Fairy Call Beck represents a transgressive phase (γ_1 is absent), and the nature of the sediments is compatible with those fringing a delta, which would possibly have been sited to the north-west of Fairystones Bridge (Wright, 1978). The Hackness Rock Member indicates a period of reduced sedimentation with condensed sequences, prior to rapid subsidence and deposition of the Oxford Clay Formation of presumed Early Oxfordian age.

Conclusions

Fairy Call Beck is a key reference section for the Callovian succession of the western Cleveland Basin showing a complete succession including the Cornbrash, Cayton Clay and Osgodby formations. The exposure of the Redcliff Rock Member here is the most complete and fossiliferous in the area. The fossils that have been recorded aid regional stratigraphical correlation as well as palaeoenvironmental analysis.

IRON SCAR–HUNDALE AND HUNDALE POINT–SCALBY NESS, NORTH YORKSHIRE (TA 017 964, TA 020 957–TA 027 945, TA 023 949–TA 037 908)

B.M. Cox

Introduction

The two sites known as 'Iron Scar–Hundale' and 'Hundale Point–Scalby Ness', assigned respectively to the Aalenian–Bajocian and Bathonian GCR blocks, overlap at Hundale Point and, apart from a *c.* 600 m stretch to the south of Iron Scar, together cover about 5 km of the coastline north of Scarborough (Figure 5.25). The slight promontory known as 'Iron Scar' provides the only coastal exposure, and the type locality, of the Eller Beck Formation. From north of Cloughton Wyke to Scalby Ness, the coastal exposures provide fine sections, including the type localities, of the Cloughton, Scarborough and Scalby formations (Figure 5.26). Sited within the structural feature known as the 'Peak Trough' (Milsom and Rawson, 1989), the coastal exposures here generally show maximal formation thicknesses.

Description

Iron Scar

The following section is taken from manuscript notes supplied by Dr R.W.O'B. Knox (BGS). The subdivision into units follows Knox (1973).

	Thickness (m)
Eller Beck Formation (overlain by **Cloughton Fm**)	
'*Upper sandstone unit*': Sandstone, flat bedded; top penetrated by rootlets; some surfaces with symmetrical ripple-marks	1.68
'*Lower sandstone unit*'	
Sandstone, thin bedded, intercalations of silty shale and beds of impersistent, silty, siderite mudstone; occasional shelly bands	1.83
Sandstone, thin bedded, laminated; interbedded with silty shale and ironstone	0.56
'*Shale unit*': Shale, silty; laminae of fine sand in upper part; shell casts in lower part	1.22
'*Ironstone unit*': Ironstone, ooidal siderite mudstone; scattered fossils; ironstone-filled burrows, including *Diplocraterion* and *Rhizocorallium*, at base	up to 0.08
Saltwick Formation	
Siltstone-shale, pale-grey, delicately laminated; comminuted plant-material; very small '*Rhizocorallium*' burrows, occasional runnels; rare bivalves seen on base of some runnel casts	1.68
Mudstone, poorly laminated; some sphaerosiderite	–

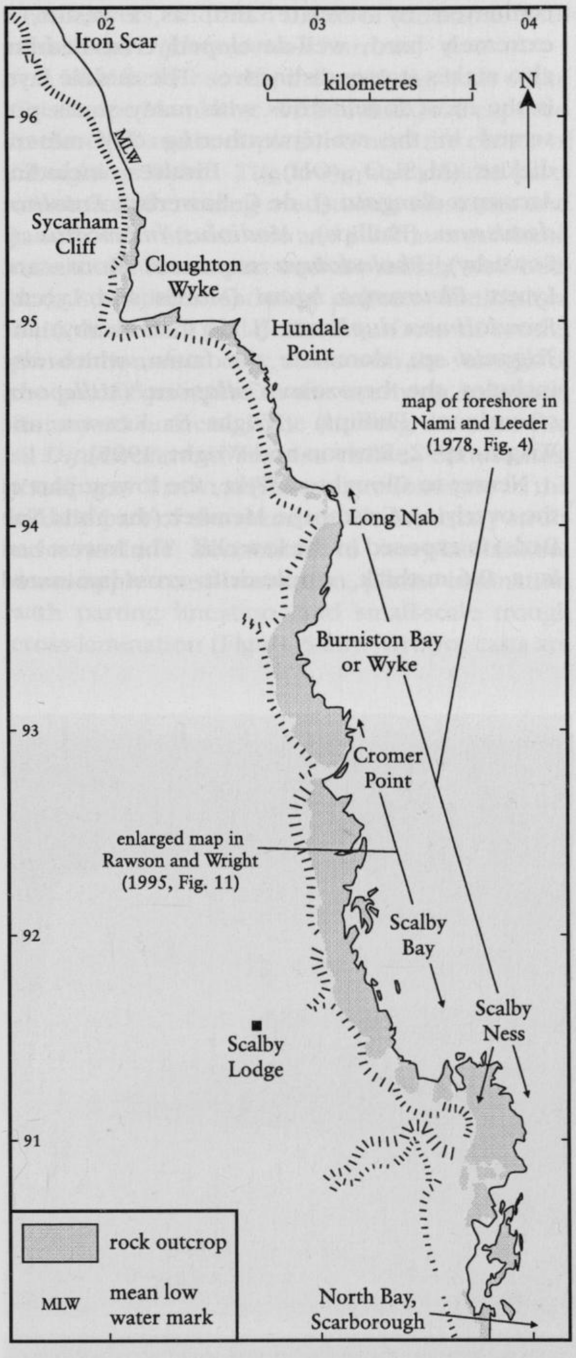


Figure 5.25 Locality map for Iron Scar–Hundale and Hundale Point–Scalby Ness.

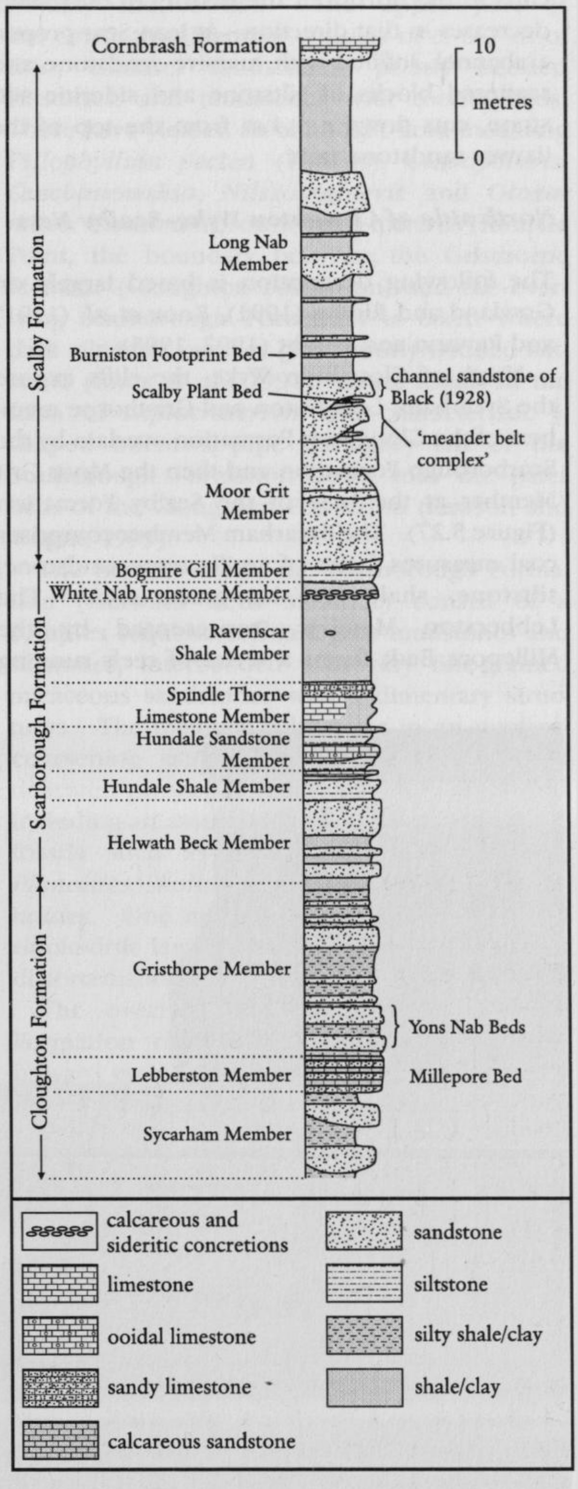


Figure 5.26 Graphic section of coastal exposures between Cloughton Wyke and Scalby Ness. (After Rawson and Wright, 1995, fig. 9.)

Similar sections are exposed in places in the cliffs to the north but the density of burrowing decreases in that direction. At Iron Scar proper, a channel, infilled with massive sandstone and scattered blocks of siltstone and sideritic siltstone, cuts down *c.* 1.4 m from the top of the 'Lower sandstone unit'.

North side of Cloughton Wyke–Scalby Ness

The following description is based largely on Gowland and Riding (1991), Knox *et al.* (1991) and Rawson and Wright (1992, 1995).

North of Cloughton Wyke, the cliffs expose the Sycarham, Lebberston and Gristhorpe members of the Cloughton Formation overlain by the Scarborough Formation and then the Moor Grit Member at the base of the Scalby Formation (Figure 5.27). The Sycarham Member comprises coal measures facies of argillaceous sandstone, siltstone, shale and low-grade coal. The Lebberston Member (represented by the Millepore Bed) forms a series of reefs running south-eastwards out to sea. It consists of three layers, each representing a coarsening-upwards cycle with sandy limestone passing up into shelly, calcareous sandstone. The top layer is cemented by siderite and, as a result, is extremely hard; well-developed cross-bedding also makes it very distinctive. The middle layer is the most fossiliferous with many shells preserved in the white-weathering clay mineral dickite ($Al_4Si_4O_{10}(OH)_8$). Bivalves, including *Arcomya elongata* (J. de C. Sowerby), *Entolium demissum* (Phillips), *Modiolus imbricatus* (J. Sowerby), *Pholadomya saemanni* Morris and Lycett, *Pleuromya beani* (Morris and Lycett), *Pseudolimea duplicata* (J. de C. Sowerby) and *Trigonia* sp., dominate the fauna, which also includes the bryozoan *Collapora* (*Millepora*) *straminea* (Phillips) (Wright in Rawson and Wright, 1992; Rawson and Wright, 1995).

Nearer to Cloughton Wyke, the lowest part of the overlying Gristhorpe Member (the Yons Nab Beds) is exposed in the low cliff. The lowest bed is a 0.6 m-thick, ripple-drift cross-laminated

Figure 5.27 Cloughton Wyke and cliffs from Hundale Point; the cliff in the foreground is Moor Grit Member, the reefs on the right Scarborough Formation. The reefs at the projecting headlands in the distance are formed by the Millepore Bed (Lebberston Member) and Eller Beck Formation. (Photo: British Geological Survey, No. A5494, 1931.)

sandstone, which is overlain successively by 1.6 m of flaser-bedded, shaly sandstone with numerous bivalves including oysters, pectinids and *Trigonia*, 1 m of shale with coaly, carbonaceous layers, and then 2.6 m of sandstone with occasional *Diplocraterion* burrows.

A little farther south, the overlying beds of the Gristhorpe Member, *c.* 12.5 m thick, are exposed in the cliffs and rock platform near the centre of Cloughton Wyke. The lower and middle parts consist of alternating mudstones, siltstones and sandstones. Mudstones and siltstones predominate in the lower part and are mostly well bedded, sometimes showing delicate lamination. Thin coals and well-defined surfaces of rootlet penetration also occur, some with the vestiges of the plant *Equisetites* in the overlying sediment. Burrowed surfaces, some showing the trace fossil *Diplocraterion*, are also visible. Sandstones, totalling *c.* 2 m in thickness, predominate in the middle part of the member. Sedimentary structures include horizontal- to wavy-lamination, wave-ripple cross-lamination, planar lamination with parting lineation, and small-scale trough cross-lamination (Figure 5.28). Groove casts are present on the base of some sandstone sheets, notably the lowest. The upper part of the Gristhorpe Member consists of *c.* 6–7 m of thin, channel sandstones, poorly bedded siltstones, and mudstones with rootlet beds. These have yielded an abundant flora including *Ptilophyllum pecten* (Phillips), *Cladophlebis*, *Czechanowskia*, *Nilssoniopteris* and *Otozamites*. Continuing southwards towards Hundale Point, the boundary between the Gristhorpe Member (Cloughton Formation) and the overlying Scarborough Formation is taken where dark siltstone overlies grey, poorly bedded siltstone (Knox *et al.*, 1991). Trace fossils in the form of *Diplocraterion* and characteristic J-shaped burrows pipe dark-grey silt of the Scarborough Formation down into the paler beds of the Cloughton Formation (Rawson and Wright, 1995).

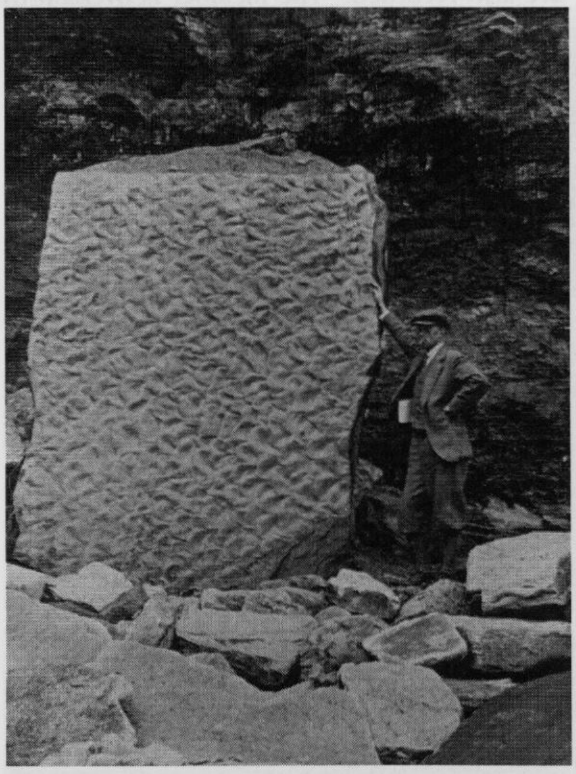


Figure 5.28 Ripple-marked sandstone (Gristhorpe Member), north side of Cloughton Wyke. (Photo: British Geological Survey, No. A5497, 1931.)

The basal 7.6 m of the Scarborough Formation (Helwath Beck Member) consist of a complex sequence of dark-grey mudstones and siltstones, interbedded with very fine-grained micaceous sandstones with sedimentary structures. The member culminates in an upward-coarsening sandstone showing a variety of delicately preserved sedimentary structures, and including an assemblage of well-preserved trace fossils such as *Arenolites*, *Diplocraterion*, *Planolites*, *Skolithos*, *Teichichnus* and *Thalassinoides*. One metre above the base, a bed of ripple-drift laminated sand has been intensely distorted and 'balled up'.

The overlying beds of the Scarborough Formation comprise a series of coarsening-upward cycles, with residual primary sedimentary structures, capped by a thick mudstone sequence that becomes increasingly silty with thin sandy layers. Following Parsons (1977b) as amended by Gowland and Riding (1991), these beds are divided into six members: from below, Hundale Shale, Hundale Sandstone, Spindle Thorn Limestone, Ravenscar Shale, White Nab Ironstone and Bogmire Gill. The measured section with numbered beds of Parsons (1977b), who included informal bed names based on Hudleston (1874), has been largely superseded by descriptions of the section based on more recent detailed sedimentological work and sequence stratigraphical studies (notably Gowland and Riding, 1991); the latter authors featured a graphic log showing details of the sedimentary structures, trace fossils, bivalves, palynomorphs and lithostratigraphy, as well as the biostratigraphical classification and deduced depositional environments.

The Hundale Shale Member, totalling 2.64 m, is seen best in the upper rock platform between Hundale Scar and Hundale Point. The lower and greater part (2.11 m) of the member is a dark-grey siltstone that coarsens upwards into discontinuous, partially calcite-cemented, silty, fine- to medium-grained sandstone centimetre-scale stringers. It has a trace-fossil assemblage dominated by *Planolites*, *Teichichnus* and *Thalassinoides*; sand-filled burrows of *Thalassinoides* are prominent in the upper part, together with rare cidarid echinoids. Bivalves include abundant *Gervillella scarburgensis* (Paris) as well as *Camptonectes laminatus* (J. Sowerby), *Meleagrinella lycetti* (Rollier) and *Nanogyra nana* (J. Sowerby). *Gresslya abducta* (Phillips) and *Pleuromya uniformis* (J. Sowerby) can be seen in life position at the top of this unit, which is strongly bioturbated and overlain by an iron-rich calcareous mudstone that weathers red ('Lower Iron Scar'). The latter is 0.41 m thick and includes an additional bivalve fauna of *'Astarte' minima* Phillips, *Plagiostoma rodburghensis* (Whidborne) and *Pholadomya* sp., as well as the gastropods *Alaria* cf. *unicarinata* Hudleston, *A.* cf. *praelonga* Hudleston, *Melanioptyxis* cf. *altararis* Cossmann, *Natica adductor* Phillips, *Nerinea cingenda* Phillips and *Procerithium vetustum* Phillips, echinoderm debris and serpulids. The uppermost part of the member is a 0.12 m-thick, dark-grey, poorly fossiliferous, carbonaceous siltstone.

The overlying Hundale Sandstone Member comprises two coarsening-upward siltstone–sandstone sequences with an intervening thin, red-weathering shale–mudstone couplet containing *'Astarte' minima*, *Camptonectes laminatus*, *Meleagrinella lycetti* and *Nanogyra nana*. The lower siltstone–sandstone (2.01 m thick) is thin-bedded and flaggy with ripple forms and abundant trace fossils including *Asterosoma*, *Chondrites*, *Diplocraterion*, *Planolites*, *Rhizocorallium*, *Selichnites*, *Teichichnus* and *Thalassinoides*. The upper unit is more massive with hummocky cross-stratification, scour surfaces and shell lags, and a well-preserved trace-fossil assemblage including *Rhizocorallium*, *Teichichnus* and *Thalassinoides*. The member is capped by a coarse, shelly, calcareous sandstone packed with serpulids, bivalves, echinoderm fragments and belemnites.

The Spindle Thorn Limestone Member, *c.* 3.67 m thick, is well exposed in the base of the cliff. It comprises three poorly defined, coarsening-upward sequences; the coarsening largely reflects an increase in shell-debris content. Many of the fossil taxa recorded in the underlying members are present, together with the bivalves *Isognomon* sp., *Modiolus imbricatus*, *Myophorella signata* (Agassiz), *Pinna beani* Cox and Arkell, *P. cuneata* Phillips, *Protocardia* sp., *Pseudolimea* aff. *duplicata* and *Quenstedtia* sp., some in growth position. The belemnite *Megateuthis* is common but the ammonites *Dorsetensia* and *Stephanoceras* occur only rarely. Gastropods, echinoid spines and crinoid columnals are also present with the trace fossils *Teichichnus* and *Thalassinoides*, and less abundant *Rhizocorallium* and *Skolithus*.

The overlying Ravenscar Shale Member is also well exposed in the base of the cliff. It comprises 8.1 m of mid- to dark-grey, shaly siltstones with numerous ammonites, including *Dorsetensia* and *Stephanoceras*, and a relatively low-diversity bivalve fauna of which *Meleagrinella lycetti* is by far the most abundant. The belemnite *Megateuthis* and small colonies of serpulids are also recorded. The member is overlain by bioturbated, silty sandstones and sandy siltstones, with the bivalves *Gervillella scarburgensis*, *Meleagrinella lycetti* and *Liostrea*, followed by sideritic siltstone capped by nodular siderite. The latter contains bivalves and gastropods, and the ammonite *Teloceras*. These beds comprise the White Nab Ironstone Member, which here totals 1.33 m in thickness.

The Bogmire Gill Member is the final part of the Scarborough Formation with a preserved thickness of 2.5 m beneath the transgressive base of the Moor Grit Member of the overlying Scalby Formation. It comprises a single coarsening-upward sequence grading from micaceous, sandy siltstone to fine-grained sandstone. Trace fossils, including *Chondrites*, *Skolithos* and *Teichichnus*, are predominant.

The Scarborough Formation disappears rapidly southwards beneath beach level, and from Hundale Point to Scarborough, the cliffs and rock platform are composed of sandstones, ironstones and shales of the Scalby Formation. The fine- to coarse-grained sandstones of the Moor Grit Member (*c.* 10 m thick) form the cliff throughout much of the bay immediately south of Hundale Point to Long Nab. They display a wide variety of sedimentary structures including spectacular giant sets of large-scale trough cross-stratification up to 10 m thick, and are rich in coalified plant remains with subordinate charcoal fragments (Cope, 1993). According to Knox *et al*. (1991), detailed analysis of the basal sandstones of the Scalby Formation shows that they can be divided into three units: the lowest comprises mud-free sandstone with medium- to large-scale cross-stratification; the middle unit comprises sandstone with a basal muddy layer and with muddy laminae and medium-scale cross-stratification; and the uppermost unit comprises extremely muddy sandstone or siltstone with medium-scale cross-bedding or, locally, horizontal bedding, and with abundant soft-sediment deformation in the muddier sets. This uppermost unit marks the base of the Long Nab Member of Leeder and Nami (1979); the latter is exposed in the cliff section from the south side of Long Nab into Burniston Bay (or Wyke) and in spectacular foreshore exposures there. Above this basal sandstone unit, the overlying beds of the Long Nab Member comprise 2–3 m of grey clay with some dark, carbonaceous beds full of flattened plant-stems; rootlets penetrate the underlying sandstone. In both clay and sandstone, sideritization is intense, with large sideritic concretions and beds of sphaerosiderite. The clays are overlain by thin, level-bedded alternations of sandstone and silty clay and with localized channel-fills first described by Black (1928, 1929). In many places in the cliffs, the level-bedded strata are seen to pass laterally into strongly cross-bedded channel sandstones with the channels frequently cutting right through to the underlying clays. Above the rock platform, near the centre of the bay, and just above the level at which channels are developed, casts of dinosaur footprints (Figure 5.29) are preserved in a bed of silty sandstone (Burniston Footprint Bed), which forms an overhanging ledge at Burniston Steps (Hargreaves, 1913, 1914; Fox-Strangways and Barrow, 1915). Towards the southern end of the bay and about 3 m above the Footprint Bed, there is a 0.9 m-thick bed of well-sorted, ripple-drift laminated, fine-grained sandstone; the lower surface reveals numerous infilled burrows and the upper surface, numerous rootlets. Followed south-eastwards and near where this bed wedges out,

Figure 5.29 Dinosaur footprint in the Burniston Footprint Bed. (Photo: D.N. and J.K. Wright; reproduced with permission of the Geologists' Association.)

its base reveals spectacular infilled, slightly sinuous, U-shaped scour channels or gutter marks, at least 7 m long and 0.10 m deep, running parallel to the cliff. At Cromer Point, at the southern end of Burniston Bay, the sea has cut a natural arch through a massive channel sandstone that shows well-defined lateral accretion sets and abundant well-developed mudstone rip-up clasts; the sandstone passes laterally and rapidly into laminated siltstones and sandstones.

The basal sandstones of the Long Nab Member are again well exposed, dipping southwards, in the rock platform in Scalby Bay (Figure 5.30), to the south of Cromer Point. In the centre of Scalby Bay, they are seen in a 180° sweep across the rock platform with cross-bedding dips swinging round from north-east through south-west to south-east. The cliffs expose a series of small, sand-filled channels stacked one above the other, some choked with the carbonized remains of tree trunks, and with much slumping. Near high water mark in the rock platform north-east of Scalby Lodge, a 10 m-long trail of dinosaur footprints is exposed, having been revealed by the selective erosion of the overlying argillaceous sandstone (Delair and Sarjeant, 1985, fig. 3). At Scalby Ness, the gentle seaward dip carries the overlying silty shales of the Long Nab Member into the base of the cliff. These constitute the Scalby Plant Bed (Black, 1929), which yields relatively abundant well-preserved leaves of *Ginkgo huttoni* (Sternberg) (Rawson and Wright, 1992). A borehole (TA 0363 9108) drilled at Scalby Ness for the Yorkshire River Authority cored, beneath 17.8 m of Quaternary deposits, *c.* 27.5 m of Scalby Formation, on *c.* 21 m of Scarborough Formation, on *c.* 37 m of Cloughton Formation. Drilling terminated within the Sycarham Member and it is estimated that at least a further 40 m of Ravenscar Group underlie the site (Lott and Humphreys, 1992).

Interpretation

The coastal sections described above expose a large part of the predominantly non-marine Ravenscar Group in which the Eller Beck Formation, Lebberston Member and Scarborough Formation represent three separate marine intervals. Phillips (1829) and Fox-Strangways (1892) speculated that the non-marine beds were of estuarine origin, but Kendall and Wroot (1924) and Black (1928, 1929), suggested a

Figure 5.30 Scalby Bay foreshore showing 'meander-belt complex' of the Long Nab Member. (Photo: J.K. Wright; reproduced with permission of the Geologists' Association.)

deltaic origin. Since then, the depositional environment of these beds has been the subject of much discussion mainly centred on whether they represented the deposits of a delta or coastal alluvial-plain (Alexander, 1989 and references therein). Features interpreted as characteristic of both these environments are recognized, as summarized by Rawson and Wright (1992). Coarsening-upwards cycles of bioturbated, laminated, intertidal siltstones with crevasse-splay sheet sandstones, succeeded by rapidly filled distributory channels with slumps and water-escape structures suggest a deltaic origin; meandering streams, floodplains with desiccation cracks and footprint trails, lakes with beds of the bivalve *Unio*, marsh deposits, fossil soils with rootlet beds and the extensive development of sphaerosiderite suggest an alluvial origin. Rawson and Wright (1992) concluded that the overall evidence suggests that following each marine interval, there was rapid development of small prograding deltas, deposited by rivers flowing from the north, which ultimately coalesced into a large coastal alluvial-plain close to sea level and susceptible to marine influence; there is no evidence of a large single river-system feeding into a large delta (Alexander, 1986, 1987; Rawson and Wright, 1995). The marine incursions represented by the Eller Beck and Scarborough formations are thought probably to have come from the east or south-east, and that represented by the Lebberston Member, probably came from the shelf to the south (Knox, 1973; Parsons, 1977b; Rawson and Wright, 1992).

The bulk of the Saltwick Formation, the top of which is seen beneath the Eller Beck Formation at Iron Scar, consists of fluvio-deltaic deposits including lacustrine, levee, crevasse-splay and mudcracked overbank sediments as well as channel sandstones; thick roots mark periods of major plant colonization, especially near the base (Livera and Leeder, 1981). The formation shows an upward transition from a well-drained floodplain complex with major bedload channels to a saturated marsh drained by smaller mixed load channels suggestive of a gradual abandonment of a delta lobe with time. According to Livera and Leeder (1981), sedimentation in the overlying Eller Beck Formation evidently occurred as a prograding strand line with deposition by wave and tidal currents. Bioturbation is common in the middle parts of the sandstone suggesting that wave energy was moderated by the shallow water-depths (6–7 m) over the marine platform. The top of the sandstone was densely colonized by plants, which mark the return to non-marine sedimentation. The section at Iron Scar is the type locality of the formation (Hemingway and Knox, 1973; Knox, 1973).

The Cloughton Formation comprises coal-measure facies cut by channel sandstones but these do not show the vertical passage seen in the Saltwick Formation and described above (Rawson and Wright, 1995). The Lebberston Member (represented by the Millepore Bed) generally rests with a sharp, erosive base on the underlying fluvio-deltaic Sycarham Member, the type locality of which is at Sycarham Cliff (TA 021 957) (Hemingway and Knox, 1973). North of Cloughton Wyke, the Millepore Bed was probably deposited as a southerly migrating strand line. At Cloughton Wyke, a hardground is overlain by storm-derived conglomerate with beach deposits above and below (Livera and Leeder, 1981). According to these authors, the Yons Nab Beds at Cloughton Wyke, which overlie the Millepore Bed, are now taken to comprise the basal part of the Gristhorpe Member rather than the upper part of the Lebberston Member (following Knox in Rawson and Wright, 1995; see **Gristhorpe Bay, Yons Nab and Red Cliff–Cunstone Nab** GCR site report, this volume); they seem to represent part of a prograding system of sand ridges separated by silt-dominated lagoonal deposits. The low level of bioturbation suggests medium wave energy, whilst the minor tidal channel at Cloughton Wyke and lack of major washover sandstones suggests that the environment was influenced by both tides and waves, neither of which was dominant. The thin coal with poor root foundation, seen in the basal dark shales of the Gristhorpe Member at Cloughton Wyke, was probably formed by drifted plant input into standing water; this and the overlying siltstones and sandstones represent a continuation of the lagoonal environments proposed for the Yons Nab Beds. Sheet sands and sandstones of crevasse-splay origin, which dominate the middle part of the overlying fluvio-deltaic sequence of the Gristhorpe Member, extend over hundreds of metres. They overlie lacustrine, plant-rich sediments and are themselves cut into by later channel sandstones (Livera and Leeder, 1981); they appear to have been immediately colonized after deposition by plants.

The overlying Scarborough Formation is the highest and best-developed marine sequence in the Ravenscar Group. Detailed work by Gowland and Riding (1991) and Knox *et al.* (1991) has suggested the depositional environments represented by the different members. The Helwath Beck Member is believed to represent fair-weather, and storm, sedimentation (Knox *et al.*, 1991) in an increasingly shallow (possibly <4 m deep), brackish-water, marine embayment open to the east; its sedimentary structures are wave-induced. The 'balled up' bed of ripple-drift laminated sand near its base is a widespread horizon of soft-sediment deformation that can be traced northwards for more than 5 km and which was probably caused by seismic shock (Livera, 1981; Gowland, 1987; Gowland and Riding, 1991). The overlying Hundale Shale Member represents a nearshore siliciclastic shelf shoal and the top beds a muddy carbonate, shallow-marine shelf environment. Hummocky cross-stratification, scour surfaces and shell lags in the upper part of the overlying Hundale Sandstone Member indicate deposition from powerful, episodic storm-driven flows and, in general, a vertically accreted inner-shelf sand-shoal. The abundance of inferred stenohaline fossils, such as crinoids and belemnites, in the top sandstone unit, suggests deposition in an open marine shelf setting for at least the uppermost part of the member. Elsewhere, crinoids are common throughout this member, which is why it was originally called the 'Crinoid Grit' (Richardson, 1911c). The fossil assemblage combined with the presence of silt and clay in the overlying Spindle Thorn Limestone Member suggests deposition in a shallow-marine setting transitional between a siliciclastic coastal system and an open carbonate shelf, but the coastline probably lay outside the confines of the present outcrop. The presence of ammonites in the Ravenscar Shale Member is thought to indicate deposition in an open marine setting, although Gowland and Riding (1991) suggested that the low-diversity bivalve fauna indicated physiological stress, with low oxygen levels, in the sea-floor community. The association of ammonites, bivalves, gastropods, echinoderms and serpulids in the White Nab Ironstone Member is sufficient to suggest a relatively open shallow-marine shelf depositional environment. Gowland and Riding (1991) felt that Leeder and Nami (1979) had convincingly attributed the typical coarsening-upward sequence seen in the Bogmire Gill Member to the progradation of a wave-dominated sandy shoreface, and that eastward progradation of the shoreface was indicated by the fact that the member conformably overlies the Ravenscar Shale Member in the western part of the Cleveland Basin, but is conformable on the White Nab Ironstone Member in coastal outcrops (Gowland, 1987; Gowland and Riding, 1991). At Hundale Point, type locality of the Scarborough Formation (Hemingway and Knox, 1973), the fluvial channel sandstones of the Moor Grit Member of the Scalby Formation, with a basal erosion surface, overlie the progradational wave-dominated shoreface deposits of the Bogmire Gill Member. Since recent palynological analyses fail to support a significant time gap at the contact (Riding and Wright, 1989), Gowland and Riding (1991) thought it attractive to interpret the Bogmire Gill Member as representing the wave-dominated coastal fringe of a Scalby Formation delta lobe.

There has been considerable speculation about the depositional environments of the Scalby Formation, the type locality of which is at Scalby Cliff (TA 031 924) (Hemingway and Knox, 1973). Black (1929) suggested that the Moor Grit Member represented the foreset deposits of a prograding delta-front, and that the overlying level-bedded, finer-grained sediments of the Long Nab Member represented a delta-top environment, but Nami and Leeder (1978) proposed a predominantly alluvial model with the Moor Grit Member representing the channel-fills of a braided river-system. The basal beds of the Long Nab Member, which are spectacularly exposed on the foreshore of both Burniston and Scalby bays, are interpreted as a meander belt complex crossing an alluvial plain. A map of the meander belt channels in Scalby Bay, based on field mapping by J.K. Wright in 1969, is included in Rawson and Wright (1992, 1995) and another, between Long Nab and Scalby Ness, is included in Nami and Leeder (1978). Fisher and Hancock (1985) believed that Leeder and Nami's (1979) interpretation of these beds as an 'uplifted fluvial sequence' was not tenable and that the Scalby Formation was deposited in an overall delta-plain setting with saline interdistributary environments. They believed the Moor Grit Member to represent a deltaic distributary system and that the Long Nab Member was also dominated by similar saline-influenced delta-plain deposition with smaller, variably sinuous distributary channels, some of which may have been tidal. According to Hancock and Fisher (1981), the delta front lay to the south-east, and is seen in offshore well sections. Cromer Point and Long Nab are formed of isolated channel sandstone bodies.

The plants of the Scalby Plant Bed, which occurs close above the 'meander belt complex', are believed to be drifted rather than *in situ*, in contrast to those of the Gristhorpe Plant Bed (see **Gristhorpe Bay, Yons Nab and Red Cliff–Cunstone Nab** GCR site report, this volume). According to Black (1929), the plants are often fragmentary and large pieces of delicate fronds are never found; the plants are spread out fairly evenly along the bedding planes, and there is no evidence of roots or of a seatearth. Both Cloughton Wyke and Scalby Ness feature as sites in the GCR Mesozoic Palaeobotany Block (Cleal *et al.*, 2001). A little higher in the succession, the Burniston Footprint Bed is a sheet sandstone thought by Knox *et al.* (1991) to represent the invasion of a shallow lake by sandstone brought in by unidirectional sheet flow. Desiccation cracks, groove casts and climbing ripples are well displayed. The dinosaur footprints were made in soft, silty clay and subsequently infilled by a gentle incursion of silt and sand that preserved the footprints as moulds (Rawson and Wright, 1995).

Dating of the succession is dependent on ammonite faunas in the Scarborough Formation and palynomorphs in the Scalby Formation. The age of the exposed succession is constrained by reliable dating elsewhere of the Dogger Formation as Aalenian in age (Opalinum–Murchisonae zones) and the Cornbrash Formation as Early Callovian in age (Herveyi Zone, Terebratus Subzone). The only well-dated horizon within the Ravenscar Group is the Scarborough Formation where species of the ammonite *Dorsetensia* from the Ravenscar Shale Member include *D.* aff. *deltafalcata* (Quenstedt), *D. liostraca* S.S. Buckman and *D. romani* (Oppel) indicative of the Lower Bajocian Humphriesianum Zone, Romani Subzone. The highest part of the member has yielded *Stephanoceras* and *S.* (*Normannites*) suggestive of the Humphriesianum Zone and Subzone. Specimens of *Teloceras* cf. *acuticostatum* Weisert and *T.* cf. *lotharingicum* Maubeuge in the White Nab Ironstone Member indicate a higher level of the latter zone and subzone (Parsons, 1977b; Gowland and Riding, 1991).

Palynological data (dinoflagellate cysts) suggest that the Moor Grit and basal Long Nab members of the Scalby Formation are of latest Bajocian to Bathonian age. Those recovered from the upper part of the Long Nab Member inland indicate the Bathonian Stage (Riding and Wright, 1989). The current view is that the Scalby Formation probably represents a long period of very interrupted sedimentation spanning much of late Bajocian and Bathonian times.

Conclusions

The coastal exposures of the two GCR sites (Iron Scar–Hundale and Hundale Point–Scalby Ness) include the type localities of the Eller Beck, Cloughton, Scarborough and Scalby formations, and some of their constituent members. They are thus important reference sections for the Cleveland and North Sea basins. The spectacular sedimentary features seen in these exposures bear witness to a Mid Jurassic environment in which small prograding deltas, deposited by rivers flowing southwards, periodically coalesced into a large coastal alluvial-plain close to sea level. These exposures, more than any others, have played a vital role in providing analogues for the oil-bearing Middle Jurassic strata of the North Sea area.

BLEA WYKE, NORTH YORKSHIRE (NZ 990 013)

B.M. Cox

Introduction

The GCR site known as 'Blea Wyke' comprises the headland Blea Wyke Point (with its surrounding wave-cut platform Blea Wyke Steel) (Figure 5.31) and the adjacent coastal section to the south-east. The cliffs here expose the topmost beds of the Lias Group (Blea Wyke Sandstone Formation – which also forms Blea Wyke Steel) overlain successively by the Dogger, Saltwick, Eller Beck, Cloughton and Scarborough formations (Figure 5.32). The Blea Wyke Sandstone is of Early Jurassic (Toarcian) age and will not therefore be considered in detail herein. The main interest of the section rests with the overlying Dogger Formation of which the site is the most important coastal exposure, with a formational thickness of *c.* 12 m (Figure 5.33).

Figure 5.31 Blea Wyke Sandstone Formation (Lias Group) overlain by the Dogger Formation. (Photo: British Geological Survey, No. A5504, 1931.)

Description

The Dogger Formation is seen dipping gently south-eastwards in the lower part of the cliff face to the south-east of Blea Wyke Point and soon reaches beach level (Hemingway and Wright in Rawson and Wright, 1992; Figure 5.32). It consists of strongly ferruginous, brown-weathering sandstone; when fresh, it is greyish-green owing to the presence of berthierine both in the matrix and as ooids. Its basal boundary is marked by slender vertical tubular burrows (*Skolithos*) that penetrate the top of the underlying Yellow Sandstone Member of the Blea Wyke Sandstone Formation. The basal bed (0.45 m thick) contains abundant phosphate pebbles and casts of terebratulid brachiopods (the Terebratula Bed). The pebbles may be fine-grained, or silty/sandy and ooidal. As well as the brachiopod *Lobothyris* (formerly *Terebratula*) *trilineata* (Young and Bird), there are less common bivalves (including *Gresslya donaciformis* (Phillips) and *Myophorella ramsayi* (Wright)), pentacrinoids, belemnites and fossil wood. Just above the Terebratula Bed, there is a similar thickness of micaceous shaly ironstone that is, however, lenticular. In the overlying sandstone, there are two other pebble or nodule horizons (0.08 m thick), but the most notable and distinctive horizon is the highly fossiliferous lenticular shell-bed known as the 'Nerinea Bed', which occurs about 3 m below the top of the formation. As well as the high-spired gastropod *Nerinea cingenda* (Phillips), which gives its name to the bed, it includes the gastropods *Natica* and *Cerithium*, and a rich fauna of bivalves including, in particular, *Neocrassina elegans* (J. Sowerby), *Gervillella* sp. and *Trigonia costata* J. Sowerby. Brachiopods (*Rhactorhynchia subobsoleta* (Davidson)) and corals are also recorded. The original calcareous shells are replaced by siderite and weather in sharp relief from a matrix of sandy berthierine oolite. The extensive faunal lists for the Dogger Formation given by Wright (1860), Hudleston (1874) and Fox-Strangways (1892) are largely based on this bed; within the main body of sandstone, the Dogger Formation is generally poorly fossiliferous.

Sedimentary structures are generally lacking in the Dogger Formation, but above the Nerinea Bed, large-scale, low-angle stratification is seen. The top metre or so contains abundant

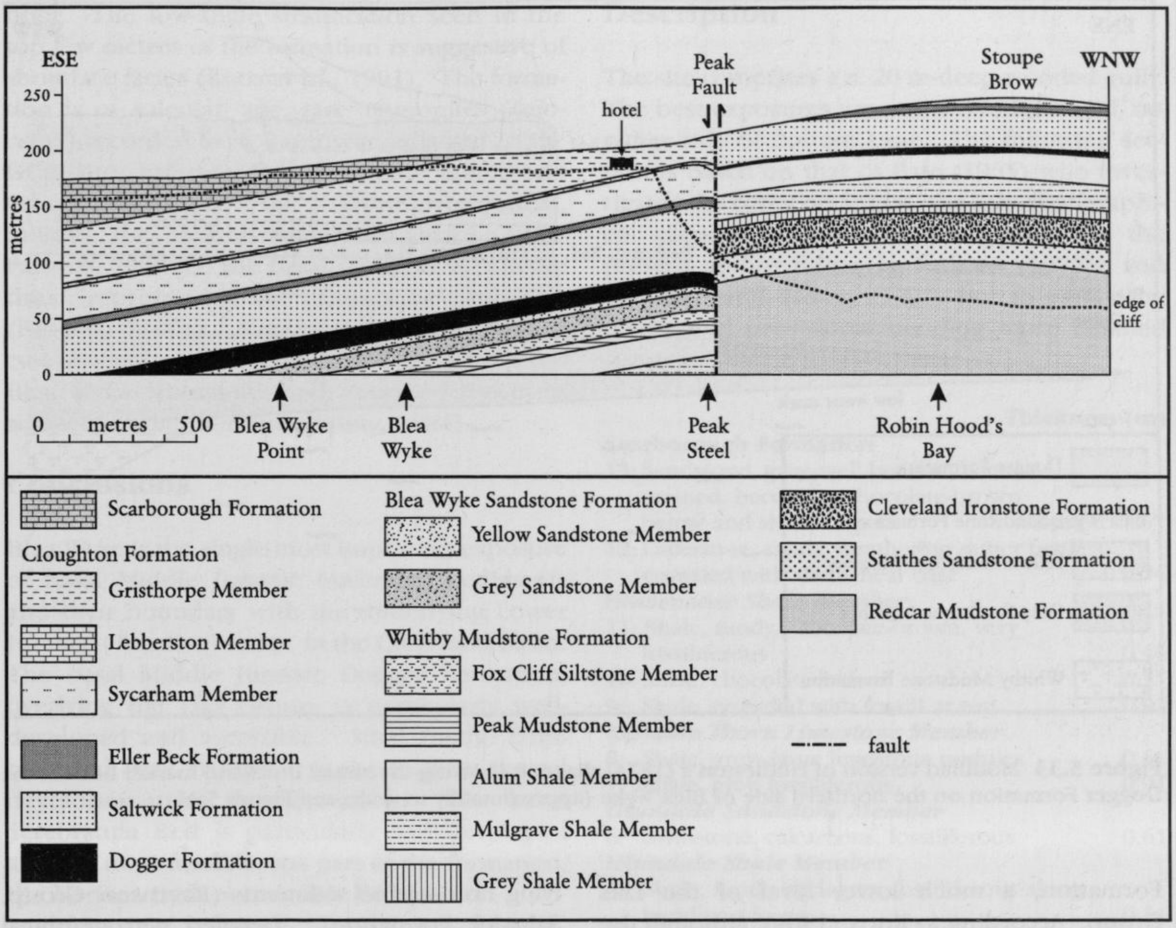


Figure 5.32 Diagrammatic cross-section through the Peak Fault at Ravenscar and adjoining cliffs. (After Rawson and Wright, 1992, fig. 13.)

spherulitic siderite. The junction with the overlying Saltwick Formation is usually sharp but locally the top of the Dogger Formation appears to have been reworked (Knox *et al.*, 1991).

Within the GCR site, the other formations of the Ravenscar Group are not easily accessible but the Eller Beck Formation makes a feature about 50 m above the Dogger Formation. The Scarborough Formation caps the cliff.

Interpretation

Many of the early investigators of the section at Blea Wyke Point (e.g. Wright, 1860; Hudleston, 1874; Tate and Blake, 1876; Fox-Strangways, 1892; Richardson, 1911c; Fox-Strangways and Barrow, 1915) were concerned with how it related to the Lias Group and Inferior Oolite Group successions in southern England, and where the boundary between these two units should be placed at Blea Wyke. All were agreed that the Dogger Formation was the basal bed of the 'Inferior Oolite' but there was disagreement about where the base of the Dogger Formation should be drawn. The present position (at the base of the Terebratula Bed) follows Rastall and Hemingway (1939). Wright (1860) had taken the boundary at the top of that bed but other workers chose positions ranging from as low as within the Peak Mudstone Member of the Whitby Mudstone Formation (Lias Group) up to as high as the base of the Nerinea Bed in the upper part of the Dogger Formation, a range of some 40 m. A comparison of some of the different interpretations is shown by Dean (1954, fig. 1).

At the base of the Dogger Formation at Blea Wyke, there is a hiatus that elsewhere in the Cleveland Basin is even more pronounced; in most areas, the Dogger Formation rests on the Alum Shale Member of the Whitby Mudstone

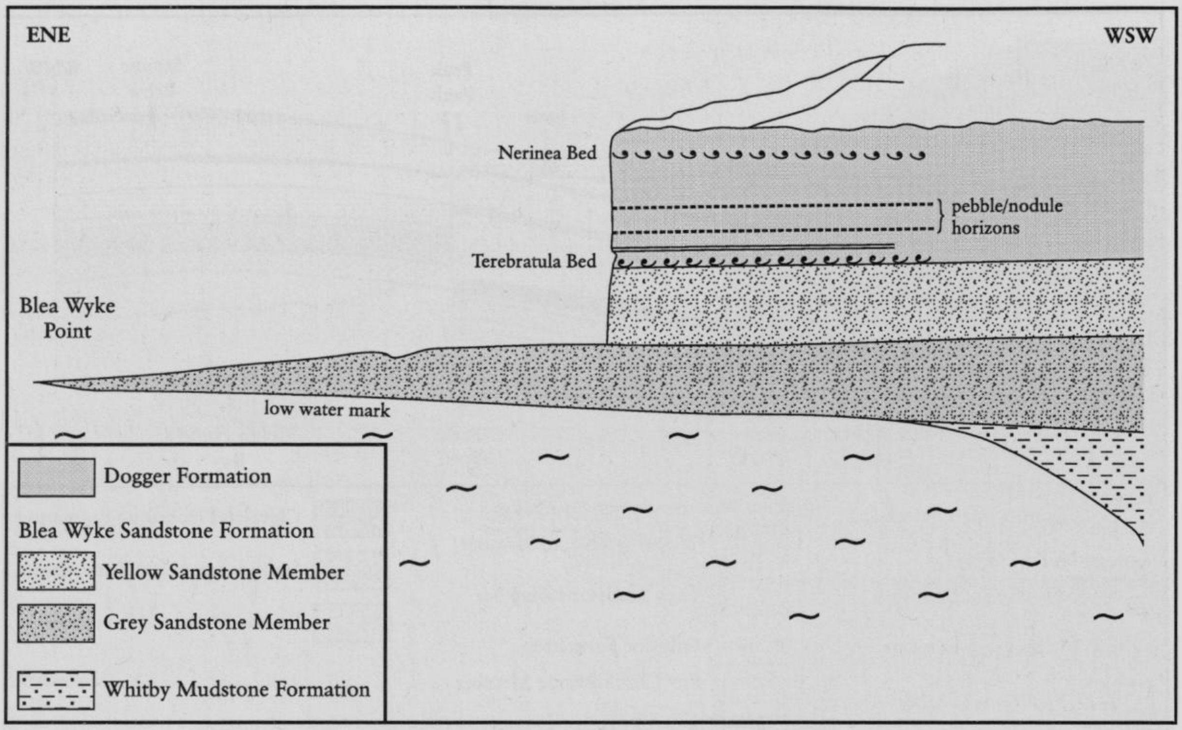


Figure 5.33 Modified version of Hudleston's (1874) diagram showing the stratal units and marker beds in the Dogger Formation on the northern side of Blea Wyke (approximately to scale; see Figure 5.31).

Formation, a much lower level of the Lias Group. According to Knox (1984), although the Dogger Formation at Blea Wyke appears superficially to be a continuation of the Late Toarcian upward-coarsening cycle developed in the underlying beds of the Blea Wyke Sandstone Formation, the sharp changes in average and modal grain-size at the base of the Dogger Formation, together with the regional evidence, argue for a significant break in sedimentation; the incoming of grains of coarse sand- and granule-grade at the base of the Dogger Formation may even indicate emergence of new source areas. The phosphatic pebbles in the basal bed of the Dogger Formation (Terebratula Bed) are derived from the underlying Lias Group; the fine-grained types from the Alum Shale and Peak Mudstone members of the Whitby Mudstone Formation, the silty/sandy and oolitic types from the Fox Cliff Siltstone Member of the Whitby Mudstone and the Blea Wyke Sandstone Formation (Knox *et al.*, 1991). The abundant spherulitic siderite in the top metre or so of the Dogger Formation is presumed to have developed through the downward percolation of meteoric water during deposition of the overlying non-marine sediments (Ravenscar Group, Saltwick Formation). Detailed petrographical descriptions of the lithologies of the Dogger Formation have been undertaken by Rastall and Hemingway (1940b), although they appear to have considered only the exposures west and north of the Peak Fault (Rastall and Hemingway, 1940a). This fault bounds the western margin of a narrow graben (the Peak Trough) in which syndepositional movements allowed greater thicknesses of sediment to accumulate (Milsom and Rawson, 1989). Consequently, the Dogger Formation at Blea Wyke Point is relatively thick.

The ammonite fauna from the top beds of the underlying Lias Group (Blea Wyke Sandstone Formation, Yellow Sandstone Member) indicates that they belong to the Upper Toarcian, Levesquei Zone, Moorei Subzone (Dean, 1954; Howarth, 1980). These beds are believed to have been deposited in shallow, sublittoral marine environments, above the wave base (Knox, 1984). According to Rastall and Hemingway (1940b) and Hemingway (1974), the succeeding Dogger Formation, with its basal hiatus, was deposited in fairly open sea of not more than 20 m depth with a well-oxygenated floor. The low-angle stratification seen in the top few metres of the formation is suggestive of shoreface facies (Knox *et al*., 1991). The formation is of Aalenian age; rare ammonites (*Leioceras*) recorded from Ravenscar, adjacent to the GCR site, indicate the Opalinum Zone, and others (*Ludwigia*), from a little farther afield, indicate the Murchisonae Zone (Black, 1934; Parsons, 1980a). The basal hiatus at Blea Wyke thus represents one ammonite subzone (Parsons, 1980a). Age-indicative dinoflagellate cyst assemblages have been recovered from the Blea Wyke Sandstone and Dogger formations adjacent to the GCR site (Riding, 1984).

Conclusions

Blea Wyke is the single most important exposure of basal Middle Jurassic (Aalenian) sediments and their boundary with the underlying Lower Jurassic (Toarcian) strata, in the Cleveland Basin. The basal Middle Jurassic Dogger Formation, overlying the Lias Group, is particularly well-developed and accessible. Sited in the fault-bounded Peak Trough, it is the thickest coastal development of the formation. The basal Terebratula Bed is particularly well-developed and the most fossiliferous part of the formation, the Nerinea Bed, occurs only here.

HAWSKER BOTTOMS, NORTH YORKSHIRE (NZ 937 080)

B.M. Cox

Introduction

The site comprises a *c*. 350 m-long section along the Oakham Beck at Hawsker Bottoms, *c*. 5 km south-east of Whitby. It extends from just south of the ford where the Oakham Beck crosses Bottom Lane to a point *c*. 240 m south-west of Maw Wyke Hole where the beck reaches the coast. The section runs along the north-western boundary of the Northcliffe Holiday Park. It is said to be one of the best inland exposures of the Scarborough Formation (Ravenscar Group), which is better known on the coast (see **Iron Scar–Hundale and Hundale Point–Scalby Ness** GCR site report, this volume), and to have yielded one of the most varied faunas from this interval, including the only corals so far recorded from the Scarborough Formation (English Nature files).

Description

The site comprises a *c*. 20 m-deep wooded gully. The best exposures are at the southern end, on either side of Bottom Lane. The following section is based on that of Bate (1965) who investigated the ostracod faunas; the lithostratigraphical classification has been updated by the present author following Parsons (1977b) and Gowland and Riding (1991) but this must be considered provisional pending more detailed logging of the section.

	Thickness (m)
Scarborough Formation	
13: Sandstone, grey, well bedded, coarse grained; becoming chocolate-brown below and shelly in part	seen to 1.57
12: Limestone, sandy, weathering rather fissile; crowded with shells near base	0.74
?Ravenscar Shale Member	
11: Shale, sandy, chocolate-brown, very fossiliferous	0.46
10: Shale, chocolate-brown	0.51
9: Shale, crowded with fossils at top	0.91
?Spindle Thorn Limestone Member	
8: Shale, grey; large limestone nodules	0.61
7: Shale, grey, fossiliferous	0.91
?Hundale Sandstone Member	
6: Sandstone, calcareous, fossiliferous	0.61
?Hundale Shale Member	
5: Shale, sandy, dark-grey, fossiliferous along bedding planes	0.51
Helwath Beck Member	
4: Shale, pale-grey; sandstone lenses	0.20
3: Shale, sandy, laminated grey and white; sandstone lenses	0.63
2: Shale, sandy, grey, carbonaceous with plant remains; 0.33 m-thick sandstone lens at top	0.91
Cloughton Formation	
Gristhorpe Member	
1: Sandstone, grey	seen 1.37

Interpretation

Bate (1965) assigned beds 1–4 to the 'Middle Deltaic Series' and beds 5–13 to the 'Grey Limestone Series'. These stratal names were subsequently replaced respectively by the Cloughton Formation and the Scarborough Formation (Hemingway and Knox, 1973). However, following Livera (1981), beds 2–4 have been reclassified as the basal member of the Scarborough Formation, called the 'Blea Wyke Member' by Livera (1981) and Gowland (1987) but renamed the Helwath Beck Member by Gowland and Riding (1991).

The Helwath Beck Member is the only part of the succession at Hawsker Bottoms that has been discussed in detail in recent literature. Gowland (1987) recognized four sedimentary facies within it. He described Bed 2 of the above section as being dominated by 'pinstriped' argillaceous siltstones cut by a lens of very fine-grained sandstone with a sharp basal erosion surface and a basal lag of coarse, coalified, woody debris. Within the sandstone, medium-scale trough cross-stratification, comparable to that produced by the migration of subaqueous dunes, is the dominant sedimentary structure; bedforms indicate transport towards the north-west. Wave-modified current-ripples with E–W-orientated crestlines are also reported towards the top of the sandstone unit. He perceived the overlying strata (Bed 3 of the above section) as burrow-mottled sands and silts that probably originated as lenticular and wavy bedded units; he recorded the trace fossils *Teichichnus* and *Thalassinoides*. The topmost part of the member (Bed 4 of the above section) shows a predominance of hummocky cross-stratification and displays a well-developed, wave-rippled zone; between the hummocks, lags of shelly material, notably disarticulated valves of the small oyster *Nanogyra*, were reported by Gowland (1987). Overall, the Helwath Beck Member is believed to represent both fair-weather and storm-sedimentation (Knox *et al.*, 1991) in a shallow, brackish-water, marine embayment open to the east (see also **Iron Scar–Hundale and Hundale Point–Scalby Ness** GCR site report, this volume).

Recognition of the other members of the Scarborough Formation away from the coastal sections (see **Iron Scar–Hundale and Hundale Point–Scalby Ness** GCR site report, this volume) must be considered as speculative. Bate (1965) correlated his Bed 6 with the 'Crinoid Grit' elsewhere, presumably because it contained an abundance of crinoid debris. However, Gowland and Riding (1991) replaced Parsons' (1977b) 'Crinoid Grit Member', as developed in coastal outcrops, by the term 'Hunsdale Sandstone Member' because they considered that there was 'no lithostratigraphical continuity or clear time correlation' with the true Crinoid Grit of Richardson (1911c), which is well developed and readily mappable inland (Gowland, 1987). The beds exposed in the waterfall north of the ford at Bottom Lane (Figure 5.34) are presumed to be the next youngest Spindle Thorn Limestone Member and overlying Ravenscar Shale Member. Fox-Strangways' (1892) record of ironstones at the top of a section in 'Gate Holm Beck just where the lane to Hawsker Bottoms crosses that stream' is suggestive of the next youngest White Nab Ironstone Member but the top of the formation has not been reported hereabouts.

Figure 5.34 Waterfall exposure of the Scarborough Formation north of Bottom Lane, Hawsker Bottoms. (Photo: M.G. Sumbler.)

Conclusions

The sections at the Hawsker Bottoms GCR site are some of the best inland exposures of the Scarborough Formation near its northern limit and, together with the coastal sections at Hundale Point (see **Iron Scar–Hundale and Hundale Point–Scalby Ness** GCR site report, this volume) contribute to an understanding of the palaeogeography and depositional environments of this area in Bajocian times.