Marine Permian of England

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Chapter 4

North-east England (Yorkshire Province)

INTRODUCTION

In this province, lying to the south of Cleveland High, the outcrop of the Magnesian Limestone generally lies closer to the western shoreline than in the Durham Province and the position of the shoreline or of offshore islands is clearly seen at a number of places including Knaresborough and North Deighton (near Wetherby); here a number of prominent rounded hills of resistant Carboniferous sandstone rose above the general plane of the early Permian land surface and were progressively onlapped by Cycle EZ1 shallow-water carbonate rocks and even, exceptionally, by the mixed sediments of the succeeding Edlington Formation. This shows that, unlike Durham, the original basin-filling transgression failed to reach the position of the present outcrop in the Yorkshire Province, which was inundated somewhat later as a result of world sea-level changes or relative subsidence.

Virtually all the outcropping carbonate rocks of Cycle EZ1a in the Yorkshire Province are shallow-water shelf deposits indicative of at least moderate energy deposition, but borehole evidence shows that they grade eastwards over 10–30 km into much-resedimented, finer-grained, slope carbonates indistinguishable from equivalent strata in the Durham Province. This implies that a shallow-water shelf prism similar to that in Yorkshire may have been built up in Durham, but has since been eroded off. In contrast, the carbonate rocks of Cycle EZ1b in the Yorkshire Province differ fundamentally and as yet inexplicably from those in the Durham Province and it is providential that rocks of this age are well exposed in both provinces.

The two provinces also differ in that the shelf and barrier carbonate rocks of Cycle EZ2 in the Yorkshire Province lie too far east to crop out, their place being taken by highly varied but poorly exposed rocks of the Edlington Formation (Figure 1.4). These varied strata extend across the Cleveland High into the southern parts of County Durham and adjoining areas and presumably at one time overlaid lagoonal ooidal grainstone of the Ford Formation in central and northern parts of the Durham Province.

The waning influence of the Cleveland High is well displayed by the Cycle EZ3 carbonate rocks, which are faunally and lithologically similar in the two provinces; the lack of a full GCR site in these rocks in the Yorkshire Province is thus not wholly critical because the rocks are readily available for research at Seaham and elsewhere in the Durham Province.

With the exception of Bilham Quarry and the Ure River Cliff, all the marine Permian GCR sites in the Yorkshire Province are in carbonate units of Cycle EZ1 (Figure 4.1); these are by far the most diverse and well-exposed parts of the Magnesian Limestone here, but the site network concentrates on the spectacular and the ordinary is poorly represented.

Bilham Quarry (near Doncaster) epitomizes the Basal Permian (or Yellow) Sands, traditionally classed as early Permian, but in the Yorkshire Province now reclassified as late Permian because the desert sands are believed to have been reworked completely during the Zechstein transgression (Versey, 1925; Pryor, 1971). Quarries in the Basal Sands are all shallow and are especially vulnerable to waste fill; the preservation of part of Bilham Quarry ensures that at least one face remains accessible for future study, together with the lowest few metres of the Wetherby Member of the Cadeby Formation. The Bilham exposure may be supplemented by the re-exposure of the red pebbly Basal Sands and breccias at Ashfield Brick-clay Pit (Conisbrough) if plans to re-excavate the lower part of this site are implemented.

Most of the GCR sites in Cycle EZ1 strata (the Cadeby Formation) in Yorkshire are in quarries and together they span the whole formation. All are in dolomitized shelf carbonates and include rocks inferred to have been formed in many of the shallow-water environments observed in modern tropical marine carbonate shelves and platforms. Five sites contain patch-reefs in the Wetherby Member and include the classic exposure at Newsome Bridge Quarry (North Deighton, near Wetherby) where an inferred bryozoan–algal patch-reef lies atop an eminence on the Carboniferous–Permian unconformity and is surrounded by shallow-water shelly grainstones. Such grainstones also surround the superbly-exposed algal-stromatolite patch-reef at South Elmsall Quarry and the several atypically tall patch-reefs in the vast working quarry at Cadeby, but are not seen (though probably are present) at the Wood Lee Common (Maltby) site, where saccolithic bryozoan patch-reefs form striking tor-like masses on a grassy slope; elsewhere the relationships of saccolithic bryozoan patch-reefs to surrounding grainstones is especially clear at Ashfield Brick-clay Pit (Conisbrough) and in the many small exposures in the picturesque village of Hooton Pagnell (SE 4808, near Doncaster), itself not a GCR site.

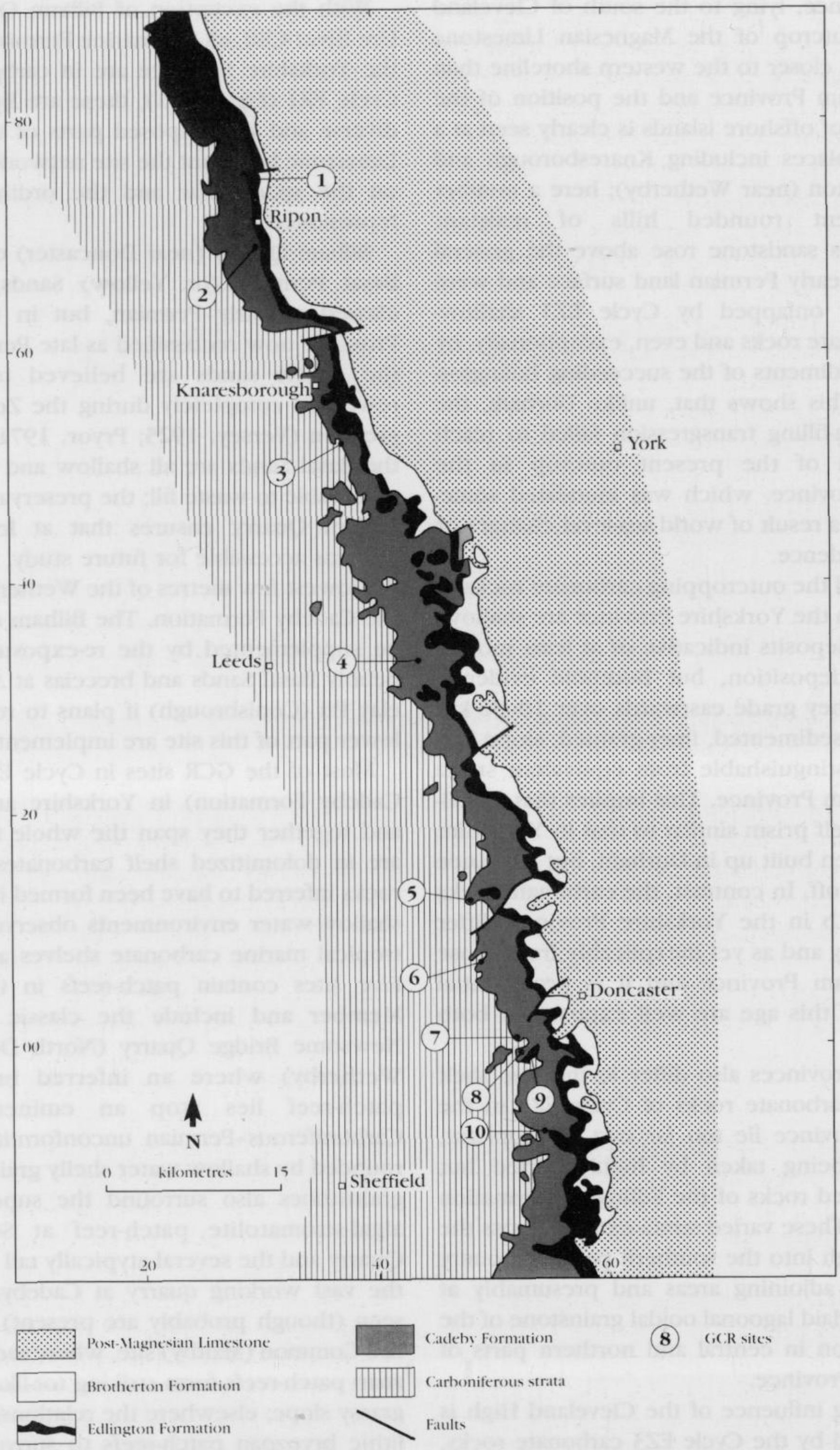


Figure 4.1 The distribution of Permian marine rocks in the Yorkshire Province, showing the location of Permian marine GCR sites: 1, River Ure Cliff; 2, Quarry Moor; 3, Newsome Bridge Quarry; 4, Micklefield Quarry; 5, South Elmsall Quarry; 6, Bilham Quarry; 7, Cadeby Quarry; 8, Ashfield Brick-clay Pit; 9, New Edlington Brick-clay Pits; 10, Wood Lee Common, Maltby.

Cadeby Quarry is the type locality of the Cadeby Formation (Smith *et al.*, 1986) and, in addition to patch-reefs and grainstones of the Wetherby Member, it exposes the typical ooidal grainstone sandwave facies of the Sprotbrough Member and unusually thick Hampole Beds; the latter span the contact between the two members and overlie an intraformational erosion surface, the Hampole Discontinuity, with a relief of up to 3 m. The Hampole Beds and the underlying discontinuity are also seen in Micklefield Quarry, together with the lower part of the sandwave facies of the Sprotbrough Member, but the largest and most impressive exposures of this facies include those at Knaresborough, Jackdaw Crag Quarry (SE 4641, near Tadcaster) and Warmsworth Quarry (SE 5300), which are not GCR sites. The remaining Cadeby Formation site in the Yorkshire Province is at Quarry Moor, Ripon, where ooidal dolomites and dedolomites at the top of the formation are partly algal-laminated and pass upwards by intercalation into interbedded ooidal grainstones and inferred evaporite dissolution residues (possibly of the basal Edlington Formation); a marine high-subtidal to intertidal shelf evolving to a marine sabkha is envisaged for this sequence, which is of a type unique amongst surface exposures in the Yorkshire Province, but has been seen in several cored boreholes east of the outcrop.

There are no thick Cycle EZ2 carbonate rocks at outcrop in the Yorkshire Province, where their approximate equivalent is partly represented by the interbedded siliciclastic and evaporite rocks of the Edlington Formation. These mixed strata, together with thin carbonate units, are exposed in the well-known River Ure Cliff section, near Ripon, where lower parts are only broadly folded, but upper parts are spectacularly tightly folded; the cause of the folding has been a matter of much controversy and remains uncertain, and recrystallization of the evaporites has obscured most primary fabrics. The River Ure Cliff is the only exposure of the Edlington Formation in the GCR site network, the type locality GCR site at New Edlington Clay Pits having recently been filled, and is one of only a very small number of exposures of this formation in the Yorkshire Province.

Cycle EZ3 carbonate rocks, the Brotherton Formation, are not the main interest at any Yorkshire Permian marine GCR site, but a few metres of rocks typical of this formation lie at the southern extremity of the Ure River Cliff site where they have foundered and been partly brecciated through dissolution of the gypsum of the Edlington Formation (Smith, 1974a; Cooper, 1987a). There are, however, many large exposures of these strata in and around Brotherton (SE 4825), Knottingley (SE 4923) and Womersley (SE 5319), although basal beds are generally poorly represented.

The main features of the GCR Marine Permian sites in the Yorkshire Province are summarized in Table 4.1 and their approximate stratigraphical positions are shown in Figure 4.2.

RIVER URE CLIFF, RIPON PARKS (SE 3073 7526–3083 7517)

Highlights

The low river cliff at Ripon Parks (box 1 in Figure 4.2) is one of the few exposures of the Edlington Formation in Yorkshire and is unique in containing thick beds of gypsum. The thickest gypsum lies at the base of the sequence and is only gently folded, but overlying thinner-bedded mudstone, siltstone, dolomite and gypsum is spectacularly tightly folded and fractured; these higher beds also contain many conspicuous veins of white fibrous gypsum.

Introduction

The river cliff lies on the west bank of the River Ure at Ripon Parks, about 3 km north of Ripon; it is partly concealed by vegetation and the base of the cliff is almost constantly washed (and undermined) by the fast-flowing river. Except for a mantle of red-brown boulder clay, all the strata seen in the cliff are thought to be part of the Edlington Formation, here in the floor of the narrow fault-bounded Coxwold–Gilling Trough. Strata in the cliff comprise several metres of gently folded gypsum overlain by a somewhat thinner, but partly strongly folded and faulted, sequence of thin-bedded mudstones, siltstones and dolomites. These upper beds contain many veins, lenses and sheets of secondary fibrous gypsum, and, at the southern end of the face, are separated from the underlying gypsum by a low-angle slip plane. Foundered beds of the Brotherton Formation lie in the bed of the river at the southern end of the main cliff.

The section has been known to geologists for well over a century, having been mentioned by Sedgwick (1829), Tute (1868a, b, 1870, 1884), Cameron (1881) and Fox-Strangways *et al.* (1885) in the last century. More recently the section has been described and illustrated in greater detail by

Table 4.1 Main geological features of the marine Permian GCR sites in the Yorkshire Province of the English Zechstein.

YORKSHIRE PROVINCE		
	Site	**Interest**
Cycle 1 / Cycle 2 Edlington Formation	River Ure Cliff, Ripon	The only permanent surface exposure of Permian evaporites in north-east England; much gypsum after anhydrite, partly strongly internally folded; many satin-spar veins; foundered limestones of Brotherton Formation (Cycle 3) with *Calcinema*
Cycle 1 Cadeby Formation (Sprotbrough Member), transitional to Edlington Formation	Quarry Moor, Ripon	Unevenly interbedded algal-laminated dedolomitized ooid grainstones and evaporite dissolution residues; expansion structures; algal-laminated dolomite ooid grainstones
Sprotbrough Member on Wetherby Member	Micklefield Quarry, New Micklefield	Typical dolomitized ooid grainstones of sandwave facies rests on full sequence of peritidal Hampole Beds; fenestral ('birds' eye') fabric; Hampole Discontinuity
	Cadeby Quarry, Cadeby	Typical dolomitized ooid grainstones of sandwave facies rests on atypically thick Hampole Beds; Hampole Discontinuity with relief of 3 m+; Wetherby Member with unusually tall patch-reefs and thick dolomite domed algal laminites
Wetherby Member	Wood Lee Common, Maltby	Selectively eroded dolomitized bryozoan patch-reefs form tors on grassy slope
	South Elmsall Quarry	Dolomitized bryozoan-algal patch-reef in peloidal and oncoidal shelf grainstones; stromatolite domes
	Ashfield Brick-clay Pit, Conisbrough	Dolomitized bryozoan patch-reef in dolomitized ooid grainstones, on bedded skeletal grainstones and rudstones (coquinas), on dolomitic siliciclastic mudstones
	Newsome Bridge Quarry, North Deighton	Dolomitized inferred patch-reef in peloidal and oncoidal shelf grainstones lies on eminence in Carboniferous - Permian unconformity; rock litter
Wetherby Member on Basal Permian Sands	Bilham Quarry	Basal shelf dolomite mudstones/wackestones of the Cadeby Formation on incoherent marine-redistributed aeolian sand-rock
	Ashfield Brick-clay Pit, Conisbrough	Basal dolomitic siliciclastic mudstones on atypically pebbly red friable sandstone

Kendall and Wroot (1924), Forbes (1958) and James *et al.* (1981). Sedgwick was unsure whether the gypsum at Ripon Parks formed part of the 'lower marl and gypsum' (now the Edlington Formation) or of the 'lower part of the upper red sandstone' (now the Roxby Formation), but Tute (1870, p. 5) favoured the former. Kendall and Wroot (1924) adopted the alternative (later) age and this view was accepted by visiting parties (e.g. Hudson *et al.*, 1938, p. 369) and by Forbes (1958). Smith (1974a, b, 1989), however, reverted to Tute's view on the evidence of increased knowledge of the local rock sequences and this interpretation has been accepted by James *et al.* (1981), Cooper (1986, 1987a, 1988) and Powell *et al.* (1992).

Description

The position of the River Ure Cliff is shown in Figure 4.3. The section is about 500 m long and

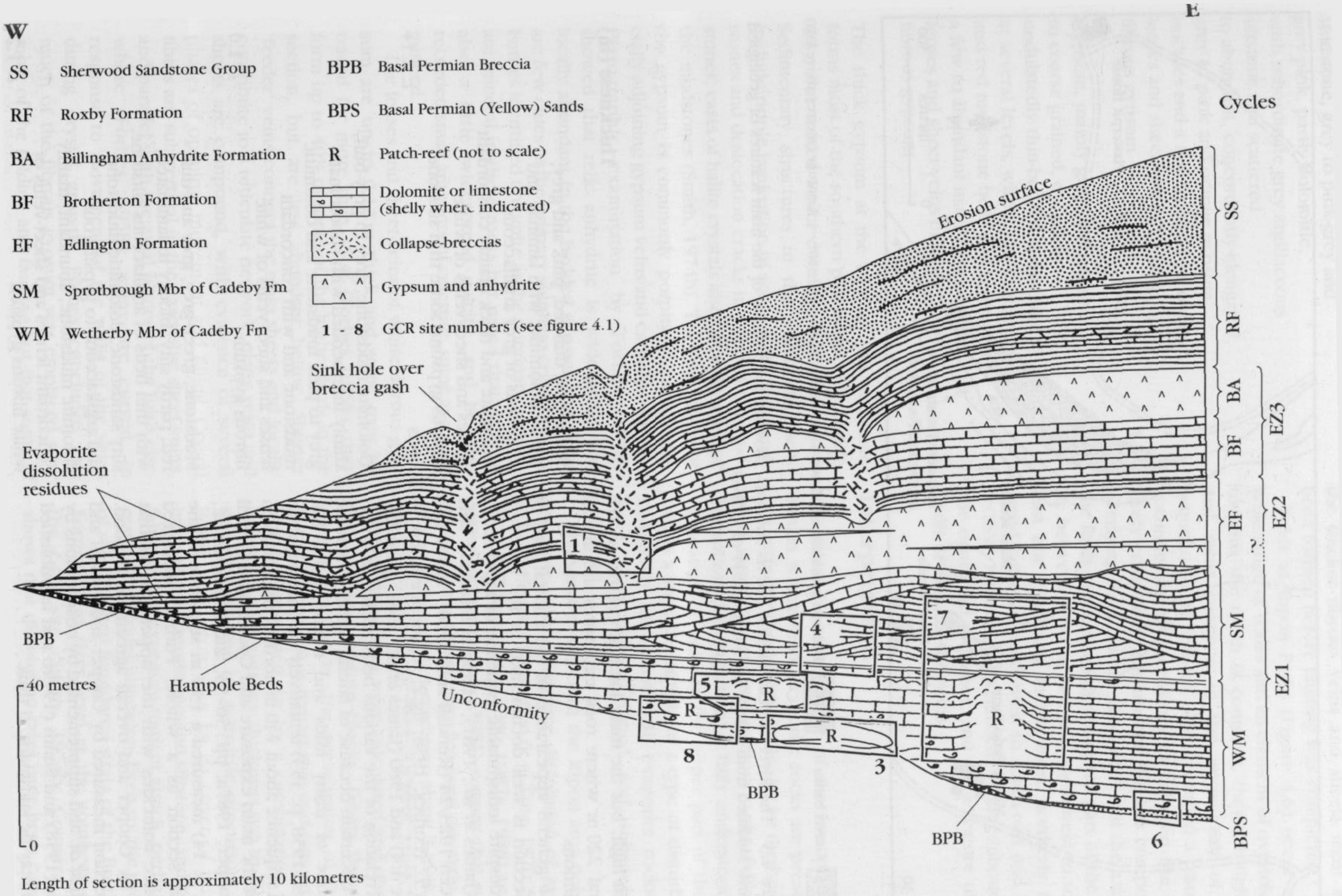


Figure 4.2 Approximate stratigraphical position of marine Permian GCR sites in the Yorkshire Province of north-east England (diagrammatic). Some sites cannot be shown on this line of section and have been omitted.

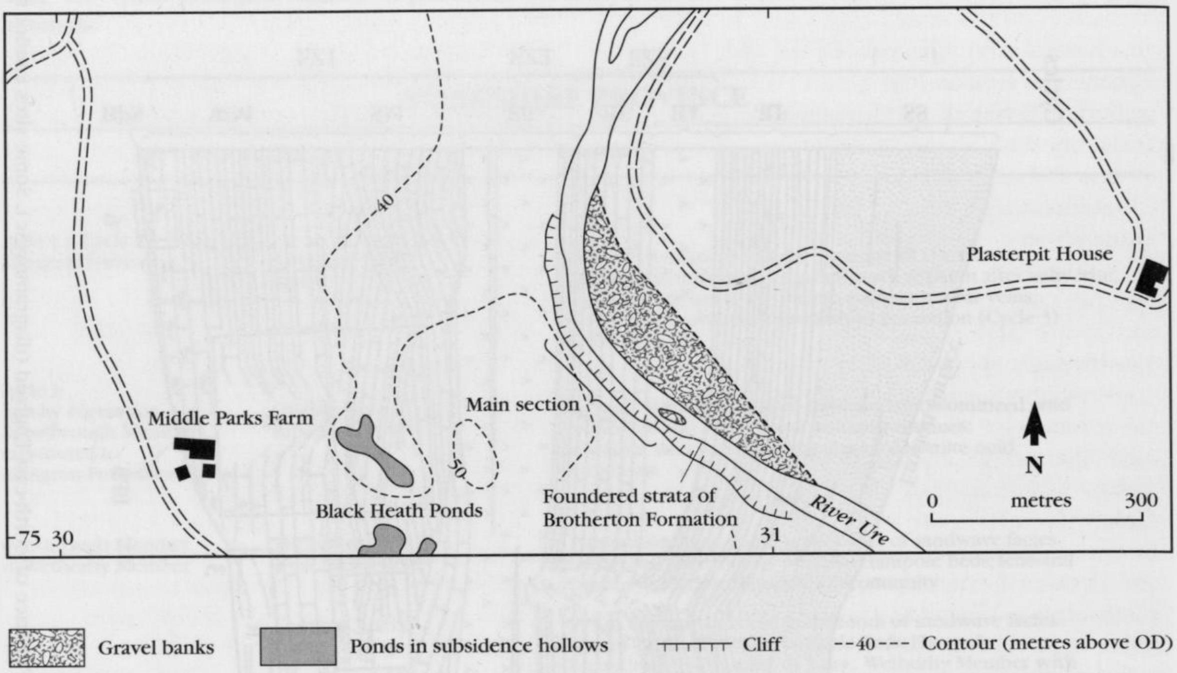


Figure 4.3 The River Ure cliff section and its environs, showing the position of the main features of geological interest. Modified from part of fig. 3 of James *et al.* (1981).

6–9 m high, but the main interest centres on the central 220 m where rock exposures are almost continuous.

The general appearance of the central part of the section is well documented in the literature and, despite indisputable evidence of rapid recession (James *et al.*, 1981), changed relatively little between 1923/24 (Kendall and Wroot, 1924), and 1956/57 (Forbes, 1958, fig.2, reproduced here as Figure 4.4) and 1980 (James *et al.*, 1981, plate 22).

Correlation of the various beds present is somewhat uncertain because of lateral variation and the presence of many folds and minor faults, but Forbes (1958, p. 353) tentatively reconstructed an 8.4 m sequence about 140 m north of the southern end of the main exposure and Cooper and Powell (in Cooper, 1987a, pp. 50–53, and Powell *et al.*, 1992, p. 14) measured a 13.7 m sequence in the central section as a whole; Forbes' measured sequence coincides with the upper part of that given by Cooper and overall agreement is good. The section measured by Cooper and Powell and Powell *et al.* and supplemented by observations by Forbes (1958) and Smith (1974b and unpublished notes) may be summarized thus:

	Thickness (m)
Mudstone, dull red, pink and grey, partly dolomitic, with laminae and thin beds of grey argillaceous dolomite and thick mainly concordant lenses and sheet-veins of white fibrous gypsum; some thin siltstone beds	*c.* 2.1+
Dolomite mudstone, grey to grey-buff, thinly interbedded with subordinate grey to pink mudstone and dolomitic mudstone and with concordant lenses and sheet-veins of white fibrous gypsum	*c.* 1.0
Mudstone, green-grey, grey and dull red, partly silty, blocky to laminated, with thin beds of argillaceous siltstone, silty sandstone, dolomitic mudstone and argillaceous to gypsiferous dolomite mudstone; abundant, mainly concordant lenses and sheet-veins of white fibrous gypsum	*c.* 1.2

Mudstone, grey to pink-grey and grey-pink, partly dolomitic, with subordinate grey argillaceous siltstone and scattered to abundant, concordantly-elongated, grey to pink and orange gypsum nodules and a few mainly concordant lenses and sheet-veins of white fibrous gypsum	*c.* 1.5
Gypsum, mainly grey, alabastrine to coarse grained, evenly to undulatedly thin-bedded to laminated at several levels, with a few thin grey and red mudstone beds and laminae; a few to abundant mainly concordant lenses and sheet-veins of white fibrous gypsum	7.6+

The thick gypsum at the base of this sequence forms most of the southern part of the cliff (Figure 4.5), but mixed strata dominate the remainder. Sedimentary structures in the siliciclastic beds include ripple lamination in some of the thin sandstones and desiccation cracks in some of the mudstones; casts of halite crystals also occur in some of the mudstones (Smith, 1974b). The basal layer of the gypsum is commonly porphyroblastic, especially adjoining gypsum veins and carbonate layers. Petrographic examination by Forbes (1958) showed that relic anhydrite is widespread and locally abundant in the bedded gypsum but there are few clues to the primary sulphate crystal fabric. Forbes identified dolomite as the dominant carbonate mineral in these rocks but noted that there is also a little widespread calcite, and he also recorded small amounts of celestite, some as a vein mineral.

The lenses and sheet-veins of white fibrous gypsum are up to 0.12 m thick and some may be traced for more than 15 m (Forbes, 1958); they form up to 40% of some of the higher beds in the section, but are less abundant below. Shorter 'feeder' veins connect the main sheets and locally contribute to a reticulate network; many veins and sheets are compound, with evidence of several phases of opening, movement and filling. Crystal fibres are sub-vertical in the extensive sheet-veins, and parallel with the axial planes of the folds elsewhere (Forbes, 1958); many are curved, in response to movement of the walls of the veins during crystal growth. Forbes concluded that much of the fibrous gypsum was emplaced after most of the folding and faulting but that some of the thicker fibrous veins and sheets must have been formed before faulting was completed.

Folds at Ripon Parks (Figure 4.6) occur on a wide range of scales and an element of overfolding towards the north is common; they are tightest and most common in the upper half of the sequence, and Forbes (1958) recorded a plane of accommodation (decollement) between the relatively competent gypsum and the less competent overlying beds. Forbes also noted that the axes of the folds in the strongly contorted part of the cliff lie between west to east and north-west to south-east but that those in the more northerly faces trend between north-west to south-east and NNE to SSW. Polished (slickensided) surfaces abound in the contorted sequence, and are a feature of the walls of many of the veins.

Interpretation

The River Ure Cliff is one of the few places in Britain where thick evaporite rocks are preserved in a surface exposure and is also by far the best and most instructive natural section in the Edlington Formation. Although not yet fully understood, the dislocation of strata in the upper part of the section is a superb example of a type of disturbance commonly associated with evaporite rocks that have been deeply buried and subsequently exhumed.

Abundant evidence in the Ripon area points to relatively rapid subsurface dissolution of gypsum in the Edlington Formation (e.g. Tute, 1870; Smith, 1972, 1974b; Cooper, 1986, 1987a, 1988) and estimates by James *et al.* (1981) suggest that surface dissolution of the gypsum has been the main cause of Ure cliff recession averaging about 1 m in every 10–20 years between 1853 and 1956. Much higher rates of dissolution were calculated and observed for detached gypsum blocks. Given these high rates of dissolution, the preservation of the Ure river cliff gypsum is remarkable and can probably best be accounted for by a combination of the unusually great primary thickness (up to 30 m) of the gypsum (and its anhydrite precursor) in the Ripon area, protection by its cover of relatively impermeable mudstone and siltstone, and by only fairly recent exposure to river attack, perhaps as a result of meander migration. Even so, the presence of steeply tilted foundered strata of the Brotherton Formation at river level at the southern end of the GCR site (Smith, 1974b; Cooper, 1987a) shows that dissolution rates have been capable of

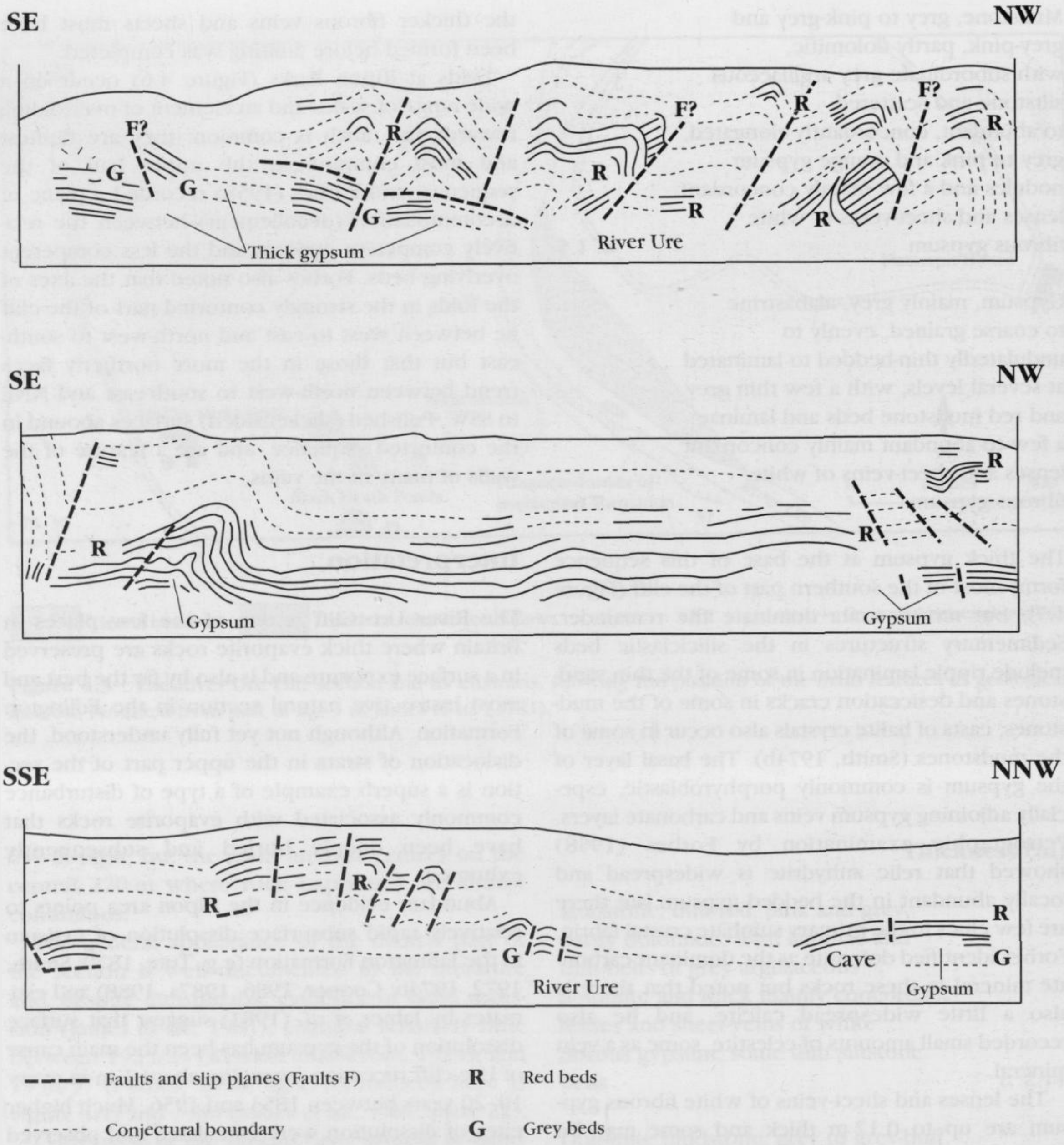


Figure 4.4 Sketch (top left to bottom right) of the main face of the River Ure Cliff, showing the principal geological features; slightly modified from Forbes (1958, fig. 2). Gypsum lies mainly at the base of the cliff except at the southern end. Total length of section shown is about 220 m, height about 7.5 m.

removing most or all of the gypsum there, perhaps indicating that other special factors accounted for the preservation of the gypsum cliff a few metres to the north.

The gypsum of the Ure cliffs is now thought likely to be the hydrated equivalent of anhydrite that is extensive at the base of the Edlington Formation (Smith, 1974a, b; James *et al.*, 1981; Cooper, 1987a) and which locally makes up more than half of the formation; this unit is tentatively correlated with the Hayton Anhydrite of English Zechstein Cycle 1b age (Smith, 1974b, 1980a, 1989; James *et al.*, 1981), but no direct connection can be demonstrated and it seems more likely to be an approximate age equivalent than part of a continuous rock body. Primary fabrics having been obliterated by hydration, the gypsum of the Ure river cliffs offers few clues to its original depositional environment and, even in the subsurface, the equivalent anhydrite is almost entirely of the mosaic type with a dolomite net; this

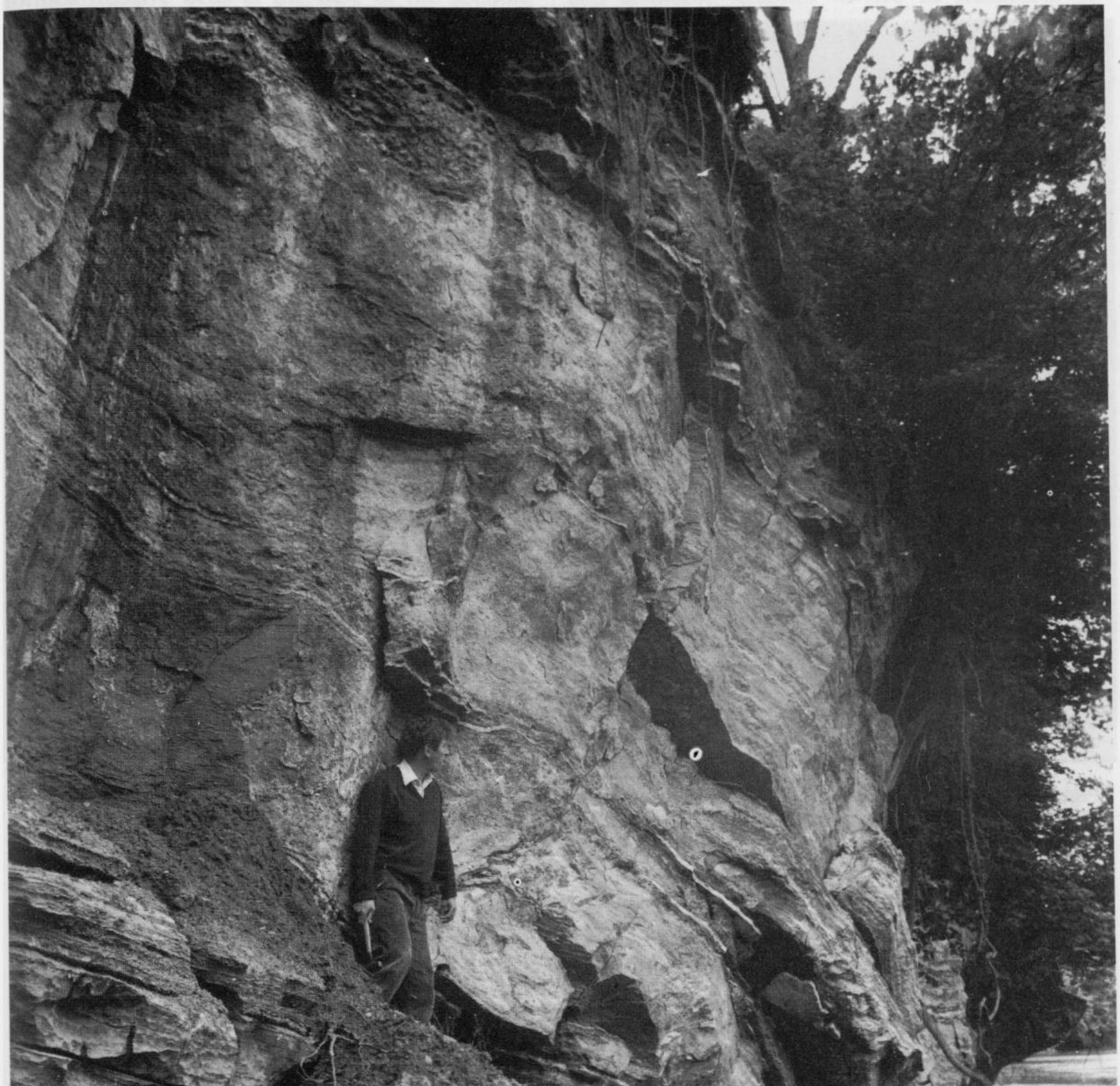


Figure 4.5 Gypsum, possibly equivalent to the Hayton Anhydrite, forming most of the river cliff at the southern end of the main rock section at Ripon Parks. Note the abundant sub-concordant sheet-veins of fibrous gypsum (white) in the upper part of the section. (Photo: A.H. Cooper.)

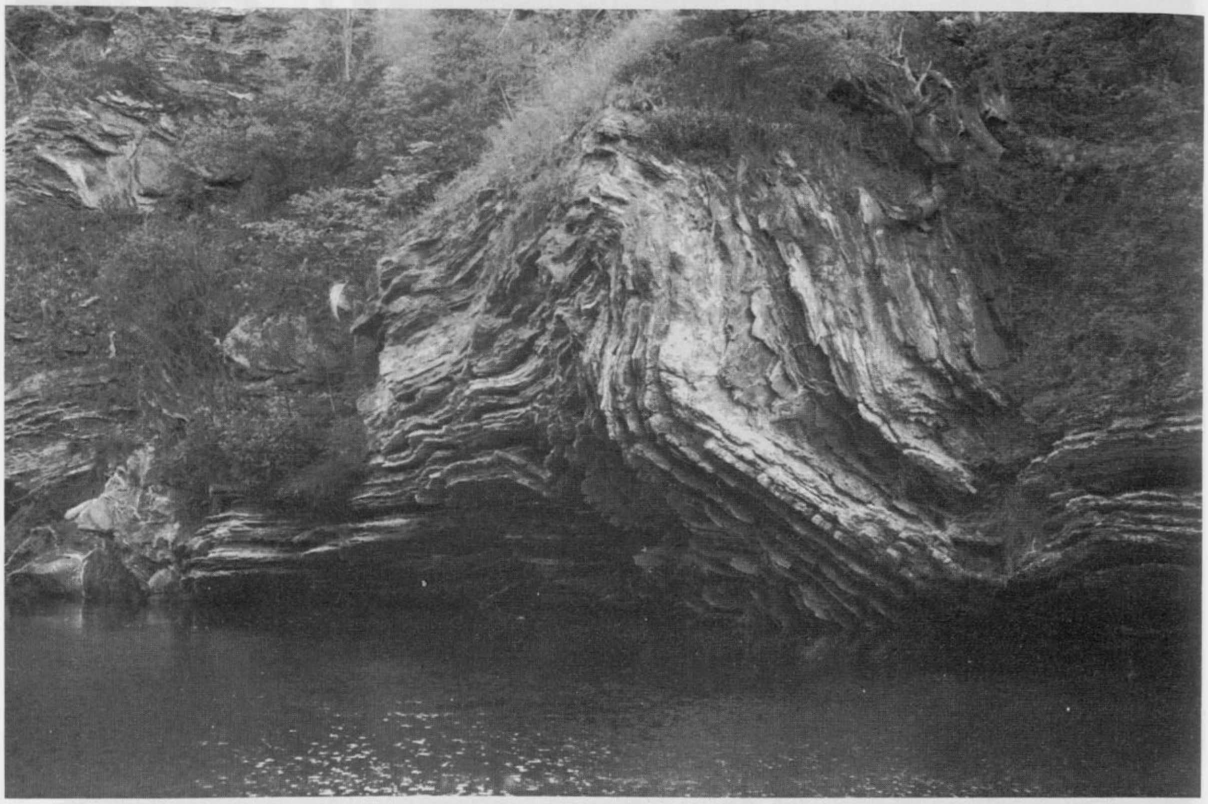


Figure 4.6 Sharp fold in mainly siliciclastic strata of the Edlington Formation with bedded gypsum (?=Hayton Anhydrite) at the base, and with many sub-concordant sheet-veins of fibrous gypsum (white). The fold is still recognizable at the southern end of the middle sector in Forbes' drawing of 1958 (Figure 4.4). The cliff is about 6 m high at this point. (Photo: A.H. Cooper.)

fabric, too, may be secondary and hence may throw little light on the rock's early history. Farther north, however, equivalent sulphate beds in the Edlington Formation on Tees-side were shown by Goodall (1987) to have been formed subaqueously in a stratified, hypersaline lagoon complex subject to oscillating brine levels and shorelines, and Smith (1989, fig. 8) envisages a generally comparable, but more extensive, lagoonal setting for the Ure river cliff sulphates.

The mainly siliciclastic rocks above the gypsum in the river cliff are typical of more marginal deposits, perhaps formed when the area lay near the shoreline and sedimentation was on an extensive, brine-soaked coastal plain or sabkha that was periodically extensively inundated and subaerially exposed as the lagoon expanded and contracted. The dolomite in the upper part of the measured section may be a feather-edge of the Kirkham Abbey Formation, but this supposition, like the correlation of the anhydrite, is difficult to prove and the rock may be of lagoonal rather than marine origin. Thin dolomite beds are widespread in much of the comparable inner shelf/lagoon area of the Edlington Formation (Smith, 1974a, b, 1989, fig. 9). Halite, too, is widespread in the Edlington Formation in a NNW to SSE belt through York and may formerly have extended into the Ripon area but has since been dissolved.

The cause and locus of the dislocation in the higher parts of the section remains controversial, and both deep and shallower settings have their proponents. The latter setting, favoured by James *et al.* (1981), Cooper (1987a) and Powell *et al.* (1992), ascribes the dislocation to pressures created during the hydration of the precursor anhydrite, theoretically involving a 63% increase in volume. Most gypsum beds formed from anhydrite elsewhere are not strongly folded, however, and the most strongly dislocated beds here apparently contained less anhydrite than the relatively undeformed massive beds at the base of the section. Forbes (1958), moreover, commented that his petrographic evidence from the Ure river section tended to show that the anhydrite–gypsum transition took place at depth on a volume for volume basis. Though not venturing a positive opinion on the cause of the folding, Forbes nevertheless remarked on the readiness of gypsum to flow under stress, implying a deep-seated cause. The writer sympathizes with this view, believing that the initial phases of deformation may have taken place at considerable depth (perhaps before hydration) and resulted from plastic flow of the evaporites (including halite) caused by differential loading; in this interpretation the pressure differential could have arisen during the Coxwold–Gilling faulting episode or early phases of evaporite dissolution, and the initial dislocation was probably augmented by foundering related to continuing evaporite dissolution during the current cycle of uplift.

Future research

As one of the few remaining surface exposures of the Edlington Formation, the main value of this spectacular section lies in its general appearance and as an excellent example of what evaporites look like in the field. The petrology of secondary gypsum rocks is now reasonably well understood so that research into this aspect might not be fruitful. The crucial problem of what caused the dislocation of higher strata in the section remains unsolved, however, and awaits satisfactory resolution.

Conclusions

This is the only GCR site in which the Edlington Formation is exposed, and one of the few exposures of this formation in Yorkshire. The site is unique in that the sequence contains gypsum interfolded with associated mudstones and dolomites. The gypsum of the River Ure Cliff is considered to be the hydrated equivalent of precursor anhydrite, and as such, affords little evidence on the original environment of formation. The deformation of the gypsum has resulted from the plastic flow of the evaporites under pressure, probably at depth and perhaps in association with halite (rock salt). The preservation of evaporite rocks is also unusual, because in most parts of England only relic texture, evidence of foundering, and insoluble residues survive as reminders of their former presence.

QUARRY MOOR (SE 308691)

Highlights

Quarry Moor, Ripon, uniquely exposes sea-marginal strata of the uppermost part of the late Permian Cadeby Formation, the Sprotbrough Member, and the transition to the overlying Edlington Formation. The rocks are mainly algal-laminated ooidal dolomites and limestone but higher beds in the section are contorted and include several clayey beds that may be evaporite-dissolution residues; all were formed at or very close to the Permian shoreline and tepee-like expansion structures, not reported elsewhere in British Permian marine strata, occur at some levels.

Introduction

The exposures of late Permian marine strata at Quarry Moor lie on the west side of the Harrogate–Ripon road just south of the City of Ripon. The quarry is now almost filled, but a section preserved along the western face reveals thin boulder clay overlying a gently northwards-dipping sequence of mainly algal-laminated ooidal carbonate rocks that span the transition between the Cadeby Formation (below) and the Edlington Formation. Together the Permian strata are about 9.5 m thick, but a further 3.7 m of underlying dolomite was visible in 1968, and parts of the quarry clearly cut into even lower strata. Neither shelly fossils nor signs of bioturbation have been found in any of the strata now exposed.

The quarry at Quarry Moor has existed for well over a century, and, judging from the distinctive lithology, provided much of the stone from which the earlier walls and buildings of Ripon were constructed. It was first mentioned in the literature by Sedgwick (1829) and later by Tute (1868a), who included a sketch of slightly disturbed strata in one unspecified face; Fox-Strangways recorded several minor faults in sketches of Quarry Moor in his field notebooks (now lodged at the British Geological Survey, Keyworth) and subsequently mentioned it in the second edition of the Harrogate (Sheet 62) Memoir (Fox-Strangways, 1908, p. 13). More recently the section in the west face was described in detail by Smith (1974b, 1976) and was also discussed by Kaldi (1980, pp. 20, 154–155; 1986b) and Harwood (1981, pp. 32–33, 109–111). The lower part of the sequence is interpreted as having been formed under shallow water on a broad tropical marine shelf and the upper part is interpreted as the product of a peritidal to supratidal marine sabkha or coastal plain subject to periodic marine inundation; some of the clayey layers in this upper part are interpreted as the residues of dissolved primary and/or secondary evaporites with perhaps some siliciclastic terrigenous input. The widespread contortion, 'tepee'-like structures and partial brecciation here are regarded as the result of plastic flow, secondary volume changes and contemporaneous lithification.

The preservation of part of the western face at Quarry Moor followed representations to the local authority in 1968 by the Yorkshire Geological Society and the Yorkshire Naturalists' Trust (now the Yorkshire Wildlife Trust); tipping of domestic waste was suspended, landscaping ensued and the site was ultimately (1993) scheduled as an SSSI. An information board provides full geological information for visitors.

Description

The preserved rock face at Quarry Moor is about 110 m long and mainly 2–3.5 m high; it lies just within the western margin of the site, most of which was scheduled on botanical and entomological grounds. The position of the face and its geological sequence are shown in Figures 4.7 and 4.8 and the general disposition of strata is shown in Figure 4.9. Lower parts of the sequence extend into private property to the south of the preserved face and should not be approached without prior authorization; higher parts of the section are repeated in a heavily overgrown 60 m exposure immediately to the north of the preserved section, where strata dip unevenly southwards.

All the strata in the preserved face at Quarry Moor are provisionally assigned to the Cadeby Formation, but strata above bed 2 were clearly influenced by an intermittent but generally progressive change in the depositional environment and it can be argued that some of the higher beds in the section, especially bed 12, should be assigned to the Edlington Formation. Petrographic details of the Quarry Moor rocks were given by Smith (1976) who showed that most (if not all) of the carbonate rocks there were originally ooidal but that many of the ooids had been diagenetically altered and are now obliterated or scarcely recognizable. Algal (stromatolitic or cyanophytic) lamination is a feature of most of the carbonate beds and thin dense cryptocrystalline layers (?crusts) occur at several levels in the upper part of the section; they also underlie erosion surfaces at the tops of beds 3 and 4. Some beds in the upper part of the sequence feature a dense network of narrow calcite veins. The petrographic evidence leaves little doubt that the limestone beds and patches at

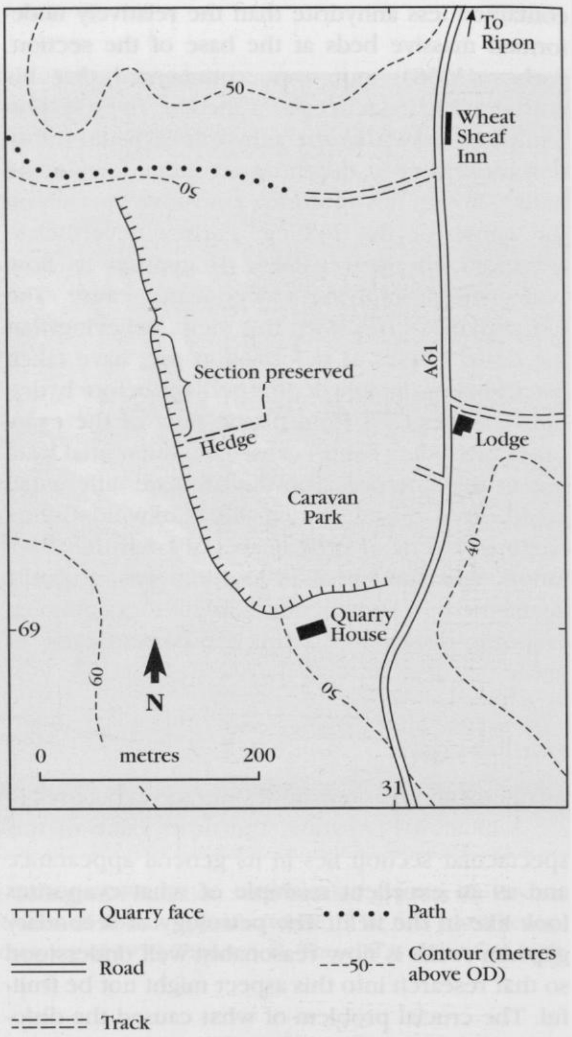
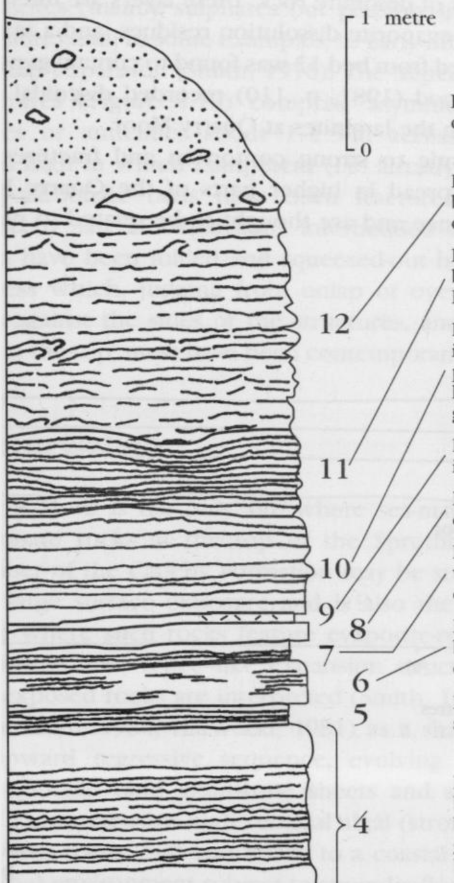


Figure 4.7 Quarry Moor, Ripon, showing the location of the preserved face.

Figure 4.8 The sequence of late Permian strata at Quarry Moor. Most of the section lies in the uppermost part of the Sprotbrough Member of the Cadeby Formation, but some of the higher beds may be part of the overlying Edlington Formation.

Quarry Moor



Description	Thickness (m)
Red-brown gritty stony clay (drift), with traces of cryoturbation in places. Largely overgrown	1-2.5
Dolomite, very calcitic and dolomitic limestone, grey and brown, crystalline (sand-grade), interbedded with thin layers of earthy and clayey dolomite. Locally strongly contorted	1.7+
Dolomite, calcitic, brown and grey-brown, irregularly thin-bedded, weakly laminated, with several thin earthy layers. Locally contorted, in places strongly	0.45-0.75
Dolomite, calcitic, pale grey-buff and dolomitic limestone, irregularly thin-bedded, with many traces of poorly-preserved wavy ?algal-stromatolic lamination and of fine hollow ooids. Abundant grey patches are of dedolomitized grey limestone with only vague traces of original ooids	0.90
Dolomite, grey and brown, laminated, earthy, partly passing into fine breccia	0.025-0.075
Limestone, grey, fine-grained, hard, dolomitic, with a sharp chunky fracture	0.15-0.20
Dolomite, grey and brown, thin-bedded, earthy, laminated, with several laminae and thin beds of grey and brown soft clayey dolomite	0.10-0.15
Dolomite, calcitic, and dolomitic limestone, cream, grey and buff, weakly algal-laminated, with ooids preserved in cream dolomitic patches	0.25-0.35
Dolomite, argillaceous, and dolomitic mudstone, grey and buff, semi-plastic when wet, with thin beds of brown mudstone	0.075-0.15
Dolomite, grey, cream and buff, calcitic, ooidal in single 0.30m bed at top and 0.45m bed at base, otherwise irregularly thinly bedded and algal-laminated and with several thin irregular grey, cream and brown earthy argillaceous beds. Parts of the bed are sharply contorted	1.5
Dolomite, yellow-buff and dolomitic limestone, soft, finely and unevenly laminated, finely saccharoidal, generally earthy and with brown clayey laminae and lenses	0.075-0.20
Dolomite, yellow and cream, porous, fairly soft, generally finely and slightly unevenly algal-laminated, ooidal. The surface of the bed is channelled and a layer of grey calcitic concretionary patches lies 0.05m to 0.15m below this surface. Algal lamination is best preserved 0.15m to 0.60m from the top of the bed and at several levels is arranged in flat-topped biscuit-like growth forms up to 0.15m high but generally less than 0.075m high. Ooids generally spherical and hollow, but at some levels include ovoid and fusiform ooids up to 3mm long and a few small pisoids and botryoidal grains	*c.*3.5
Dolomite, generally as in bed 2 but without algal lamination, in beds more than 0.90m thick. Cross-lamination in bed 1.5m from top	3.7+

Note: the lower part of bed 2 and the whole of bed 1 are not visible in the preserved section

Quarry Moor are secondary and it seems likely that most of the calcitization was accomplished by reaction of dolomite with calcium-rich waters late during uplift and erosion. Beds 3, 4, 5, 7 and 12 contain laminae and thin layers rich in siliciclastic quartz and clay minerals but are composed mainly of very fine-grained calcite and dolomite; these are interpreted as normal low-energy coastal plain or lagoonal sediments. In contrast, thin earthy layers in beds 3, 4, 5, 7, 9, 11 and 12 are streaky or irregularly laminated and comprise rubbly aggregates of dolomite rhombs, small quartz crystals and fragments of dolomite rock; these layers are interpreted as evaporite dissolution residues, and a sample X-rayed from bed 12 was found to contain gypsum. Harwood (1981, p. 110) recorded discoidal gypsum in the laminites at Quarry Moor.

Gentle to strong contortion and fractures are widespread in higher parts of the Quarry Moor sequence and are thought to be related to plastic

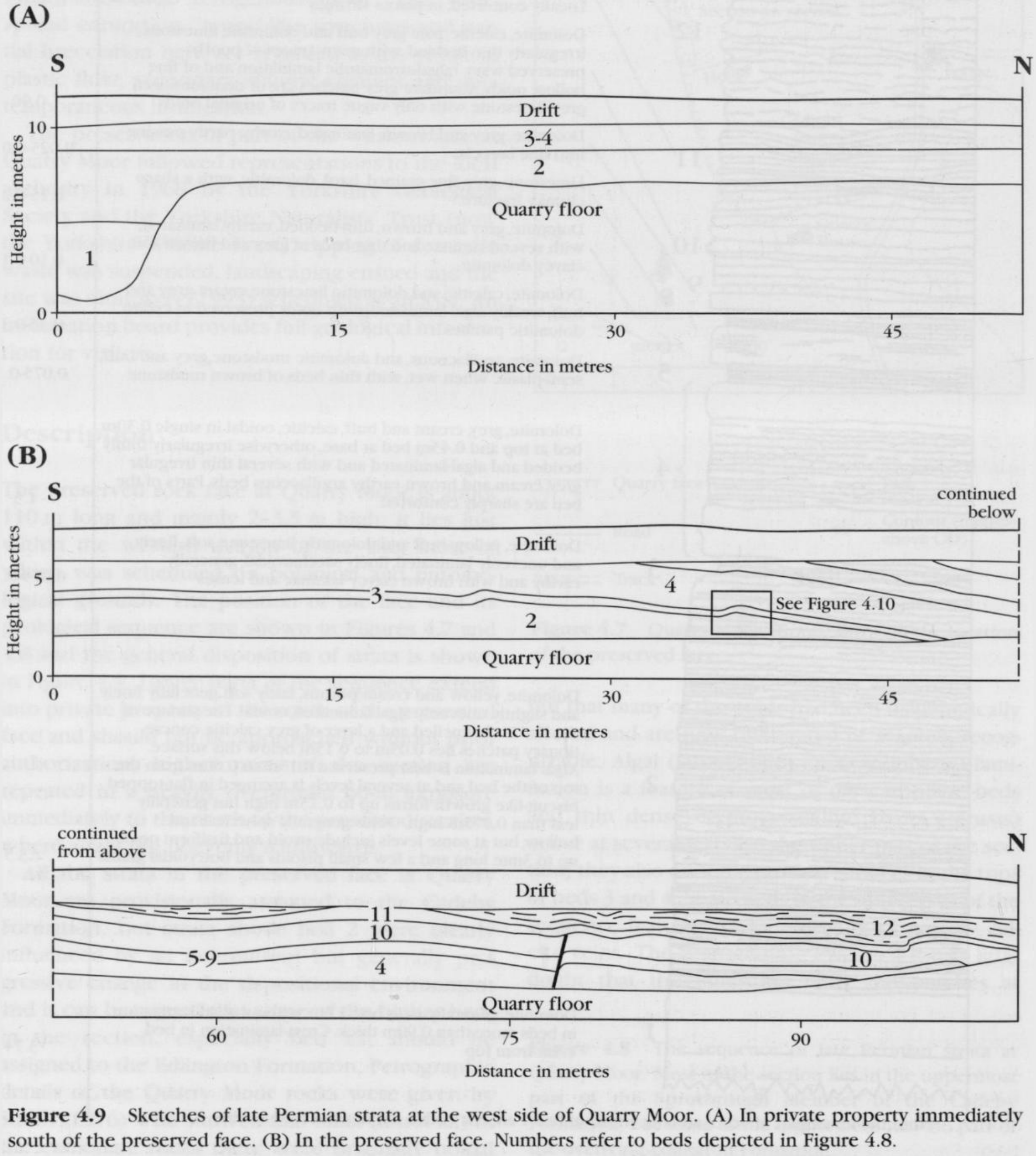


Figure 4.9 Sketches of late Permian strata at the west side of Quarry Moor. (A) In private property immediately south of the preserved face. (B) In the preserved face. Numbers refer to beds depicted in Figure 4.8.

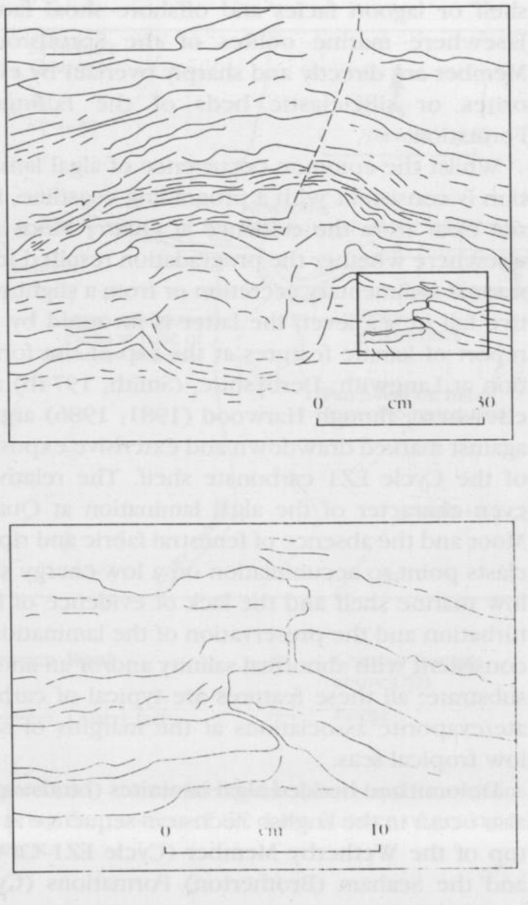
flow, volume changes resulting from the formation, dehydration, hydration and dissolution of evaporites (mainly sulphates but possibly including halite) and, in some examples, to early lithification and expansion (Smith, 1976). The 'tepee'-like structures (Figure 4.10) comprise asymmetrical domes or anticlines about 1–1.5 m across and 0.5 m high in which competent (i.e. already lithified) carbonate beds have been fractured and thrust by lateral expansion; interbedded softer strata have been folded and squeezed-out by this process which, judging from onlap of overlying beds against the sides of the structures, and erosion at the top, must have been contemporaneous.

Interpretation

Quarry Moor is the only site where sea-marginal carbonate rocks at the top of the Sprotbrough Member of the Cadeby Formation may be studied in a large surface exposure and is also the only place where such rocks feature evaporite-related contortion and 'tepee'-like expansion structures. The exposed rocks are interpreted (Smith, 1974a, 1976; Kaldi, 1980; Harwood, 1981) as a shallowing-upward regressive sequence, evolving from high subtidal ooid grainstone sheets and shoals (bed 1) to extensive high subtidal algal (stromatolitic) flats (beds 2–4) and finally to a coastal plain (sabkha) environment subject to sporadic flooding and to the formation of primary and secondary evaporites. With a tidal range probably of less than 1 metre, slopes on the coastal plain must have been negligible.

Elsewhere, algal lamination at the top of the Sprotbrough Member has been noted in surface exposures at Wallingwells (SK 570843) (Kaldi, 1980, p. 202; Harwood, 1981, p. 32) and at Darrington (SE 494202 but now almost filled); few details of the Wallingwells exposure are available but Kaldi (1980, fig. 2.2e) illustrates columnar algal stromatolites about 0.10 m in diameter and height, that he describes as capping an ooid barrier shoal. Algal lamination has also been noted at the top of the Sprotbrough Member in a number of cored boreholes, including one a few kilometres north of Ripon where evaporite-bearing basal beds of the Edlington Formation overlie 1.25 m of algal-laminated ooidal dolomite (Smith, 1976); farther away, a similar sequence in the Bank End Bore (SK 706997) contains 2.5 m of algal-laminated sabkha dolomite at this stratigraphical level (Fuzezy, 1970, 1980; Smith, 1976; Kaldi, 1980, fig 2.6c; Harwood,

(A)



(B)

Figure 4.10 (A) Non-tectonic 'tepee'-like anticline in beds 2, 3 and 4 of the sequence at Quarry Moor, with a 0.3 m shortening shown by overthrust near the base and a minor fault near the top. Note the almost level bedding and apparent onlap in the uppermost strata, implying contemporaneous formation and burial. For position see Figure 4.9(B). (B) Detail of ?contemporaneous overthrust at bottom right of (A).

1981), and algal lamination has also been recorded at this level in the Camblesforth (SE 649358) (Fuzezy 1970), Milford Hagg (SE 533323) (Harwood, 1981), and Wistow Wood (SE 567358) (Harwood, 1981) bores, and in a number of boreholes seen by the writer in the Doncaster and Whitwell areas. The list is almost certainly not exhaustive and it is probable that other comparable sequences in boreholes have not been recorded adequately. The data do not allow full assessment of the overall distribution of Quarry Moor-type sequences but it seems likely that they cap the Sprotbrough Member over perhaps one-tenth to one-fifth of the crop and near-crop area and overlie, in different places, rocks of restricted shelf or lagoon facies and offshore shoal facies. Elsewhere marine oolites of the Sprotbrough Member are directly and sharply overlain by evaporites or siliciclastic beds of the Edlington Formation.

Whilst the common occurrence of algal lamination is consistent with a prograding coastline, it is not clear from the evidence at Quarry Moor and elsewhere whether the progradation resulted from normal sedimentary accretion or from a slight relative fall in sea level; the latter is favoured by the report of karstic features at the top of the formation at Langwith, Derbyshire, (Smith, 1974b) and elsewhere, though Harwood (1981, 1986) argues against marked drawdown and extensive exposure of the Cycle EZ1 carbonate shelf. The relatively even character of the algal lamination at Quarry Moor and the absence of fenestral fabric and rip-up clasts point to accumulation on a low-energy shallow marine shelf and the lack of evidence of bioturbation and the preservation of the lamination is consistent with abnormal salinity and/or an anoxic substrate; all these features are typical of carbonate/evaporite associations at the margins of shallow tropical seas.

Dolomitized bedded algal laminites (bindstones) also occur in the English Zechstein sequence at the top of the Wetherby Member (Cycle EZ1 Ca (a)) and the Seaham (Brotherton) Formations (Cycle EZ3 Ca) but have not been reported at the top of Cycle EZ2 carbonate rocks. Those at the top of the Wetherby Member mainly comprise the lower dolomite of the Hampole Beds (Smith, 1968) and are up to 4 m thick but generally 0.2–0.8 m; they differ from those at Quarry Moor in being widely fenestral, in their common content of small clasts derived from the fracturing of thin contemporaneous crusts, and, at Bramham (SE 4242) and Wetherby (SE 4049), by the presence of small volcano-like structures (see account of Micklefield Quarry). The algal laminites at the top of the Cycle EZ3 carbonate rocks are generally less than 1 m thick and are dolomite mudstones; in County Cleveland and eastern parts of North Yorkshire they are interbedded with nodular anhydrite at the transition to the overlying Billingham Anhydrite (Smith, 1974a).

Future research

Whilst there is general agreement on the overall environmental and diagenetic interpretation of the section at Quarry Moor and in the boreholes cited, much of the petrographic and geochemical detail is virtually unknown. Future research should aim to address these aspects, with the aim of further elucidating the environmental and diagenetic history of the rocks, and, in particular, of determining the role played by probable former evaporites and early lithification. Extra information on the distribution of Quarry Moor-type strata at the top of the Sprotbrough Member must await a thorough search of confidential records and the drilling and careful logging of additional cored boreholes.

Conclusions

The site is unique in that it exposes the transitional relationship of the Sprotbrough Member of the Cadeby Formation and the overlying Edlington Formation. The lower part of the sequence comprises algal-laminated oolitic carbonates and thin clay laminae, which were formed on a shallow marine shelf at a time of increasing salinity. The shelf later shallowed further and environments evolved to intertidal and then coastal plain. In the upper part of the sequence, some clay layers are probably the residues of former evaporites, and widespread contortion, expansion structures and partial brecciation are probably the result of flowage under pressure and secondary volume changes. The site is important because of the unique features displayed, and for the exposure of a rarely seen part of the late Permian sequence in Yorkshire.

NEWSOME BRIDGE QUARRY

Highlights

Newsome Bridge Quarry (box 3 in Figure 4.2) is a superb exposure of a late Permian marine bryozoan–algal inferred patch-reef; it rests in a textbook position on a low eminence on the Carboniferous–Permian unconformity, and is flanked and partly overlain by dolomitic oolites and pisolites.

Introduction

The quarry lies on the south side of West Lane about 100 m SSE of Newsome Bridge and 1.2 km west of North Deighton village, near Wetherby. The floor has been patchily filled with farm waste, but this does not impinge on the main rock faces in the east and south sides of the quarry. Working ceased long ago and the main faces look much the same today as when they were sketched by J. C. Ward for the Harrogate Memoir (Fox-Strangways, 1874, fig. 1; 1908, fig. 1).

The section comprises a lower unit of slightly reddened, coarse-grained Namurian sandstone, the Upper Plompton Grit (4.5 m+), unconformably overlain by dolomite (7.5 m+) of the Wetherby Member of the Cadeby Formation (formerly the Lower Magnesian Limestone). The dolomite mainly comprises a massive, inferred bryozoan–algal reef, but this passes sharply into bedded variably shelly ooidal and pisoidal grainstone at the northern end of the east face; basal parts of the Magnesian Limestone contain scattered fragments of Upper Plompton Grit (Fox-Strangways, 1874, fig. 1), some of which are exceptionally large.

In addition to the sketch by Ward in Fox-Strangways (1874, 1908), the main features of Newsome Bridge Quarry – the uneven nature of the unconformity, the presence of large sandstone clasts in the overlying Magnesian Limestone, the large inferred patch-reef and adjoining bedded dolomite – were mentioned by Smith (1969b, 1974a), who noted that lowest parts of the Magnesian Limestone were absent through onlap against hills on the buried Permian land surface. A more recent account is by Cooper (1987b, p. 30) in which reef-rocks are not recognized and the Magnesian Limestone is regarded as being mainly ooidal.

Description

The position and shape of Newsome Bridge Quarry are shown in Figure 4.11, together with the main features of geological interest. The preserved faces of the quarry have a total length of about 120 m and a maximum height of about 10 m.

The general geological sequence is shown below.

	Thickness (m)
Cadeby Formation, Wetherby Member; patch-reef (inferred) and peloid grainstones	up to 7.5
---unconformity, relief at least 2.5 m--	
Upper Plompton Grit	up to 4.5

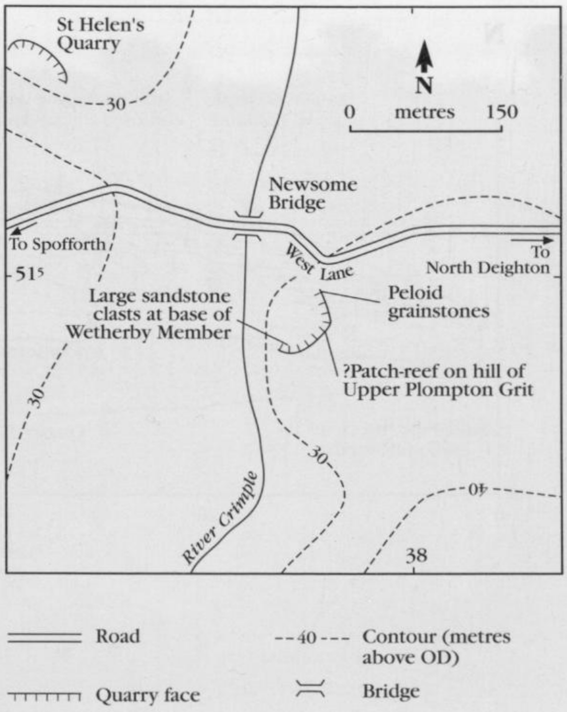


Figure 4.11 Newsome Bridge Quarry and its environs, showing the position of the main features of geological interest.

The disposition of the lithological units exposed in the east and south faces of the quarry is shown in Figure 4.12. All the Permian rocks are of buff and cream dolomite and contain scattered to abundant cavities up to 0.10 m across after secondary anhydrite.

Upper Plompton Grit

The lowest unit exposed in Newsome Bridge Quarry is a coarse-grained sparingly pebbly feldspathic sandstone assigned by Cooper (1987b) to the Upper Plompton Grit (Namurian). It is a resistant, thick-bedded (partly cross-bedded), pale grey to pale yellow-brown rock, with a faint purple discoloration consistent with its position immediately underlying the unconformity. Cooper records a patchy dolomite cement in the uppermost 1–2 m, where the rock is generally paler than below.

The Carboniferous–Permian unconformity

This is a smooth, sharp erosion surface with a total relief in the quarry of more than 2.5 m; it is

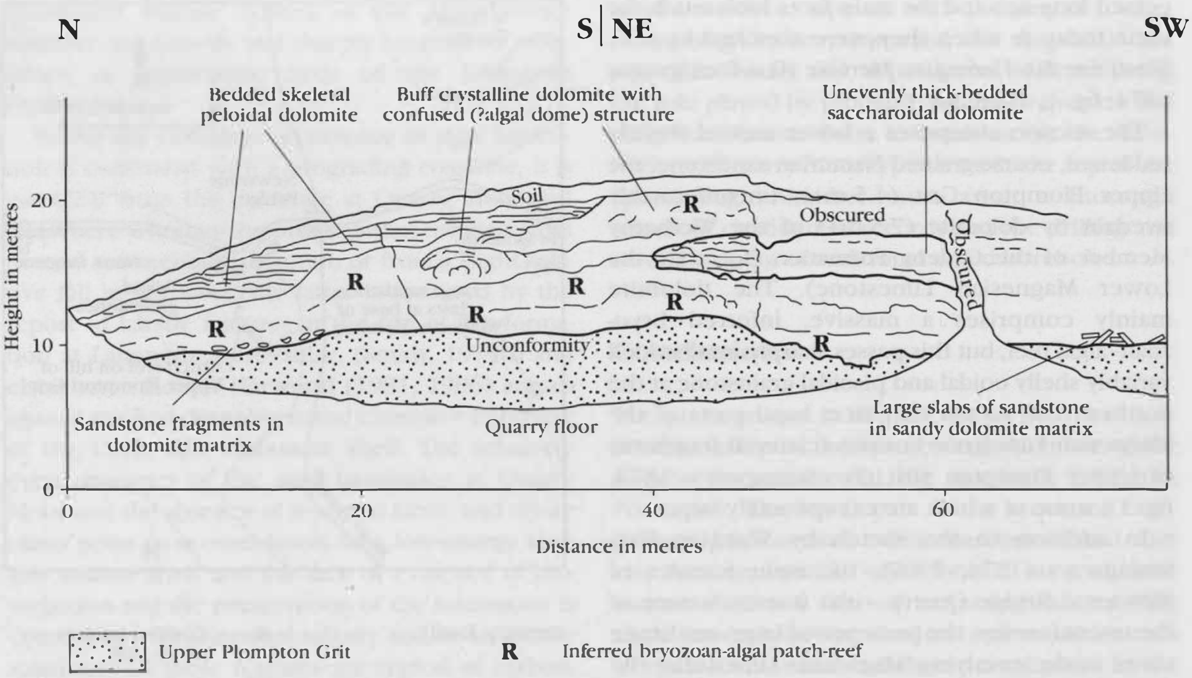


Figure 4.12 Sketch of the main faces of Newsome Bridge Quarry showing an inferred bryozoan–algal patch-reef centred on an eminence in the Carboniferous–Permian unconformity here cut onto Upper Plompton Grit.

highest in the south-eastern corner of the quarry and forms a low hill beneath the middle of the inferred patch-reef. Slopes on the surface are generally low, but in places they increase to 30° and some small near-vertical steps are present. The unconformity is generally clean-swept except where coarse debris lies in the basal 0.5 m of the overlying reef, and represents a hiatus of at least 75 million years.

Cadeby Formation, Wetherby Member, patch-reef (inferred) and peloid grainstones

The patch-reef at Newsome Bridge Quarry (Figure 4.13) extends across the full width of the preserved faces, but thins northwards towards an inferred margin just north of the quarry; it is largely obscured by vegetation on the south-west side of the quarry, where it includes a thick wedge of crudely bedded dolomite and may grade laterally into non-reefoid dolomite. In the south-east corner of the face the inferred reef forms all of the Magnesian Limestone exposed sequence, but there are hints that originally the reef was probably no more than 8 or 9 m thick.

Marked diagenetic changes have obscured most details of the primary fabric of the reef-rock and its interpretation as reefoid is based mainly on gross structure and overall relationships. In particular, the identification rests on the massive character of much of the rock, the apparent lack of ooids or pisoids, the sharp upper contact in the east face, the suggestion of saccoliths (pillow-shaped masses, Smith, 1981b) at the north end of the east face and, especially, the strong impression of presumed algal-stromatolitic doming in the upper part of the east face. Together these characteristics are so similar to those of the undoubted bryozoan stromatolite patch-reef at South Elmsall Quarry that interpretation as a reef is reasonably firm. Small bivalves (mainly *Bakevellia binneyi*) are present locally in the inferred reef but the distinctive and unmistakable framework of straggling *Acanthocladia* colonies that characterizes most reefs in this member has yet to be identified. J. Pattison (by letter, January 1990), however, records bryozoa at the south end of the quarry where the rock is believed by the writer to be reefoid; the presence of bryozoans strongly favours a reef interpretation, since in most of the shelf facies at outcrop, bryozoa are common only in and near the patch-reefs.

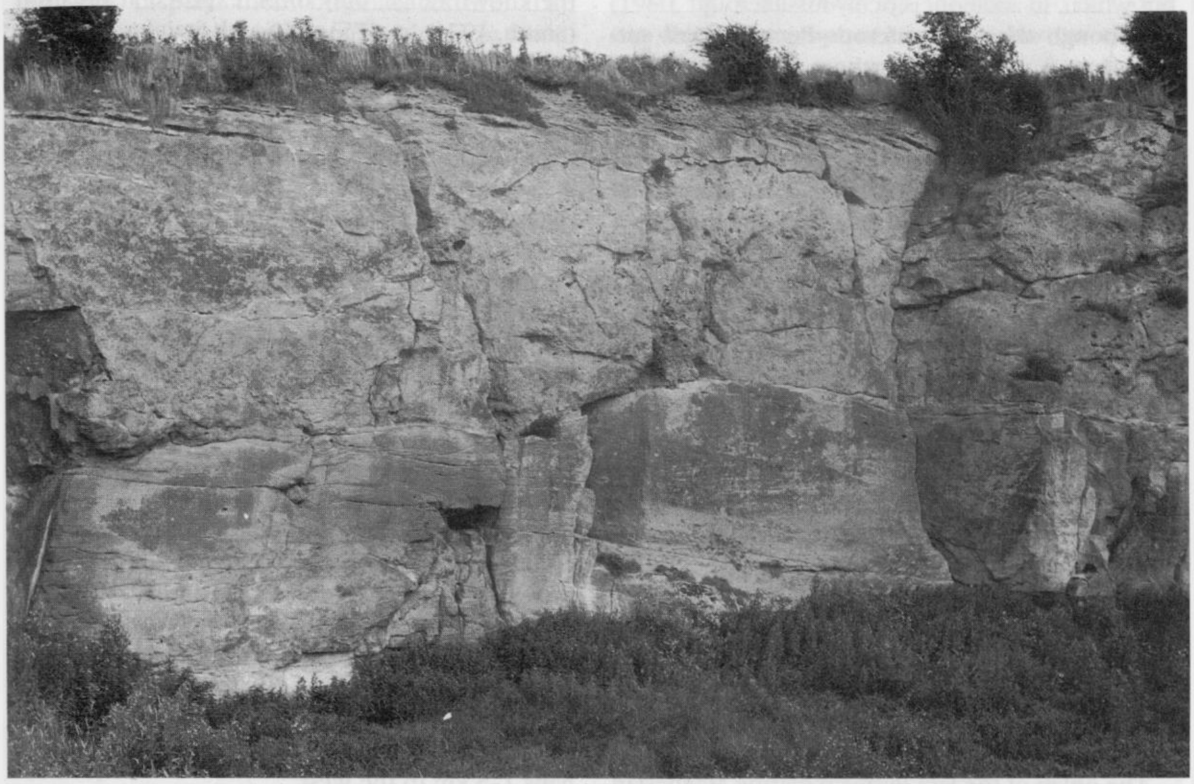


Figure 4.13 East face of the Newsome Bridge Quarry, showing the inferred patch-reef of the Wetherby Member of the Cadeby Formation and equivalent bedded strata, resting unconformably on Upper Carboniferous strata. For scale and interpretation see Figure 4.12. (Photo: Total Oil Company.)

Angular fragments of gritty sandstone are present in the basal part of the ?reef where it overlies low parts of the underlying unconformity (J.C. Ward in Fox-Strangways, 1874), and in places are crudely imbricated or vertical (Smith, 1974a; Cooper, 1987b); they are mainly flaggy and some fragments near the south-western end of the face are almost 1 m long.

The peloid dolomite that abuts against and laps onto the reef in the east face comprises a varied mixture of mainly thin-bedded, soft, skeletal ooidal and pisoidal grainstones and subordinate packstones. As in the ?reef, many fabric details have been obscured by advanced diagenesis, but ooids generally predominate. Most beds, however, contain a poorly sorted mixture of ooids and pisoids, and some beds near the top of the face are composed almost entirely of pisoids and shell remains; the pisoids include lumps, grapestones and coated compound grains, some of which bear evidence of contemporaneous fracturing, erosion and re-cementation. Some of the pisoids may be oncoids but undoubted algal filaments or structures have not been recognized. Shells in the grainstones range from thinly scattered to very abundant and most are only slightly abraded; most are small bivalves (chiefly *Bakevellia binneyi* and *Schizodus obscurus*) and gastropods, but J. Pattison (by letter, January 1990) also noted many reworked bryozoans in peloidal brash in the field above the east face.

Interpretation

Newsome Bridge Quarry is unique in combining superb exposures of both the Carboniferous–Permian unconformity and an inferred bryozoan–algal patch-reef with its enclosing grainstones; it is unmatched in the Permian of England and is rivalled in significance only by the famous quarry exposure at Bartolfelde, Germany (Richter-Bernburg, 1952, fig.1), where the sequence is generally similar but which, in addition, is richly fossiliferous.

Although the Carboniferous–Permian land surface has a low relief where it is cut onto Westphalian rocks in much of Yorkshire, there is more morphological diversity where the erosion surface is composed of resistant Namurian and earlier strata (Smith, 1974a, b). This diversity is particularly clearly seen in the Knaresborough area where local relief of up to 10 m and slopes of 30° are clearly visible; here also Aveline *et al.* (1874) demonstrated marked onlap indicative of a regional palaeorelief of at least 50 m (confirmed during the recent re-survey; see, for example, Summary of Progress of the Geological Survey for 1977, 1978, p. 37 and Cooper, 1987b). The unconformity at Newsome Bridge Quarry is probably more typical of these North Yorkshire areas, and is comparable with that exposed in St Helen's Quarry (SE 376517) nearby and in old quarries (SE 394456) near Collingham. The quarry is atypical, however, in that reddening of the underlying Namurian Sandstone is unusually faint compared with its more normal intensity as displayed, for example, at St Helen's Quarry and in some of the Knaresborough Gorge exposures.

The onlap of the late Permian marine Magnesian Limestone in the Knaresborough area locally resulted in the overlap of both the Cadeby Formation and the Edlington Formation, and Tute (1884) noted that earliest marine Permian strata are missing in Knaresborough Gorge. At Newsome Bridge Quarry, however, perhaps slightly farther from the basin margin, only the lowest few metres (?5–8) of the Wetherby Member sequence appear to be missing, though onlap is convincingly demonstrated both here and at St Helen's Quarry.

It follows therefore, that the inferred patch-reef at Newsome Bridge Quarry, although lying on the unconformity, is stratigraphically some distance above the base of the formation; this position is consistent with the overall inferred composition of the reef, with its massive core and its stromatolitic mantle (see also the account of South Elmsall Quarry). It is speculated that the reef exposed in Newsome Bridge Quarry was nucleated there because of the elevated firm substrate furnished by the Upper Plompton Grit.

As noted in the account of South Elmsall Quarry, patch-reefs in the Wetherby Member of the Cadeby Formation lie in a roughly north–south belt that is a few kilometres wide and extends from north of Harrogate to south-east of Sheffield (Smith, 1981b). The inferred reef at Newsome Bridge Quarry is thus towards the northern end of the known range, only those exposed at Brearton (Smith, 1974a, p. 375) and South Stainley (Cooper, 1987b, pp. 4 and 39) being farther to the north; it is slightly above the average size of about 20 m diameter and may not have projected much more than half a metre above the surrounding sea floor.

For further discussion of the character and biota of late Permian patch-reefs in the Wetherby Member see Smith (1981b) and the accounts (this volume) of the South Elmsall and Wood Lee Common sites.

The dolomitized peloid grainstones surrounding and onlapping the inferred patch-reef at Newsome Bridge Quarry are, like those at South Elmsall, typical of the belt of patch-reefs, though rip-up clasts have not been noted at Newsome Bridge. The rarity of carbonate muds and the large size of some of the sandstone clasts at the base of the sequence point to phases of moderate to high energy, and the general impression is of a broad unevenly shelving shallow tropical sea floored by shelly peloid sands and fine gravels and unevenly dotted with both subaqueous marine patch-reefs and irregular rounded islands, formed by incompletely submerged sandstone hills; the shoreline lay perhaps 1–5 km to the west.

Future research

As with South Elmsall Quarry, the section at Newsome Bridge Quarry derives most of its impact from spatial relationships; for this reason, it is best viewed from a distance and the main (east) face ought not to be scarred by intensive sampling. Nevertheless, it is important to try to establish whether the inferred reef has an *Acanthocladia*-rich framework and is therefore a true patch-reef or if, as thought probable by Cooper (1987b and in conversation, 1990), the reef-like body is an expression of differential diagenesis of the peloid grainstones.

Conclusions

The site is highlighted by the exposure of a probable patch-reef resting on older sandstones marking the Carboniferous–Permian unconformity. The character of the ?patch-reef is considered to be similar to the bryozoan–stromatolite patch-reef at South Elmsall Quarry, but has undergone greater diagenetic change which has obscured much of the original internal detail. Bedded oolitic and pisolitic dolomite lap against the ?reef, and still display their original texture. The Carboniferous–Permian unconformity is an undulating erosion surface, formed on resistant felspathic sandstones of the Upper Plompton Grit of Namurian age. The exposure eloquently illustrates the variability of the nearshore carbonate sedimentation and reef building on the newly-inundated erosion surface near the western margin of the Zechstein Sea.

MICKLEFIELD QUARRY (SE 445325)

Highlights

The abandoned face at Micklefield Quarry (box 4 in Figure 4.2) is the best and most readily accessible exposure of the Hampole Beds, which span the contact between the Wetherby and Sprotbrough members of the Cadeby Formation (Lower Magnesian Limestone), and also affords excellent views of the Hampole Discontinuity and large-scale cross-bedding in the ooidal dolomite of the Sprotbrough Member.

Introduction

Micklefield Quarry lies behind houses near the south end of New Micklefield village and about 100 m west of the Great North Road; most of the floor of the former quarry has been filled with builders' and domestic waste. Strata now exposed comprise the lower part of the Sprotbrough Member (7.5 m+) and the uppermost part of the underlying Wetherby Member (2 m+), but the main features of interest and importance are the Hampole Beds (about 1 m) and the underlying Hampole Discontinuity. The discontinuity is regarded (Smith, 1968) as an erosion surface cut during a minor sea-level fall and the Hampole Beds are thought to be a product of an oscillating tropical shoreline on an extensive carbonate shelf at the edge of the English Zechstein Sea. The distinctive lower dolomite of the Hampole Beds was a much valued building stone and has been extensively used in the construction of the nearby walls and houses.

The quarry was first mentioned in the literature by Edwards *et al.* (1950), who recorded 60 ft (18 m) of 'limestone' (consisting mainly of the Wetherby Member), and summaries of the strata exposed now were given by Smith (1969b); a sketch of part of the quarry face was given by Kaldi (1980, fig. 3.36, 1986a, fig. 3b) who also included (fig. 6b) a photograph of a complex burrow system there.

Preservation of the face at Micklefield Quarry followed representations to the local council in 1969. Since then vital parts of the face have twice been covered and, following protests, twice re-excavated; nevertheless they remain vulnerable to illegal tipping. An information board provides a geological interpretation for visitors.

Description

The position of Micklefield Quarry is shown in Figure 4.14; the preserved face is about 90 m long and up to about 9.5 m high. The Hampole Discontinuity is well exposed for only a short distance towards the south end of the face.

Strata present in Micklefield Quarry belong entirely to the Cadeby Formation (the Cycle EZ1

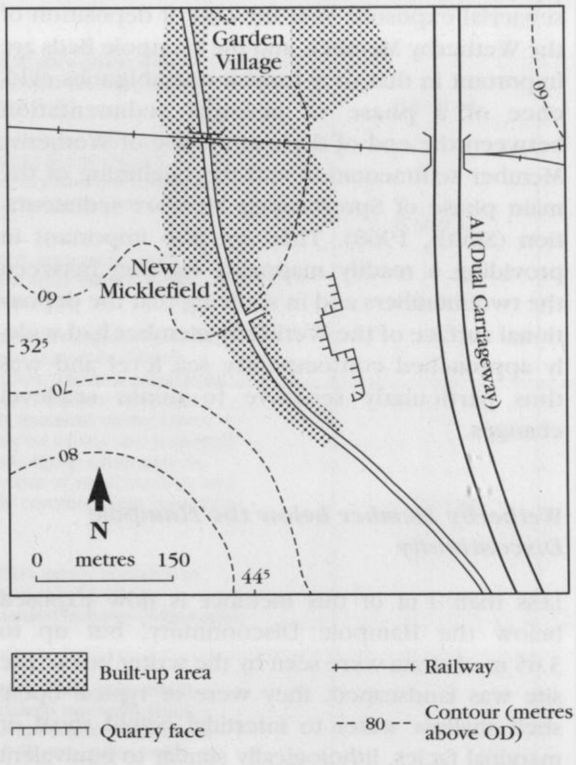


Figure 4.14 Position of Micklefield Quarry GCR site.

carbonate unit of the marginal English Zechstein sequence) and comprise parts of the Wetherby Member (below) and the Sprotbrough Member. The general geological sequence in the quarry is summarized in Figure 4.15, which emphasizes the Hampole Beds that span the contact between the two members. Cavities after secondary anhydrite are present at all levels and many of the ooids have leached centres; some of the cavities are calcite-lined.

The sequence depicted is uniform throughout the quarry and dips gently eastwards. The overall apppearance of the southern part of the face is shown in Figure 4.16.

Interpretation

Micklefield Quarry is the most accessible and best exposure of the Hampole Discontinuity and Hampole Beds in central Yorkshire, supplanting the type locality of Hampole Limeworks Quarry (SE 515097), most of which is now covered. The discontinuity (Figure 4.17) is important in that it is evidence of a phase of erosion and probably subaerial exposure near the end of deposition of the Wetherby Member, and the Hampole Beds are important in that they furnish unambiguous evidence of a phase of peritidal sedimentation between the end of the main phase of Wetherby Member sedimentation and the beginning of the main phase of Sprotbrough Member sedimentation (Smith, 1968). They are also important in providing a readily mappable horizon between the two members and in showing that the depositional surface of the Wetherby member had widely approached contemporary sea level and was thus particularly sensitive to minor sea-level changes.

Wetherby Member below the Hampole Discontinuity

Less than 1 m of this member is now exposed below the Hampole Discontinuity, but up to 3.65 m of strata were seen by the writer before the site was landscaped; they were of typical open-shelf shallow water to intertidal peloid shoal or marginal facies, lithologically similar to equivalent strata at the type locality at the former site of Wetherby Station (SE 397484) and at Hampole Limeworks Quarry (SE 515097).

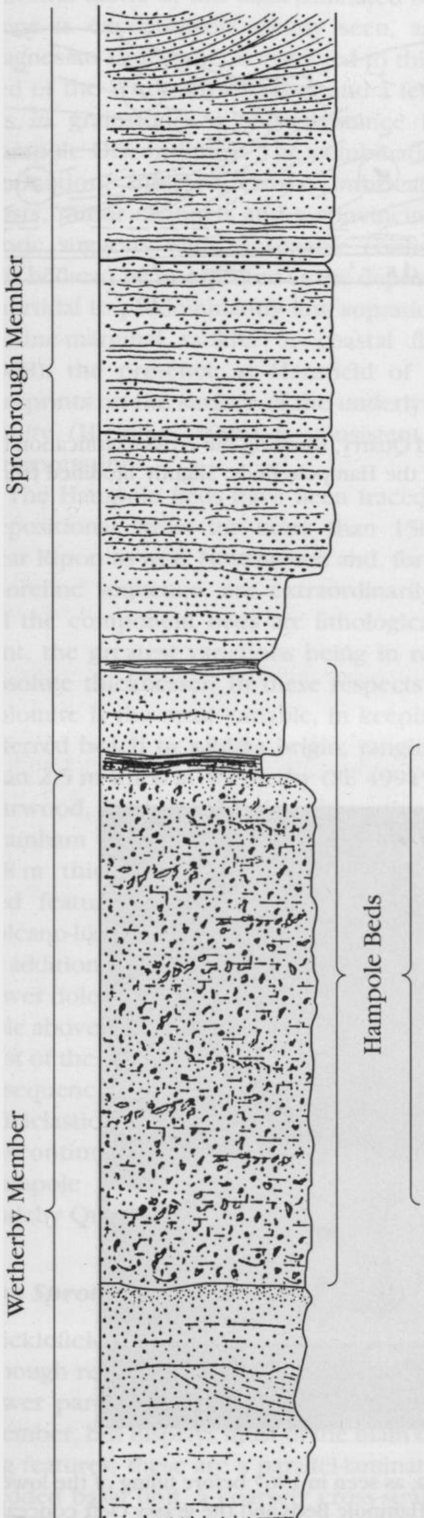
Hampole Discontinuity (HD in Figure 4.15)

The gently rolling low relief of this crusted surface at Micklefield Quarry is typical of its configuration throughout the province; as elsewhere, it bears only a few minor eminences and hollows (?channels) and only slightly truncates bedding in underlying strata (Figure 4.17). This widespread low relief is known to be exceeded only in Cadeby Quarry and its immediate surroundings, but greater relief may also be inferred in places where the lower dolomite is abnormally thick (e.g. Bramham and Wetherby) and in places such as Kirk Smeaton (SE 5116) where the lower dolomite is underlain by interbedded, multicoloured dolomite and siliciclastic mudstones like those at Cadeby Quarry.

Hampole Beds

Early workers from Sedgwick (1829) onwards recognized that the Cadeby Formation (formerly the Lower Magnesian Limestone or equivalents) could be readily divided into two main units on the basis of lithology and sedimentary characteristics, but the two units were nowhere fully defined and their mutual contact was commonly regarded as diachronous. Mitchell (in Mitchell *et al.*, 1947, p. 122), however, described a distinctive bed about 0.6 m thick at the junction between the two units in the Don Valley near Sprotbrough and this bed was informally defined in his memory as the lower dolomite of the Hampole Beds by Smith (1968); the full normal sequence of the Hampole Beds at Micklefield Quarry (Figure 4.15) differs only slightly from that at the type locality. Within the Hampole Beds, the contact between the two members is taken at the base of the middle mudstone, though Moss (1986) advocated taking the contact at the top of an inferred palaeosol in the middle of the middle mudstone in parts of the Don Valley area where this bed is thicker than its usual 10–30 mm.

Figure 4.15 Section of the Hampole Beds and other strata at Micklefield Quarry. Abbreviations signify parts of the typical Hampole Beds sequence: HD, Hampole Discontinuity; LD, lower dolomite; MM, middle mudstone; UD, upper dolomite; UM, upper mudstone. The lower mudstone is absent. The Wetherby Member–Sprotbrough Member contact is taken at the top of the lower dolomite.



Description	Thickness (m)
Dolomite ooid grainstone, pale cream, fine-grained, well-sorted, fairly evenly bedded in lowest 0.3-1.3m where locally weakly unevenly laminated to trough cross-laminated in sets up to 0.15m thick, increasingly coarsely cross-stratified above in sets up to 5m thick;1-5mm layer of grey-green plastic argillaceous dolomite or dolomitic clay at base	7.00+
Dolomite ooid grainstone, pale cream, fine-grained, partly weakly unevenly laminated, with roughly concordant minor stylolites	0.25-0.30
Dolomite ooid grainstone, pale cream, fine-grained, thin-bedded to flaggy in lower 0.15-0.18m where soft, unevenly weakly laminated above; some small-scale cross-lamination	0.35-0.40
Dolomite-illite rock, grey-green, with subordinate quartz and chlorite; shaly, plastic when damp (UM)	0.01-0.04
Dolomite ooid grainstone, pale cream, fine-grained, partly faintly finely (?algal) laminated, slightly argillaceous in lower part; a few small pisoids and ?rip-up clasts (UD)	0.10-0.15
Dolomite-illite rock, grey-green, with subordinate quartz and chlorite; shaly, plastic when damp (MM)	0.01-0.03
Dolomite ooid grainstone, pale cream-buff, mainly fine-grained, unevenly (?algal) laminated, with a few traces of small-scale cross-lamination and shallow channels; generally strongly fenestral; dense layers at some levels may be crusts and scattered (partly imbricated) rip-up clasts may be crust fragments; casts of small bivalves and gastropods locally common near base (LD)	0.75-0.90
Erosion surface (HD), gently rounded to slightly uneven, local relief 5-10cm; some minor steep-sided hollows (?channels)	
Dolomite peloid grainstone, pale cream-buff, slightly lenticularly unevenly thick-bedded with some low-angle tabular cross-lamination, cut-and-fill structures and ripple-laminaton; mainly ooidal with some compound grains;traces of fenestral fabric towards top; no fossils seen. Most of this bed now covered but formerly seen to...	3.65+

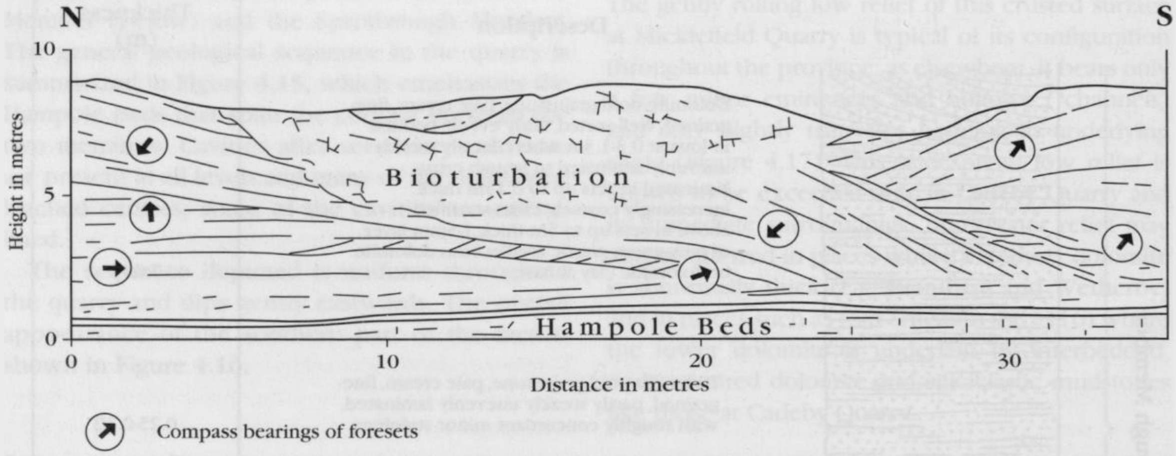


Figure 4.16 Sketch of the southern part of the main face at Micklefield Quarry, showing the cross-stratification in the Sprotbrough Member of the Cadeby Formation and the position of the Hampole Beds. Slightly modified from Kaldi (1980, fig. 3.3).

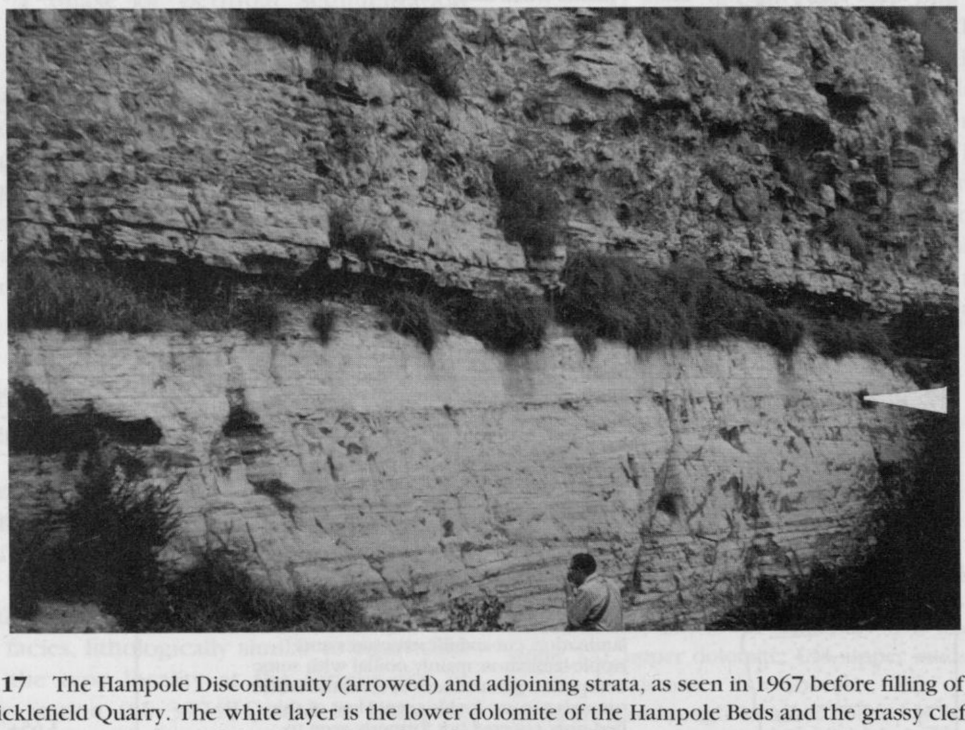


Figure 4.17 The Hampole Discontinuity (arrowed) and adjoining strata, as seen in 1967 before filling of the lower part of Micklefield Quarry. The white layer is the lower dolomite of the Hampole Beds and the grassy cleft conceals the less resistant upper parts of the Hampole Beds. (Photo: D.B. Smith.)

The most striking feature of the Hampole Beds is the unusual and environmentally significant lithology of the lower dolomite. The pronounced fenestral fabric of this algal-laminated ooidal bindstone is exceptionally clearly seen, and, in the Magnesian Limestone, is confined to this youngest bed of the Wetherby Member and a few thin lenses in grainstones a short distance below the Hampole Discontinuity. The combination of algal lamination, inferred crusts, imbricated rip-up clasts, minor channels and a convincing fenestral fabric suggests with reasonable confidence that this bed can be interpreted as the deposit of a high intertidal to predominantly low supratidal tropical marine-marginal sabkha or coastal flat (Smith, 1968); the presence at Mansfield of amphibian footprints on the surface of the underlying discontinuity (Hickling, 1906) is consistent with this interpretation.

The Hampole Beds have been traced along the depositional strike for more than 150 km from near Ripon to near Nottingham and, for a peritidal shoreline sequence, are extraordinarily uniform. All the component beds are lithologically consistent, the greatest variations being in relative and absolute thicknesses. In these respects the lower dolomite is the most variable, in keeping with its inferred beach or sabkha origin, ranging to more than 2.5 m thick at Wetherby (SE 49945) (but see Harwood, 1981, p. 82 for an alternative view) and Bramham (SE 429422), but generally being 0.2–0.8 m thick; at Wetherby and Bramham, this bed features abundant small contemporaneous volcano-like structures (?gas- or fluid-escape vents) in addition to its other distinguishing features. The lower dolomite is, of course, absent or unrecognizable above and below the tidal range (i.e. west and east of the intertidal belt). A local variant, in which a sequence of bedded dolomite and subordinate siliciclastic mudstones lies between the Hampole Discontinuity and the lower dolomite of the Hampole Beds, is discussed in the account of Cadeby Quarry.

The Sprotbrough Member

Micklefield Quarry furnishes a representative (though relatively small) cross-section through the lower part of the grainstone shoal facies of this member, but displays most of the main distinguishing features; these are a parallel-laminated to thin-bedded basal unit, a coarsely cross-stratified main body, a scarcity of shelly fossils but local abundance of burrows, and an overall makeup of well-graded small (0.10–0.15 m) dolomite ooids (Kaldi, 1980). The member is also exposed high in the face at Cadeby Quarry and in many quarry and natural sections scattered along the outcrop between Ripon (where it is in a different facies) and Nottingham. The best and most spectacular exposures of the grainstone shoal (or sandwave) facies include those at Knaresborough (SE 348571–359559), Jackdaw Crag Quarry, Tadcaster (SE 4641), Warmsworth Quarry (SE 5300), Cresswell Crags (SK 5374) and Pleasley Vale (SK 517649–525651).

The grainstone shoal facies of the Sprotbrough Member is up to 60 m thick and forms most of the outcrop from Knaresborough southwards (Smith, 1989, fig. 7). It is interpreted as marking the site of an offshore field of high-energy subaqueous dunes (Smith, 1968, 1970b), sandwaves (Kaldi, 1980, 1986a) or grainstone barriers (Harwood, 1981, 1989), and separates a shallow protected shelf or lagoon to the west from a deeper-water open marine outer shelf to the east. The sedimentology and diagenesis of these rocks was investigated in detail by Kaldi (1980, 1986a, b) and their mineralization by Harwood (1981, 1986). By analysis of the trends of the prevalent large-scale cross-stratification, Kaldi showed that the sandwaves were constructed mainly by currents from the north-east (i.e. oblique to roughly normal to the inferred contemporary shoreline) with occasional storm currents from the south-east. The change of style from parallel-bedded at the base to coarsely cross-stratified above, points to a rapid deepening of the sea following the inferred peritidal phase of the Hampole Beds (Smith, 1974a, b, 1979; Kaldi, 1980, 1986a; Harwood, 1981, 1989).

Future research

There is scope here for further detailed research on the petrography and sedimentology of the lower dolomite of the Hampole Beds and on the mineralogy and origin of the various argillaceous beds present both here and at other exposures of these strata.

Conclusions

This site provides an excellent exposure of the Hampole Beds, a remarkably persistent and uniform sequence of passage beds spanning the contact between the Wetherby and overlying Sprotbrough Members of the Cadeby Formation, and of the Hampole Discontinuity. This marine carbonate sequence evolved from shallow water to intertidal and coastal plain sediments, before the Zechstein Sea again transgressed westwards and shallow marine deposition was resumed. The site is important in recording these changing phases of deposition, and in providing evidence in the form of the Hampole Discontinuity of a phase of emergence and erosion near the top of the Wetherby Member.

SOUTH ELMSALL QUARRY (SE 483116)

Highlights

South Elmsall Quarry (box 5 in Figure 4.2) is of national importance because it provides an unusually complete and readily accessible section through a typical patch-reef in the Wetherby Member of the Cycle EZ1 Cadeby Formation. The reef has a core of massive bryozoan dolomite and a broader spectacularly domed algal mantle; it passes laterally into well-exposed shallow-water ooidal and pisoidal dolomite of types that typify a wide north to south belt that extends along much of the outcrop in Yorkshire.

Introduction

The quarry lies on the south side of Field Lane, a few hundred metres east of South Elmsall village and was cut into about 15 m of dolomitized peloid grainstones of the Wetherby Member of the Cadeby Formation; the basal unconformity was probably a few metres below the quarry floor. Most of the quarry is now filled, but the main feature of interest, a bryozoan–algal patch-reef in the upper part of the sequence in the north-east corner, has been preserved in a 9 m high vertical face. The reef has the shape of a broad inverted cone surmounted by a complex gentle dome, and is at least 8 m thick; it was described and illustrated by Smith (1981b).

The reef was discovered and brought to the Nature Conservancy Council's attention in 1966, and its conservation involved ownership disputes, complete filling and re-excavation; resolution of these problems was followed by landscaping and enclosure of the site as one of the last acts of the West Yorkshire Metropolitan County Council before it was abolished in 1986. The official opening of the site, now known as the South Elmsall Interpretative and Study Centre, was on 14 February, 1986. An information board provides a geological interpretation for visitors.

Description

The position and shape of the GCR site at South Elmsall Quarry are depicted in Figure 4.18, which also shows the location of the main feature of geological interest. The preserved faces are about 170 m long and up to 9 m high.

The entire quarry was cut into the lower half of the Wetherby Member of the Cadeby Formation (formerly the lower division of the Lower Magnesian Limestone), here composed mainly of a varied mixture of dolomitized, partly skeletal, peloid grainstones. Although well within the belt of abundant patch-reefs (Smith, 1981b, 1989), the only reef exposed when working was ceased is in the north-east corner of the quarry; it is about 105 m across and at least 8 m high (the top is not

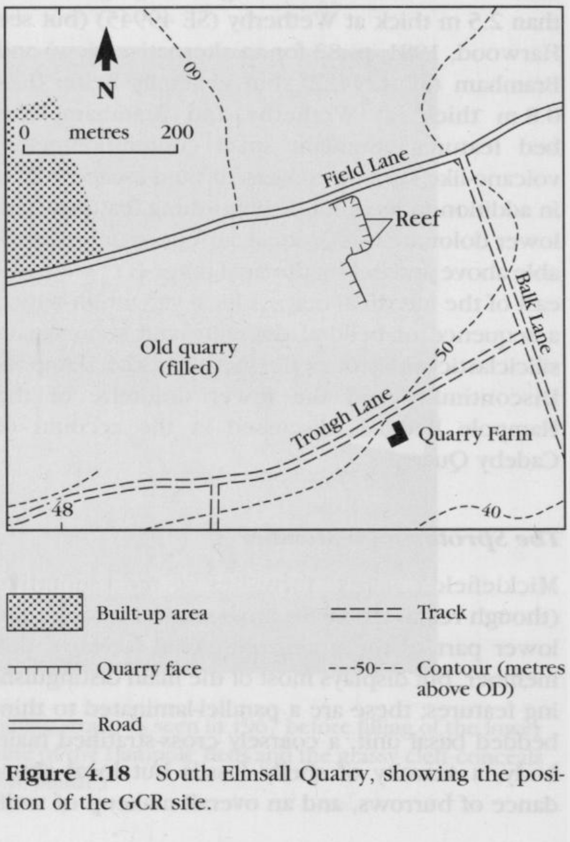


Figure 4.18 South Elmsall Quarry, showing the position of the GCR site.

exposed). This reef and its relationship to enclosing grainstones is shown in Figure 4.19.

As is common at this level in the Wetherby Member, the patch-reef in South Elmsall Quarry is in two main parts (Figure 4.19). The lower part, about 55 m across and up to 3.5 m thick, comprises buff, massive bryozoan boundstone (framestone/bafflestone) formed of a sparse framework of slender arborescent *Acanthocladia* colonies, and a predominant matrix of slightly turbid dolomite microspar and micrite, and, although complex diagenesis has obliterated much of the primary reef fabric, a few bivalve casts (mostly of *Bakevellia binneyi*) may still be found. The upper part of the reef (0–5 m) is composed of complexly domed, buff, laminated saccharoidal dolomites (Figure 4.20), interpreted on their morphology (Smith, 1981b, fig. 13) as algal stromatolitic (cyanophytic) bindstones; here, too, most of the delicate structures have been almost obscured by diagenetic changes and no undoubted algal remains have been detected. The base of the massive part of the reef is sharp and apparently slightly discordant, but the base of the stromatolitic mantle, where it oversteps the massive core, is less sharp, and at the northern margin the stromatolites grade almost imperceptibly into the surrounding grainstones.

Grainstones and subordinate packstones (11 m, including about 2 m now covered) exposed in the north-eastern corner of the site mainly comprise level-bedded, buff and cream-buff, peloidal dolomite. Ooidal rocks form most of the uppermost 6 m of the section and also occur in parts of the lowest 4 m, and some beds feature low-angle cross-stratification in sets up to 0.3 m thick; casts of bivalve and gastropod shells occur at several levels and are scattered abundantly, and most beds contain a few stromatolite flakes, pellets, compound coated grains and other pisoids. Pisoids up to 8 mm across are abundant, however, in a 0.9 m bed 6–7 m below the top of the section, and are accompanied by reworked flaky clasts of ooidal and pisoidal grainstone exceptionally up to 0.1 m across, but generally less than 0.03 m. Such clasts were first noted at this quarry by Mitchell *et al.* (1947, p. 122), who referred to them as 'pebbles'. The pisoids may be oncoidal (algal) in origin, but no algal filaments have been recognized. Leaching has removed the cores of many peloids and parts of the grainstone sequence also contain cavities up to 0.1 m across after leached secondary anhydrite. The biota of the grainstones in the Wetherby Member at South Elmsall Quarry has not been investigated in detail, but Mitchell *et al.* (1947, pp. 118 and 121) recorded *Bakevellia antiqua* (*binneyi*), *Liebea squamosa*, *Pleurophorus*, *Permophorus costatus*, *Schizodus truncatus* (= *S. obscurus*) and several species of small

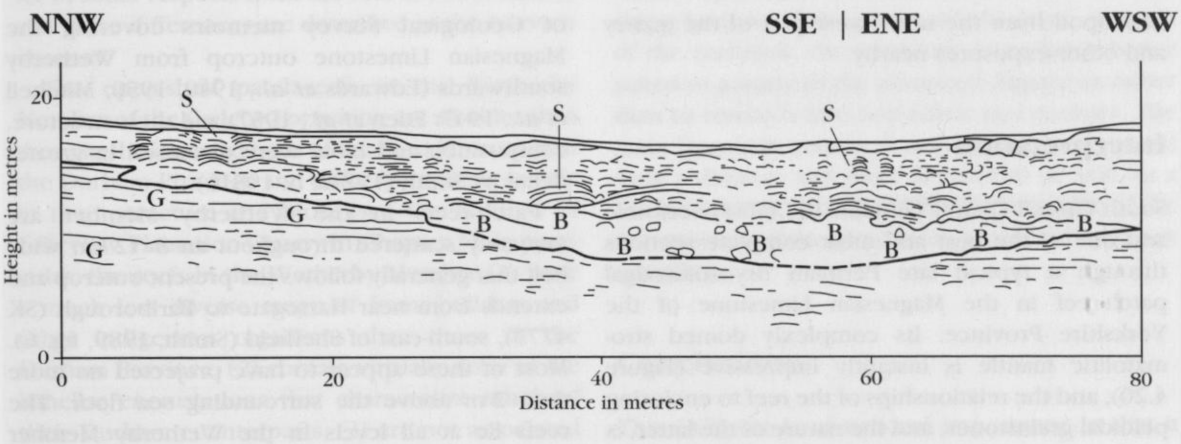


Figure 4.19 Cross-section of an algal-stromatolite reef in peloid grainstones of the Wetherby Member of the Cadeby Formation, South Elmsall Quarry. The core of the reef is of massive bryozoan boundstone and is overlain by more extensive stromatolites that pass laterally NNW into sparingly skeletal peloid grainstone. The stromatolites extend at least 30 m to the right of the area depicted. Note: lowest strata depicted are now covered. Slightly modified from Smith (1981b, fig. 12).

Figure 4.20 Complexly domed dolomitized algal-stromatolites discordantly overlying thin-bedded dolomite peloid grainstones. Central part of east face of South Elmsall Quarry. Bar: 1 m. (Photo: D.B. Smith.)

gastropod from the north-west part of the quarry and other exposures nearby.

Interpretation

South Elmsall Quarry contains the most accessible and one of the best and most complete sections through a typical late Permian bryozoan–algal patch-reef in the Magnesian Limestone of the Yorkshire Province. Its complexly domed stromatolitic mantle is instantly impressive (Figure 4.20), and the relationships of the reef to enclosing peloidal grainstones, and the nature of the latter, is particularly clear.

Although the presence of unbedded masses of dolomite in the Cadeby Formation was mentioned by several authors, including Kirkby (1861) who recognized that they contained a sessile fauna that had probably grown *in situ*, these were first described as reefs by Mitchell (1932a). These reefs were subsequently documented briefly in a series of Geological Survey memoirs covering the Magnesian Limestone outcrop from Wetherby southwards (Edwards *et al.*, 1940, 1950; Mitchell *et al.*, 1947; Eden *et al.*, 1957) and their structure, composition and biota were discussed in greater detail by Smith (1974a, b; 1981b).

Patch-reefs in the Wetherby Member are unevenly scattered throughout an 8–12 km wide belt that generally follows the present outcrop and extends from near Harrogate to Barlborough (SK 4777), south-east of Sheffield (Smith, 1989, fig. 6). Most of these appear to have projected no more than 2 m above the surrounding sea floor. The reefs lie at all levels in the Wetherby Member between the top of the widespread Bakevellia Bed (which may have provided a stable substrate) and the Hampole Discontinuity, and range from simple hemispherical bodies less than 1 m across and 0.4 m thick to complex bodies more than 100 m across and up to 30 m thick; most are 10 to 25 m across and 3 to 8 m thick, and many of the largest bodies were formed by the coalescence of a number of smaller reefs. In places such as Hooton Pagnell village (SE 4808), patch-reefs make up at least half of the Wetherby Member, and more than 20 reefs have been partly to wholly quarried away during the excavation of the 1 km^2 site at Cadeby Quarry; elsewhere, as at South Elmsall Quarry, reefs are relatively uncommon.

The character and shape of the reefs varies according to the stratigraphical level at which they occur within the member (Smith, 1974b, 1981b), and all the main types are represented in one or more of the reef GCR sites in the Yorkshire Province. Those formed near the base of the formation, as exemplified by the reefs of the Wood Lee Common site, Maltby, comprise an untidy aggregate of bryozoan saccoliths, and those near the top of the member, such as the youngest of those at Cadeby Quarry, are mainly of domed algal stromatolites. Those at stratigraphically intermediate levels, such as the reefs at the South Elmsall and Newsome Bridge sites, have a core of bryozoan saccoliths and a mantle of algal stromatolites. It is possible, of course, that some apparently wholly stromatolitic reefs near the top of the member may be founded on saccolithic cores outside the plane of section. Other stromatolite-mantled reefs were formerly exposed in a road cutting at Collingham (SE 398460), near Wetherby, and in Alverley Grange Quarry (SK 554992) near Doncaster, and are poorly exposed behind houses in the village of Bramham (SE 435428); those at Cadeby Quarry differ in some respects from the reef at South Elmsall and these differences are described in the relevant account.

The open-shelf patch-reefs in the Wetherby Member of the Cadeby Formation are all older than those in the lagoonal beds of the Ford Formation of the Durham Province and differ from them greatly in their structure and biota (see the account of Gilleylaw Plantation Quarry in Chapter 3); in particular, the reefs in the Wetherby Member (1) have a much less diverse range of frame-builders and other indigenous organisms than those in the Durham Province, (2) contain virtually none of the lamellar encrustations that characterize much of their Durham counterparts, (3) are not associated with contemporaneous talus and (4) many have evolved into stromatolite bodies that have no parallel in Durham. No patch-reefs like those in the Yorkshire Province have been reported from the contemporaneous Raisby Formation of the Durham Province, but the Durham rocks belong mainly to a deeper-water facies found east of the reef belt in Yorkshire, and reefs could have lain west of the present Durham outcrop, but since been removed by erosion.

The dolomitized grainstones surrounding the South Elmsall reef are typical of much of the outcropping Wetherby Member wherever patch-reefs are present and are also well-exposed in several neighbouring quarries. The generally good grading and the cross-lamination of the ooidal rocks, and the comparative rarity of carbonate muds, point to accumulation and winnowing under at least moderately agitated conditions though large bedforms are uncommon, and the local abundance of compound grains and rip-up clasts suggest phases of sea-floor cementation and perhaps of relative quiescence punctuated by occasional storms. The general impression is of a tropical open-shelf sea no more than a few metres deep and widely dotted with generally small patch-reefs; there is no firm evidence of subaerial exposure either of the reefs or surrounding grainstones. The grainstone floor clearly supported an abundant, but low-diversity bivalve-gastropod biota, but the growth of small bush-like bryozoan colonies led to the creation of a more varied suite of reefy subenvironments in which a rather more diverse and different fauna flourished.

Future research

The main strength of the exposures of reef and surrounding strata at South Elmsall Quarry lies in their visual impact and their scale and mutual relationships; because of the profound alteration of much of the reef-rock, the exposure is probably better suited to a study of the advanced diagenesis rather than to research into reef fabric and ecology. The main face must remain, however, one best viewed from a distance and there is much to be said for a 'no hammering' policy and the preservation of the impressively photogenic faces unscarred by heavy sampling.

Conclusions

This GCR site is of national importance in that it contains one of the best sections through a patch-reef and its surrounding shallow-water carbonate rocks. The sequence is within the Wetherby Member which forms the lower part of the Cadeby Formation in Yorkshire. The morphology of the patch-reef is uniquely displayed as an inverted shallow cone with a gently dome-shaped top; the lower part contains a bryozoan framework and the dome-shaped top is composed of algal stromatolites. The surrounding oolites contain a restricted suite of fossils, chiefly bivalves and gastropods. The site illustrates the structure and spatial relationships of the reef to the surrounding sediments, and, for this reason, South Elmsall Quarry has been preserved for further study and research.

BILHAM QUARRY (SE 487066)

Highlights

Bilham Quarry is important as a representative section of the basal few metres of the Permian sequence in the central part of the Yorkshire Province. The sequence comprises most of the Basal Permian ('Yellow') Sand and lowest beds of the Cadeby Formation of the Magnesian Limestone.

Introduction

The section at Bilham Quarry (box 6 in Figure 4.2) lies amongst trees on the east side of Bilham Lane, about 1100 m south of Hooton Pagnell village church and 300 m north-east of Bilham House; it is all that remains of a large shallow quarry that has otherwise been filled and landscaped. Exposed strata comprise bedded dolomite of the Wetherby Member of the Cadeby Formation (*c.* 3.45 m+) on Basal Permian ('Yellow') Sands (*c.* 3.3 m+).

There are no published records of the section now preserved at Bilham Quarry, but Mitchell (1932a, plate 8) illustrated a similar sequence 'at Bilham House' (about 300 m to the south-west) and Mitchell *et al.* (1947, p. 117) recorded (possibly repeated) this section, then specified as 800 yards (730 m), north-east of Bilham House and at a site shown on the six-inch Geological Survey map as a small sand pit.

The face at Bilham Quarry was preserved and landscaped by the South Yorkshire County Council specifically to facilitate geology teaching and research.

Description

The position of the face at Bilham Quarry is shown in Figure 4.21; it is about 60 m long and up to 6.8 m high. The face is commonly partly obscured by vegetation and soil-wash and may be difficult to locate in high summer. The general geological sequence in Bilham Quarry is shown below.

	Thickness (m)
Cadeby Formation, Wetherby Member (shelf facies)	up to 3.45
Basal Permian ('Yellow') Sands, base not seen	up to 3.3

The strata are roughly horizontal and there are no faults; the Carboniferous–Permian Unconformity is not now exposed but was revealed temporarily during landscaping and lies an estimated 1–1.5 m below the preserved section.

Basal Permian Sands

The Basal Permian (or 'Yellow') Sands in the preserved face at Bilham Quarry comprise yellow-brown and yellow-grey, weakly-cemented to

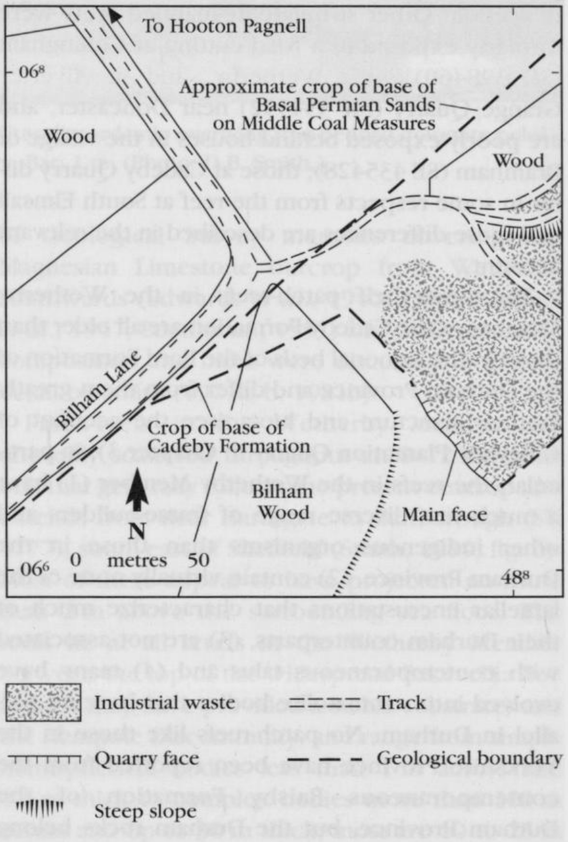


Figure 4.21 The preserved area of Bilham Quarry and its environs.

almost uncemented, medium-grained sand in generally ill-defined horizontally bedded units; a pale grey-brown bed about 1.35–1.55 m below the top has a dolomite cement and may be a sandy dolomite, and the lowest 1.8 m of the exposed sequence features rhythmic secondary banding similar to that produced by Liesegang rings. Grains in the sand are mainly of quartz and most are subangular; many beds contain a few coarse rounded to well-rounded grains, some frosted, and green and red coarse grains are scattered sparingly throughout.

The Cadeby Formation

The Wetherby Member of the Cadeby Formation at Bilham Quarry mainly comprises flaggy and thin-bedded (beds 0.04–0.20 m thick) buff dolomite wackestones and mudstones with several laminae and thin beds of soft dolomitic clay or clayey dolomite in the uppermost 2.65 m; the lowest 0.8 m of dolomite present is superficially similar to the overlying beds but may be an altered ooid grainstone or packestone. Scattered casts of bivalves (mainly species of *Bakevellia* and *Schizodus*) occur at some levels throughout the section, but the well-known and extensive Bakevellia Bed, though present in parts of the former quarry, is absent at this southern extremity. The base of the formation is flat and basal beds are only sparingly sandy.

Interpretation

Bilham Quarry is an exposure of the Basal Permian (or 'Yellow') Sands, a formation that is generally poorly and only temporarily exposed; though small, the exposure exhibits most of the features typical of this formation at outcrop in Yorkshire. Although most Permian sandstones in Britain are continental in origin and of early Permian age, the Basal Permian Sands in Yorkshire qualify for inclusion in the Marine Permian Review because they are considered (Versey, 1925; Pryor, 1971) to have been completely redistributed during or soon after the late Permian Zechstein transgression.

The Basal Permian Sands crop-out patchily along the escarpment and this patchiness is also apparent from borehole and shaft provings farther east (see Versey, 1925, and the Geological Survey memoirs for Sheets 70, 78, 87 and 100); at outcrop the sands are generally only a few metres thick, but reach a reported 8.2 m at crop at Laughton en le Morthen (SK 5288) (Eden *et al.*, 1957). The general distribution of the formation, and its geographical relationship to associated basal breccias, was summarized by Smith (1989, fig. 3); it should be noted, though, that the breccia and sand facies are not mutually exclusive and that a thin breccia not uncommonly underlies the sands (Versey, 1925; Smith, 1974b).

The petrography and sedimentology of the Basal Permian Sands at outcrop in Yorkshire were investigated by Versey (1925) and Pryor (1971), and were summarized by Smith (1974b). The deposit is mainly of uncemented to weakly-cemented, fine- to medium-grained, yellow subarkose, which is grey and blue-grey in the subsurface farther east. It owes its outcrop colour mainly to grain-surface pellicles of hydrated iron oxides and, though authigenic kaolinite is relatively abundant, the main cement (where present) is calcite. Grains are mainly of quartz, but up to 10% of potash feldspars are ubiquitous and up to 20% of rock fragments are widespread; they are predominantly rounded to subrounded in the area investigated by Pryor (from Glass Houghton northwards), with less than 10% of the coarse well-rounded grains for which the formation is noted. Level, thick bedding predominates in most exposures, including Bilham Quarry, but is commonly masked by coarse rhythmic Liesegang-type colour banding. The dominant sedimentary structure in the Leeds area is said by Pryor (1971, p. 244) to be tangential trough cross-lamination in sets typically 0.10–0.65 m thick. A suite of abraded heavy minerals dominated by garnet, tourmaline and zircon was thought by Versey (1925, p. 209) to have survived long transport or be multicyclic.

The Basal Permian Sands in Yorkshire were once widely worked for moulding sand, and in a number of places were followed underground by bord and pillar workings in faces up to 3 m high. In a number of places the roofs of such workings have proved to be unstable, leading to severe subsidence problems. All the underground workings are now closed and most of the quarries are filled; there are no present workings and the few remaining exposures are in road and rail cuttings, which are commonly bricked-over, and in small quarries that have so far escaped filling.

Future research

The Basal Permian Sands in Yorkshire, including those at Bilham Quarry, are now indifferently exposed and no longer readily susceptible to regional petrographic and sedimentological investigation. There is, however, scope for further investigation of these aspects in borehole cores from farther east, and for refining knowledge of the distribution of the formation as new borehole data become available.

Conclusions

Bilham Quarry is one of only two listed GCR sites in the Yorkshire Province that contain a section in the basal Permian deposits and the lowest beds of the overlying Cadeby Formation, the other being Ashfield Brick-clay Pit. The sands are uncemented or weakly cemented, yellow and thickly bedded. They have been extensively worked for moulding sand, but the underground workings have now been closed and most of the surface exposures have been filled in. The lower beds of the Cadeby Formation are of fine-grained, thin-bedded dolomite with thin clayey layers and contain a scattered fauna chiefly of bivalves. The sands are considered to owe their origin to reworking of former aeolian sands during the late Permian marine transgression. The site's principal claim for preservation is that it is one of the last remaining exposures of the basal part of the late Permian sequence in Yorkshire.

CADEBY QUARRY (SE 5200)

Highlights

Cadeby Quarry (box 7 in Figure 4.2) is the type locality of the Cadeby Formation and provides by far the largest and most comprehensive exposure in Yorkshire of both the Wetherby and Sprotbrough members and their mutual contact; the Wetherby Member here is of open shelf facies and contains more than 20 patch-reefs (at least some of a type found only at Cadeby) and the Sprotbrough Member is of offshore sandwave (shoal) facies with exceptionally large-scale cross-bedding. The intervening Hampole Beds are thicker here than anywhere else and atypically have yielded plant remains, and the erosion surface of the Hampole Discontinuity has a uniquely high relief of up to 3 m.

Introduction

The great working quarry at Cadeby lies on the north side of the River Don, south and east of the hamlet of Cadeby; most of the quarry is scheduled for filling, but the 18–23 m high north face is to be preserved when working ceases. Strata worked in Cadeby Quarry make up most of the Cadeby Formation, and comprise the Wetherby Member (13 m+) and the overlying Sprotbrough Member (10 m+); the latter is typical of this unit in the offshore sandwave or shoal belt of the English Zechstein marginal shelf, but the Wetherby Member is a uniquely spectacular mosaic of large byozoan-algal patch-reefs and surrounding skeletal grainstones. The Hampole Beds (?1–4 m) are atypical in containing abundant siliciclastic mudstones.

There are no comprehensive published accounts of Cadeby Quarry though summaries of strata have been given (Smith, 1969b, 1981b; Smith *et al.*, 1986). Reefs and associated strata exposed in nearby railway cuttings and on the opposite bank of the Don were mentioned by Mitchell (1932a) and Mitchell *et al.* (1947) and a typical Cadeby Quarry reef was discussed and illustrated by Smith (1981b, fig. 5). The presence of plants in the mudstones of the Hampole Beds was mentioned by Downie (1967) and a comprehensive account of the geochemistry of the Hampole Beds exposed in an abandoned railway cutting a short distance east of the quarry was given by Moss (1986).

Description

The position of Cadeby Quarry and its extent in 1990 is shown in Figure 4.22, which also shows the position of the retreating north face where the GCR site is concentrated. This face is about 18–23 m high (according to position) and 300–400 m long.

The quarry is cut through most of the Cadeby Formation, an estimated 7 m of which (proved by boreholes) underlies the quarry floor and a small thickness (probably less than 5 m) has been eroded from the top. The general geological sequence in the quarry is shown diagrammatically in Figure 4.23.

Wetherby Member, including most of the Hampole Beds

The Wetherby Member at Cadeby Quarry comprises three main rock types, all dolomite; peloid grainstones (with some packstones), bryozoan-rich boundstone (in patch-reefs) and domed stromatolitic laminites. In general the reefs are scattered

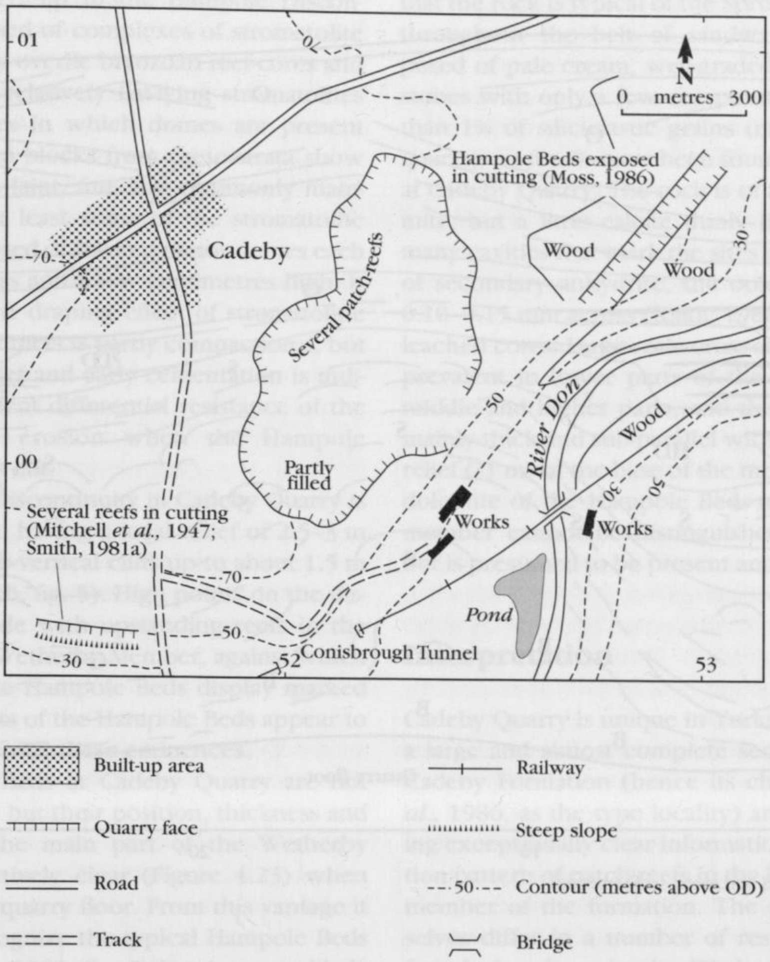
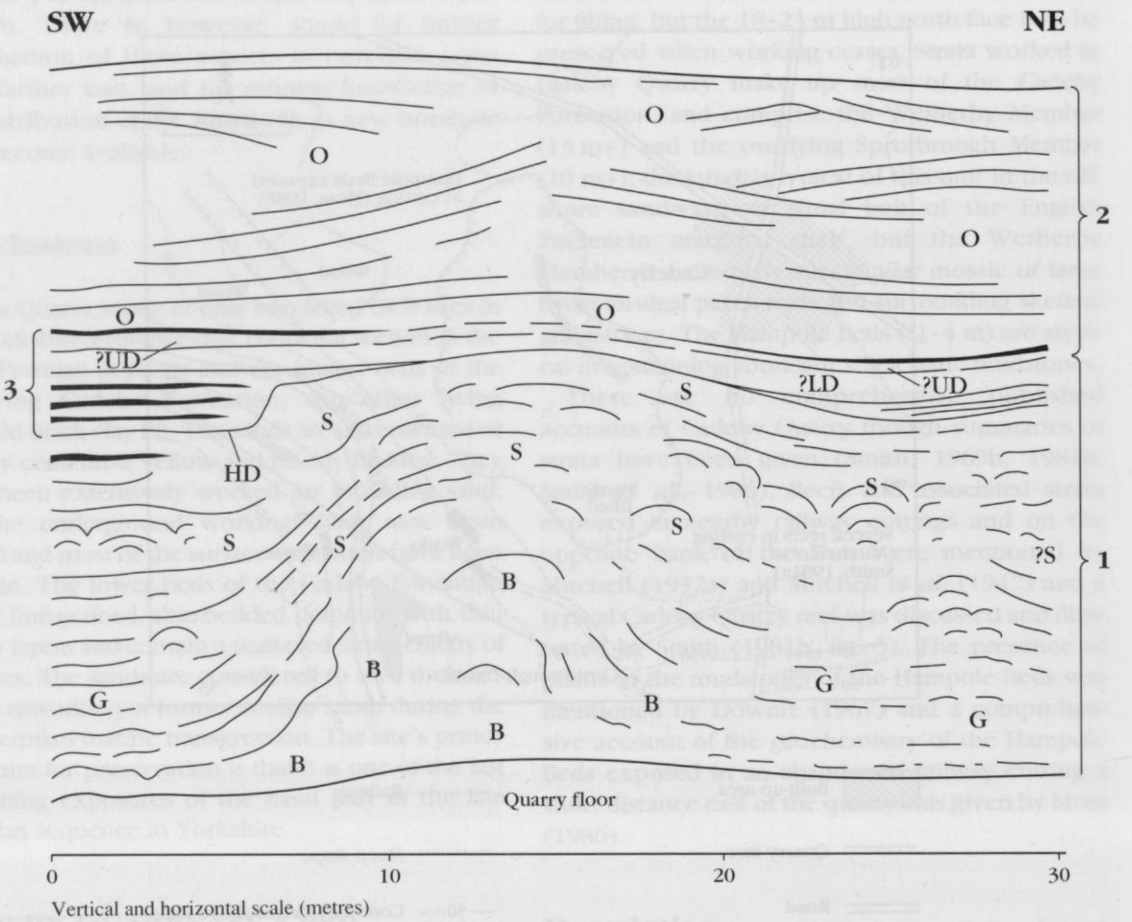


Figure 4.22 Cadeby Quarry and its environs, showing the location of the main features of geological interest.

unevenly in an otherwise continuous sheet of grainstones and grade upwards into stromatolite mantles that progressively extend to form much of the upper part of the member.

Grainstones in the Wetherby Member at Cadeby Quarry are similar to those surrounding the patch-reefs at South Elmsall Quarry and Newsome Bridge Quarry and comprise a varied mixture of pale buff, poorly-sorted ooids (predominant), pellets, compound grains, botryoidal grains, lumps, pisoids, stromatolite flakes, scattered tabular clasts up to 0.1 m across of ooid grainstone, and bioclasts. Some or all of the pisoids may be oncoidal (algal) in origin but no undoubted algal filaments have been recognized. The bioclasts are mainly represented by casts of largely unworn bivalves (*Bakevellia, Liebea, Permophorus* and *Schizodus*) and small gastropods, and they occur in profusion at some levels. Cavities after secondary anhydrite abound.

Patch-reefs in the Wetherby Member at Cadeby Quarry occur at intervals of 100–200 m in the north and west faces and similarly-spaced low eminences on the quarry floor show where others have been almost quarried away; more than 20 reefs are, or have been, present. Most of the reefs are roughly circular in plan and 15–50 m across at the level of the quarry floor; they have a buff and grey-buff, hard bryozoan boundstone (framestone) core at least 8 m high (bases not seen) and most are steep-sided mounds (Figure 4.23). In detail, the reef-cores are dense masses of dolomite mudstone and siltstone with a varied 5–50% framework of straggling and pinnate bryozoans, including species



O	Ooid grainstones	HD	Hampole Discontinuity
▬	Dolomitic mudstones	S	Domed and planar algal stromatolites
UD	Inferred upper dolomite of Hampole Beds	G	Peloid grainstones
LD	Inferred lower dolomite of Hampole Beds	B	Bryozoan boundstone reef-core

Figure 4.23 Diagrammatic sketch showing the relationships of the stratigraphical units and main rock types in the north-west face of Cadeby Quarry. The face is about 22 m high. 1, Wetherby Member; 2, Sprotbrough Member; 3, Hampole Beds, resting on the Hampole Discontinuity.

of *Fenestella* which have not been recorded from other patch-reefs in this member; a photomicrograph of typical reef dolomite from a patch-reef near to Cadeby Quarry was published by Smith (1981b, fig. 11B). At least one of the reefs features striking arrays of finger-sized stromatolite columns, also not reported from other patch-reefs in the Wetherby Member.

Upper parts of the bryozoan patch-reefs at Cadeby Quarry are thickly draped with complexly-domed, cream to pale buff, finely saccharoidal laminites which extend part of the way down the reef sides and either merge with mantles draping adjacent reefs or pass into peloid grainstones. Details are difficult to determine because of the inaccessibility of most of the exposures, but it appears that much or most of the upper part of the Wetherby Member, up to the Hampole Discontinuity, is composed of complexes of stromatolite domes that mainly overlie bryozoan reef-cores and are separated by relatively flat-lying stromatolites and/or grainstones in which domes are present only locally. Fallen blocks from these strata show that lamination is faint, fine and commonly mammilar, and that at least some of the stromatolite domes are composed of stacked minor domes each 0.10–0.30 m across and a few centimetres high. It is possible that the draping effect of stromatolitic dolomite over the reefs is partly compactional, but some primary relief and early cementation is indicated by the evident differential resistance of the reef mantles to erosion when the Hampole Discontinuity was cut.

The Hampole Discontinuity in Cadeby Quarry is unusually uneven, having a local relief of 2.5–3 m and, in places, sub-vertical cliffs up to about 1.5 m high (Smith, 1981b, fig. 5). High points on the discontinuity coincide with upstanding reefs in the main part of the Wetherby Member, against which lower parts of the Hampole Beds display marked onlap; higher parts of the Hampole Beds appear to thin only slightly over these eminences.

The Hampole Beds at Cadeby Quarry are not readily accessible but their position, thickness and relationship to the main part of the Wetherby Member are relatively clear (Figure 4.23) when viewed from the quarry floor. From this vantage it is difficult to recognize the typical Hampole Beds sequence (Smith, 1968, fig. 2) but it seems likely that the usual members of this sequence form the upper (more uniform, Sprotbrough Member) part of the Hampole Beds at Cadeby Quarry and are augmented by a discontinuous lowest unit (up to 1.8 m thick, part of the Wetherby Formation) which occupies hollows in the discontinuity surface. Fallen blocks from this lowest unit reveal it to be mainly of thin- to thick-bedded, buff to grey-green, slightly argillaceous dolomite mudstone with thin beds and lenses of grey, green and red siliciclastic mudstone from which Downie (1967) recorded remains of a land conifer.

Sprotbrough Member, including the upper part of the Hampole Beds

This forms the upper part of the faces all round the quarry and is about 7–10 m thick in the north face; it is not readily accessible, but can be seen from the quarry floor to be mainly coarsely cross-stratified in wedge-shaped sets individually up to about 8 m high. Fallen blocks from this unit show that the rock is typical of the Sprotbrough Member throughout the belt of sandwaves, being composed of pale cream, well-graded, fine ooid grainstones with only a few compound grains and less than 1% of siliciclastic grains (mainly subangular quartz); no fossils have been found in this member at Cadeby Quarry. The rock is of almost pure dolomite, but a little calcite thinly lines some of the many cavities that mark the sites of former patches of secondary anhydrite; the ooids average about 0.10–0.15 mm across (Kaldi, 1980) and many have leached cores. Large-scale cross-stratification is less prevalent in lower parts of the member than in middle and higher parts, and the lowest beds are mainly thick and sub-parallel with the slight rolling relief (?1 m) of the base of the member. The upper dolomite of the Hampole Beds at the base of the member cannot be distinguished with certainty, but is presumed to be present and 0.1–0.3 m thick.

Interpretation

Cadeby Quarry is unique in Yorkshire in providing a large and almost complete section through the Cadeby Formation (hence its choice by Smith *et al.*, 1986, as the type locality) and also in furnishing exceptionally clear information on the distribution pattern of patch-reefs in the lower (Wetherby) member of the formation. The patch-reefs themselves differ in a number of respects from those found elsewhere in the Wetherby Member, and the Hampole Beds are atypically thick and more diverse than in most other places.

Wetherby Member

The main interest in Cadeby Quarry, and its main asset as a GCR site, lies in (a) the many spectacular patch-reefs and enclosing strata and (b) the unusually high relief of the Hampole Discontinuity and the atypically great thickness of the Hampole Beds.

Patch-reefs and enclosing strata

The distribution and character of patch-reefs in the Wetherby Member in Yorkshire were described by Smith (1974b, 1981b, 1989) and are summarized here in the accounts of the Newsome Bridge, South Elmsall and Wood Lee Common sites; they occur in a roughly north to south belt a few kilometres wide that is parallel with the depositional strike and present outcrop, and lie at a range of levels between the Bakevellia Bed and the Hampole Discontinuity. Despite the relatively large number of exposures of patch-reefs, their spacing and relationship to enclosing strata is nowhere as clearly seen as in Cadeby Quarry.

Reefs are particularly abundant in parts of the area west of Doncaster and were first identified as such by Mitchell (1932a); the presence here of beds packed with bryozoans was however, recognized by Kirkby (1861) who inferred that they were the remains of prolific sessile benthic communities that would probably now be termed reefs. Mitchell *et al.* (1947) noted the presence of reefs in a railway cutting (SK 513996 – 519995) (Figure 4.22) and Smith (1981b, figs 10 and 11B) illustrated bryozoan boundstone from there. In general, however, few of the reefs in the Don Valley between Cadeby and Conisbrough are fully exposed and their detailed composition and relationships are less clear than at Cadeby Quarry.

Most large patch-reefs in the Wetherby Member in the Yorkshire Province have a bryozoan boundstone (framestone) core and a mantle of coarsely domed algal stromatolites, and in these characteristics the Cadeby Quarry reefs are no exception. They differ from most reefs in the member, however, in being narrower in relation to their height, in not being constructed of obvious saccoliths based on ramose bryozoans such as *Acanthocladia* (though this fossil is very abundant), in containing fenestrate bryozoans such as *Fenestella,* and also in containing narrow ('finger') columnar stromatolites and sinuous stromatolite sheets. The significance of these differences from the general range of patch-reefs in the Yorkshire Province is unclear and merits further study; slightly greater initial water depth and slightly lower salinity are two possible causes.

Grainstones and packstones enclosing the Cadeby Quarry patch-reefs are normal for the reef belt, and require little special comment. They are well seen in the railway cutting a short distance to the south where many weathered faces show the constituent grains more clearly than in the fresh quarry sections. The grainstones there and nearby are exceptional only in their local content of scattered reworked grainstone clasts up to 0.13 m across and of even larger clasts of rock described by Mitchell *et al.* (1947, p. 120) as 'close-grained dolomite'; the presence of these implies contemporaneous (?submarine) cementation and occasional considerable energy levels.

Algal-stromatolite (cyanophyte) mantles widely characterize patch-reefs that extend into the upper part of the Wetherby Member, and were discussed in the accounts of Newsome Bridge Quarry and South Elmsall Quarry; those at Cadeby Quarry are, however, exceptionally thick and extensive and it appears (but is difficult to prove in the available vertical faces) that most of the uppermost 6 m of the member here may be stromatolitic. Only the section at the former Alverley Grange Quarry (SK 554992, near Doncaster) was comparable in this respect. As with the differences between the patch-reefs at Cadeby Quarry and those elsewhere, the reasons for the atypical thickness and extent of the stromatolites is unclear.

The Hampole Discontinuity and the Hampole Beds

Almost throughout its range from near Ripon to near Nottingham, the Hampole Discontinuity has a gentle rolling relief of only a few centimetres, that at the exposure at Micklefield Quarry being typical (see Figure 4.17); the relief of up to 3 m at Cadeby Quarry and of 2.5 m at a nearby abandoned railway cutting (Moss, 1986) is therefore exceptional, as are the buried cliff notches surrounding reefs high in the quarry faces at Cadeby. The thickness of strata removed during the erosion of the discontinuity and, by implication, the sea-level decline that caused the erosion, cannot be estimated elsewhere in the Yorkshire Province but is shown at Cadeby to have been at least 3 m. The more normal relief was seen in former exposures of the Hampole Discontinuity at Boat Lane Quarry (SE 533013) at Sprotbrough, a little over 1 km to the north-east.

The atypically large thickness of much of the Hampole Beds at Cadeby Quarry is clearly a response to the abnormal relief of the discontinuity, the additional beds filling a local hollow and surrounding the more resistant reef-top mounds. Smith (1969b, p. 177) and Moss (1986) suggest that the beds filling these hollows may be estuarine. For further discussion of the Hampole Beds near Cadeby Quarry see Moss (1986) and for discussion of the Hampole Beds in general see Smith (1968) and the account here of Micklefield Quarry.

Sprotbrough Member

Difficulty of safe access to the high faces in which the Sprotbrough Member is seen in Cadeby Quarry limits the value of these for teaching and research purposes, but they nevertheless provide an excellent section through an assemblage of large ooid sandwaves and show their spatial relationship to the underlying Hampole Beds. Other, thicker, sections of these strata may be seen and are more readily accessible at many other places, however, including the nearby Warmsworth Cliff (SE 538009). The distribution and environmental significance of the sandwave facies of the Sprotbrough Member of the Cadeby Formation are discussed in more detail in the account of Micklefield Quarry.

Future research

The present inaccessibility of much of the main face at Cadeby Quarry has resulted in much uncertainty and has left ample scope for future research. In particular the biota, ecology and petrography of the patch-reefs is in need of careful study in view of the apparent differences between the Cadeby Quarry reefs and those elsewhere, and the character and flora of the multi-coloured beds between the Hampole Discontinuity and the lower dolomite of the Hampole Beds would amply repay further research.

Conclusions

This exceptionally large quarry is the type locality of the Cadeby Formation, although the lowest beds lie below the floor of the quarry and the highest beds have been eroded off. The most complete sequence is in the north face of the quarry, where the Wetherby (lower) Member comprises cross-bedded oolitic dolomite and algal-laminated dolomite, and contains a number of patch-reefs that are taller and steeper sided than patch-reefs found in the Wetherby Member elsewhere in Yorkshire. The overlying Sprotbrough Member mainly comprises finely-oolitic dolomite and features spectacularly large-scale cross-bedding of a type thought to indicate deposition in offshore oolite shoals. The Hampole Beds at the contact of the two members are unusually thick here, and the underlying Hampole Discontinuity has an erosional relief of 2.5–3 m. This unusually steep relief is thought to have been caused when sea level fell by a few metres, exposing the Wetherby Member to a phase of weathering and intertidal conditions before the sea returned and the Sprotbrough Member was formed.

The site is extremely important for the study of reef development, and is more extensive than others in Yorkshire. This should afford opportunities for the closer study of fauna, palaeoecology and petrography of the reefs and the surrounding strata, as well as the changes in depositional environment indicated by the character of the overlying Hampole Beds.

ASHFIELD BRICK-CLAY PIT, CONISBROUGH (SK 515981)

Highlights

This section, preserved for geological study since 1955 but nevertheless partly filled and soon to be re-excavated, vividly illustrates how much geology can be packed into one quite small rock face. In a vertical range of less than 20 m of strata, it contains Carboniferous coal measures formed in an equatorial coastal setting, an exhumed desert land surface formed by the tropical erosion and removal of more than 500 m of Carboniferous strata, a suite of water-laid desert litter and sand trapped in minor hollows in the desert surface and, in the main part of the face, evidence that the desert was then flooded by the tropical Zechstein Sea in which was formed, successively, lagoonal muds and open-sea shallow-water oolites full of the remains of a teeming marine life; scattered small reefs complete the range.

Introduction

This exposure, in the south-east outskirts of Conisbrough (Figure 4.24), spans strata high in the local Upper Coal Measures unconformably overlain by thin basal Permian deposits and the lower part of the Wetherby Member of the Cadeby Formation. The section was first described by Gilligan (1918), who recorded an unusually pebbly facies of the basal Permian deposits and an atypical 3.5 m sequence of multi-coloured 'marls' and 'limestones' at the base of the Lower Magnesian Limestone (now the Cadeby Formation). Mitchell *et al.* (1947) gave some details of the section as it was in 1930 and Downie (1967) noted that unspecified marine microfossils were present in the lower (argillaceous) beds of the Cadeby Formation. Downie also recorded reefs in the higher Magnesian Limestone beds present.

Description

The mainly late Permian sequence exposed at Ashfield Brick-clay Pit in late 1993 is shown on page 170.

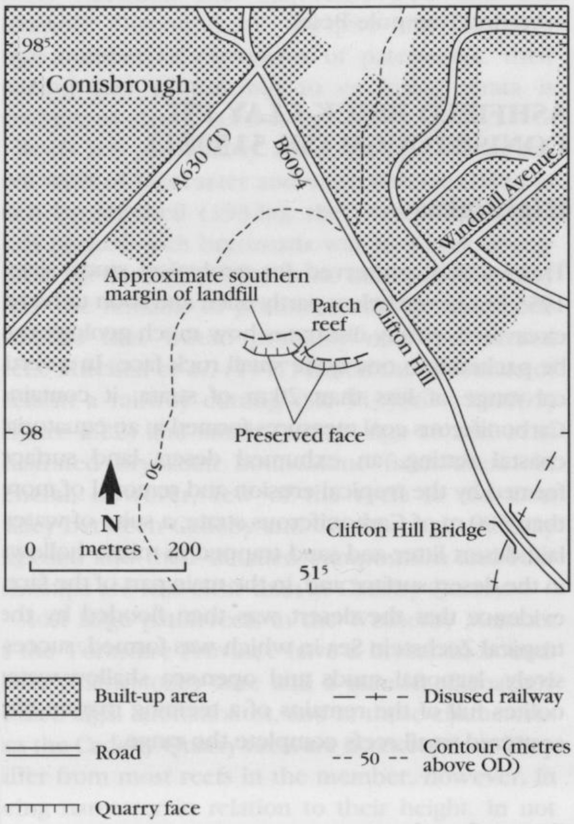


Figure 4.24 Ashfield Brick-clay Pit, Conisbrough, and its environs, showing the location of the main features of geological interest.

	Thickness (m)
Soil and dolomite brash	0.2–0.4
Cadeby Formation, Wetherby Member (open shelf facies)	
Dolomite, cream and buff, saccharoidal (fine sand-grade), porous, in fairly even beds 0.20–0.70 m thick. Passes sharply laterally into a bryozoan boundstone patch-reef about 30 m across, with some arching of overlying strata	*c.* 4.00
Dolomite, cream and buff, saccharoidal (fine sand-grade), unevenly thin- and medium-bedded (locally merging to thick-bedded)	0.60
Dolomite, buff, saccharoidal (fine sand-grade), in one to three beds, with 0–06 m of grey and dark red mottled clayey mudstone filling hollows at the top and a 0.07–0.12 m basal group of thin wavy-bedded dolomites with several laminae of red dolomitic clay	0.45
Dolomite, cream-buff, saccharoidal (fine sand-grade), in four beds 0.12–0.55 m thick; bivalves are abundant at several levels including *c.* 0.28 and 0.75 m above base. Red friable dolomite on bedding plane *c.* 0.70 m above base	1.25
Dolomite grainstone, buff, ooidal, a single bed, with traces of large ripples and cut-and-fill structures and with very abundant casts of bivalves (mainly *Bakevellia*). The Bakevellia Bed'	0.90
Dolomite, grey-buff, saccharoidal (very fine sand-grade), in unevenly flaggy beds, with two discontinuous brick-red clayey 0–0.15 mm layers 0.03 m apart at the top and other red layers in the upper part. Some irregular dark red patches. A few poor casts of bivalves,especially of *Bakevellia*	0.45
Dolomite, buff-cream, dense, saccharoidal (very fine sand-grade), in two 0.15–0.20 m beds, separated by a 0.02–0.05 m irregular layer of denser finely-mottled buff and purple-red dolomite. Both main beds contain bivalve casts and the lower also contains bryozoan casts. Probably an altered ooid grainstone	0.40
Dolomite, cream, porous, soft, saccharoidal (sand-grade), in one bed, with fairly abundant bivalve casts; brick-red patches near top. Scattered U-burrows about 13–16 mm diameter. Uneven sharp base on channelled erosion surface. Probably an altered ooid grainstone	*c.* 0.55
Dolomite, cream, saccharoidal (very fine sand-grade), thin-bedded and flasery	0.18
Dolomite, buff, saccharoidal (very fine sand-grade), one bed	0.28

Underlying strata were not visible in 1993 but are expected to be re-exposed late in 1994. The following section, based mainly on information given by Gilligan (1918), lies stratigraphically directly below that now visible and is likely to differ only in detail from that to be re-exposed.

	Thickness (m)
Cadeby Formation, Wetherby Member (Lower Marl facies)	
'Marl' (mudstone), red and grey, dolomitic	0.7
'Marl' (mudstone), kaolin-rich	0.4
Interbedded thin calcitic dolomite and red and grey 'marls'	1.3
'Marl' (mudstone), grey calcitic (0.05 m) on 'marl', red, finely bedded (0.05 m)	0.1
Dolomite, buff with thin 'marl' layers	0.4
'Marl' (mudstone), brown, slightly dolomitic and calcitic	0.2
'Marl' (mudstone), dark grey, slightly dolomitic and calcitic	0.2
'Marl' (mudstone), grey grading up to dull brown-red, calcitic, with scattered casts of *Schizodus*. Sharp base	0.2
Basal Permian deposits	
Breccio-conglomerate with persistent beds of fine-grained, weakly cemented sand, red, passing into pebbly sand where thin	0.4 – 1.7
----unconformity-----	
Carboniferous (Westphalian, Upper Coal Measures)	
Sandstone and silty shale, red at top	

Basal Permian deposits

Gilligan (1918) was moved to document this section by the unusual (to him) character of the basal Permian deposits and of the overlying basal beds of the Cadeby Formation (then known as the Lower Magnesian Limestone). The face measured by Gilligan has since been quarried away, but the basal Permian deposits were described as a friable fine sandy breccia or conglomerate with fairly persistent thin beds of sand. The deposits filled a hollow (?minor valley) on the old land surface (i.e. the unconformity), thinning westwards in 4.5 m from 1.7 m to 0.5 m and passing into sparingly pebbly sand-rock. Pebbles in the breccia and sand were generally less than 25 mm across and mainly comprised local Coal Measures (Westphalian) sandstone, hematite, chert and pink felspar. Polycrystalline quartz and chert were identified by Gilligan as the main constituents of the sand, the more resistant grains of which were 'exceedingly well rounded'; large flakes of muscovite were also recorded, and an extensive suite of heavy minerals was identified, the latter all potentially derived from Coal Measures rocks in the region. Gilligan noted that the sand in the deposits was in all respects except colour, like typical Basal Permian Sands, but it was left to Mitchell *et al.* (1947) to note that the colour was red. The face had retreated appreciably when Downie (1967) recorded a basal bed 0.75 m thick consisting of coarse, friable, gritty sand with layers of pebbles (mostly brown ironstone eroded from the local Coal Measures).

Cadeby Formation, Wetherby Member, ?Lower Marl facies

This unit, 3.5 m thick according to Gilligan (1918), 4.9 m thick according to Mitchell *et al.* (1947) and about 5.3 m thick according to Downie (1967), was described in detail by Gilligan (see tabulation) who included chemical analyses of each bed; these analyses showed that the unit mainly comprised red, brown and grey 'marls' (dolomitic and siliciclastic calcitic mudstone and argillaceous dolomite) with subordinate beds of calcitic dolomite. In addition to Gilligan's (1918) record of casts of *Schizodus* in the basal bed of this unit, Downie (1967) noted that the unit yielded unspecified marine microfossils. This unit is assigned to the Lower Marl facies on the basis of its bulk composition and clay mineral content but differs in several respects from its more extensive counterpart farther south.

Cadeby Formation, Wetherby Member, open shelf facies

This unit here comprises two main parts, a lower varied sub-unit mainly of shelly dolomite with several laminae and thin beds of red and grey dolomitic siliciclastic mudstone, and an upper sub-unit (4.6 m+) of relatively pure dolomite that, in its upper part, locally passes into a lenticular patch-reef at least 4 m thick.

Beds in the lower sub-unit range from thin and semi-nodular to thick and even, and several feature patchy purple-red hematite staining. At least two beds are of altered ooid grainstone but, as Mitchell *et al.* (1947) noted, other beds that superficially appear to be of porous saccharoidal dolomite also prove, on close inspection, to be of highly altered ooid grainstone. Casts of *Bakevellia* are common to abundant in some beds and reach rock-forming proportions in others; commonly they are associated with lesser numbers of other bivalves (*Liebea* and *Schizodus*). Casts of small fragments of the ramose bryozoan *Acanthocladia* are present in at least one bed.

Bedding in the upper sub-unit is less even than that in the lower sub-unit, but the rock-type is more uniform and less fossiliferous; most, if not all, is of highly altered dolomite ooid grainstone and most faunal remains comprise casts of *Bakevellia* that are abundant only at certain levels. The coarsely saccolithic boundstone reef into which the beds of this upper sub-unit sharply pass, however, is rich in the remains of frame-forming *Acanthocladia*. Arching of the youngest beds in the quarry against the flanks of the reef may be a compactional effect.

Interpretation

The sequence of Permian strata conserved at Ashfield Brick-clay Pit provides a window into the rarely-seen part of the sequence and an uncommon view of the Carboniferous–Permian unconformity. The latter, in this part of Yorkshire, is generally flat to very gently rolling, and bears a thin scattering of mainly small subangular resistant pebbles probably loosened from the old land surface by extreme temperature variations and chemical (mainly salt) weathering. It is, perhaps, not surprising that such pebbles should be concentrated in hollows like that here, swept there by occasional flash floods and typically high rates of run-off. Elsewhere, comparable hollows in the unconformity are extremely rare, perhaps the best known being those in the A1(M) road cutting (NZ 247128) at Cleasby, near Darlington. Breccias of local rock are, of course, relatively common in places such as Knaresborough, where the desert surface had a steep local relief (Fox-Strangways, 1874); amongst GCR sites, breccias of local debris are present around a minor sandstone hill at Newsome Bridge Quarry, near Wetherby. Such breccias differ considerably from the well-cemented rocks that are classed as Basal Permian Breccias; the latter form extensive sheets across much of the Cleveland High and comprise resistant multi-cyclic pebbles that probably accumulated as desert piedmont pavements.

Cadeby Formation, Wetherby Member, Lower Marl Facies

Rocks of this facies are uncommon in the Conisbrough area, being most widespread in the southern part of the outcrop and at depth farther east (see Smith, 1989, fig. 6 for distribution). The facies here is clearly a local variant, not connected with the main area of Lower Marl and one of a number of relatively small similar patches distributed unevenly along the outcrop from Sheffield northwards. The Lower Marl is an argillaceous facies of the Wetherby Member and it is not to be confused with the wholly older Marl Slate which does not crop out in the Yorkshire Province and is a deeper-water deposit formed under anoxic conditions.

The 'marly' rocks at Ashfield are assigned to the Lower Marl on the basis of their general stratigraphical equivalence with the argillaceous rocks in the main (southern) outcrop, their marine fauna and their overall lithological character. They differ, however, in their content of red and brown beds (uncommon in the main area), in the relative rarity of shelly fossils and in the high dolomite content of most of the carbonate rocks present. Their depositional environment is uncertain, but it may be speculated that they accumulated slowly in a low-energy inshore setting such as a shallow lagoon lying landward of a minor oolite shoal or barrier bar.

Cadeby Formation, Wetherby Member, normal facies

The lower sub-unit of this member at Ashfield is relatively normal for the area, though the number of dark red argillaceous layers and of red-stained patches is atypically high. The origin of this colour is not known, but it may have been derived from the strongly reddened Carboniferous clay-rocks immediately beneath and elsewhere in the area. Rocks composed mainly of ooids are widespread in this district at and near the base of the Wetherby Member, and the abundance of casts of a restricted range of bivalves is typical. The latter commonly reach rock-forming proportions (as here) in a 0.8–2.5 m bed near the base of the Magnesian Limestone sequence in many central outcrop areas; it seems likely (but cannot be proved) that this informally-named 'Bakevellia Bed' is the product of an unusually extensive single sheet coquina, and that shallow water and at least moderate energy are implied.

The upper sub-unit of the Wetherby Member at Ashfield is normal for the area. The altered ooid grainstones of which it is composed are almost entirely of dolomite and the patch-reef has a typical lithology and biota (Smith, 1981b) and is of typical size. Its base, not currently exposed, may extend below the 4 m bed at the top of the section, but no reefs have ever been reported in or below the 'Bakevellia Bed' and this reef is not likely to be an exception. As throughout the north to south belt of patch-reefs, formation on a broad, shallow, clear, open marine shelf with moderate energy is inferred (Smith, 1981b, 1989).

Conclusions

The site is an exposure of the basal Permian deposits overlain by the lowest basal part of the Wetherby Member of the Cadeby Formation. The actual unconformity is not exposed at the time of writing, but has been well-described by previous workers and is likely to be exposed by excavation planned for 1994. The basal deposits are red, and contain pebbles of derived Carboniferous ironstone and sandstone. The lower part of the Wetherby Member consists of multi-coloured ?lagoonal mudstones and argillaceous dolomites, overlain by open-shelf shelly dolomite containing abundant bivalve remains; dolomite at the top of the exposed sequence passes into a lenticular bryozoanal patch-reef.

NEW EDLINGTON BRICK-CLAY PIT (SK 530987)

This site was selected by Smith *et al.* (1986) as the type locality of the newly-defined Edlington Formation (formerly the Middle Permian Marls) and its acceptance as part of the GCR network followed. The site was subsequently covered but is included here because no other site has yet been identified as a suitable substitute.

Introduction

New Edlington Brick-clay Pit was cut into the 'Middle Permian Marls', which are here about 8–11 m thick and occupy a faulted north-east to south-west trough 800–900 m wide. The excavation was already large when the 1931 edition of the 1:10,560 Ordnance Survey map was surveyed, and brief notes on the section then visible were shown on the ensuing 1:10,560 geological map (Mitchell, 1932b). Details of the sequence in the eastern part of the workings were later given by Mitchell *et al.* (1947) and Downie (1967), and a sedimentologically updated sequence, combining sections in the west and east of the excavations, was given by Harwood *et al.* (1982) and Smith *et al.* (1986).

The sequence at New Edlington Brick-clay Pit

Before being covered, the Edlington Formation at its type locality at New Edlington Brick-clay Pit was seen to be about 8 m thick in the westernmost workings but thickened gradually to about 11 m in the eastern workings. In the west and north of the pit, it was worked beneath a thin cover of the Brotherton Formation and in the south the pit locally extended a few metres into the underlying Cadeby Formation. Strata exposed in 1982 in the west, at the type locality, were as shown below.

	Thickness (m)
Clay-loam, red-brown	0–0.30
Brotherton Formation	
Carbonate mudstone (mainly dolomite) and *Calcinema*-bivalve packstone, grey and buff, partly ripple-laminated, with semi-nodular very uneven bedding. Uneven smoothly rounded base, relief *c.* 0.1 m	*c.* 2.50
Sandstone, mainly brown-red and brown but pale khaki in lowest 0.08 m, very fine-grained to medium-grained, with scattered lenses of grey dolomite mudstone near top and two thin uneven beds of grey dolomite mudstone near base	*c.* 0.45
Edlington Formation	
Mudstone, purple-brown and red-brown, silty, blocky, with laminae of pale grey and pale grey-green silty sandstone	*c.* 0.30

Siltstone, sandy, grey-green, with thin beds of green medium-grained sandstone	*c.* 0.40
Mudstone, mottled dark red-brown and pale grey-green, blocky	*c.* 0.40+

Lower parts of the section, now wholly covered, comprised a few metres of poorly-exposed, dark red-brown, blocky mudstone with a number of thin beds of grey-green and red siltstone and fine-grained sandstone about 3–5 m below the top of the Edlington Formation. Some of these thin beds feature ripple lamination and others bear desiccation cracks (Figure 4.25) and hollow-faced casts of halite hoppers (Figure 4.26). Lower beds of the formation, especially the blocky mudstones, also contain a varied network of fibrous gypsum veins, the thickest of which are up to 0.10 m thick and are roughly concordant.

Faces in the east and south of the excavation revealed a similar sequence to that in the west with, additionally, about 3 m of the Cadeby Formation (Harwood *et al.*, 1982). This comprised pale-grey ooidal dolomite grainstone with a contemporaneously lithified bevelled and bored surface near the top, overlain by up to 1.2 m of monomict breccia derived from the underlying lithified grainstone (Harwood, 1986, fig. 3d).

Discussion and interpretation of the sequence

The short section now exposed at New Edlington is of interest in that the usual sharp simple contact between the Edlington and Brotherton formations is missing, its place being taken by a transition of interdigitating strata over about 0.45 m. Although it is rare to find evidence of substantial reworking of the top of the Edlington Formation during the succeeding marine transgression, such reworking may be implied here; if this is so, the contact between the two formations (i.e. the transgression surface) probably lies at the base of the 0.45 m sandstone bed which lies about 0.08–0.10 m below the lowest dolomite bed.

Special note

The choice by Smith *et al.* (1986) of New Edlington Brick-clay Pit as the type locality of the

Figure 4.25 Sandstone-filled desiccation cracks at the type locality of the Edlington Formation. Coin: 30 mm across. (Photo: D.B. Smith.)

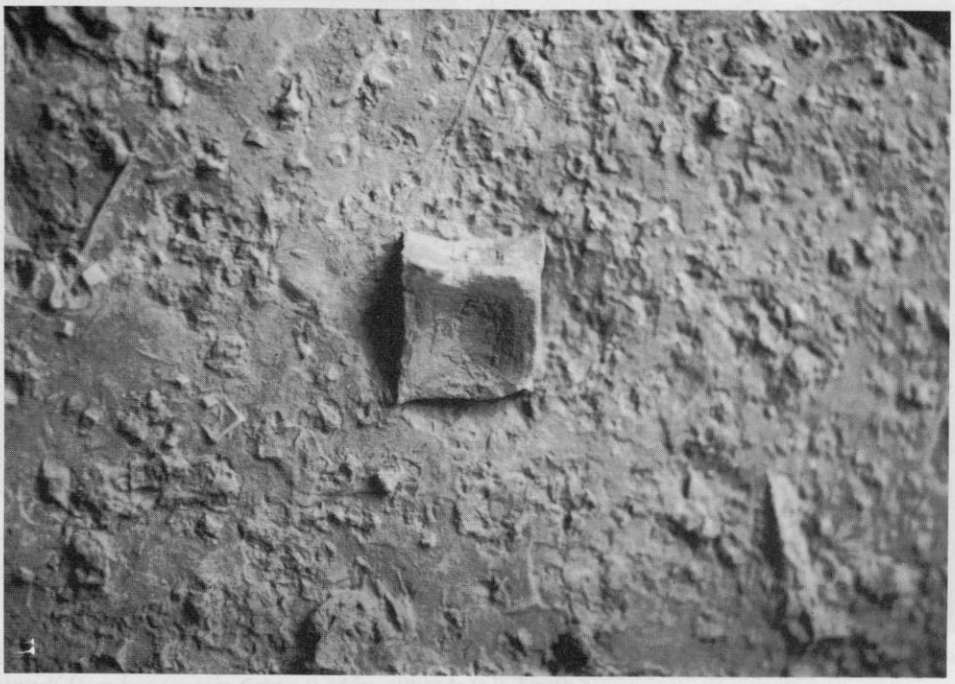


Figure 4.26 Casts of halite crystals on the underside of an argillaceous siltstone bed at the type locality of the Edlington Formation. The large cast is about 10 mm across. (Photo: D.B. Smith.)

newly-defined Edlington Formation rested mainly on the rarity of exposures of these predominantly vale-forming recessive strata. Over the years these soft rocks have been widely worked for use in brick and tile manufacture but one by one the excavations have been flooded or otherwise filled, and the exposures lost. As a type locality, the pits at New Edlington had the advantage that both the base and the top of the formation were exposed and thus readily defined, but had the disadvantage that the sequence was both atypically thin and also lacked several of the main rock types commonly present (especially beds of ooid grainstone and anhydrite).

The loss of its type locality prompts nomination of an alternative, the main candidate amongst surface exposures probably being the River Ure Cliff site, near Ripon. This section, however, does not expose the full thickness of the formation nor its base, and is therefore not wholly satisfactory. A preferred option would probably be a well-documented borehole core such as that from, for example, the Barlow No 2, Camblesforth No 1, Synthetic Chemicals No 1 (Askern), Whitemoor or Wistow Wood boreholes; substantial numbers of core specimens from most of these have been retained by either British Coal or the British Geological Survey.

WOOD LEE COMMON, MALTBY (SK 532915)

Highlights

Wood Lee Common, Maltby (not shown in Figure 4.2), is the most accessible and amongst the best localities for the study of the structure and fabric of typical bryozoan patch-reefs in the Wetherby Member of the Cadeby Formation. The reef-rock is completely dolomitized and comprises an untidy assemblage of sack-like masses of dense bryozoan-rich rock with associated bivalve, gastropod and brachiopod fossils.

Introduction

The late Permian marine patch-reefs at Wood Lee Common form scattered natural upstanding tor-like crags in south-westwards-sloping scrubby grassland on the south-western fringe of Maltby;

most of the 'tors' are only a few metres high and less than 30 m across. No other strata are exposed and so there is no information on the nature of contacts or on reef dimensions; it is not even clear whether there is one reef or several. The outstanding feature of the exposures is that differential weathering has revealed that the reefs comprise a large number of stacked sack-like bodies up to 2.5 m across, each with a complex framework of straggling bryozoans.

The craggy exposures on Wood Lee Common were mentioned by Sedgwick (1829) and illustrated photographically by Eden *et al.* (1957, pl. 4) and Smith (1981b, figs 6, 14 and 17); the detailed ecology and make-up of reefs like those at Wood Lee Common was discussed fully by Smith (1981b).

Description

Wood Lee Common lies on the south-west side of the A634 Maltby–Blyth road and is shown in detail in Figure 4.27. Rock exposures cover only a small proportion of the common and are unevenly scattered both in geographical position and at different levels on the slope. All exposures are of rock in the lower and middle part of the Wetherby Member of the Cadeby Formation, the base of which trends NNW to SSE across the middle of the slope. All the reef-rock is of dolomite.

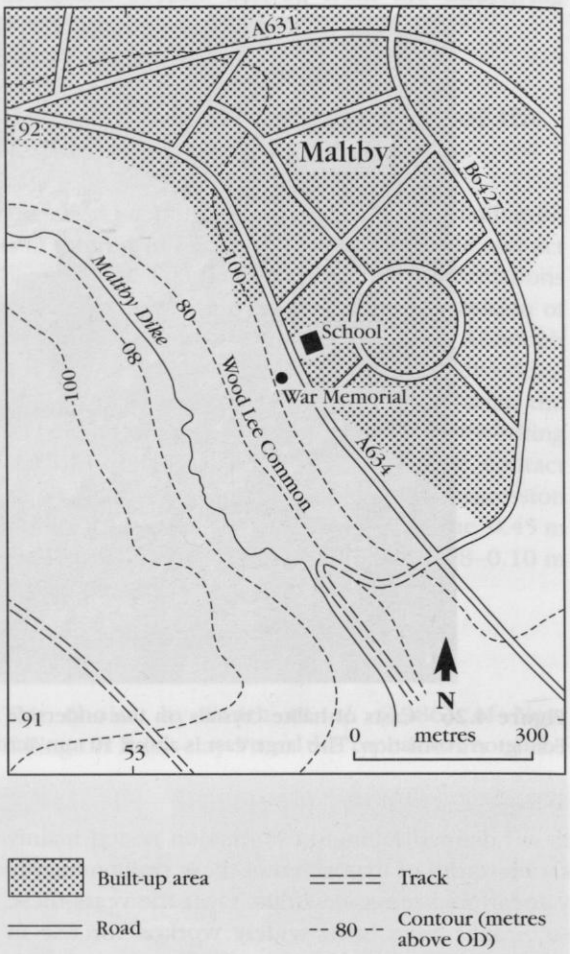


Figure 4.27 Wood Lee Common GCR site, Maltby, South Yorkshire. Most of the reef 'tors' are in the central and northern parts of the designated area.

Examination of the reef exposures reveals little of the shape or size of the reef body or bodies, but shows that the 'tors' are almost wholly composed of dense masses ('saccoliths') of bryozoan boundstone (framestone) piled apparently haphazardly beside and on top of each other. Most of the saccoliths are roughly horizontally elongated, locally giving the rock a crudely thick-bedded aspect (Figure 4.28). They range from less than 1 m across to up to 2.5 m across and 1 m thick. Many of the saccoliths are in tight mutual contact, forming a coarse mosaic, but others are partly or wholly separated by irregular pockets and lenses of fine-grained shelly detritus; shell remains in the detritus are mainly of small bivalves (*Bakevellia, Liebea, Permophorus, Schizodus*) and small gastropods, but also locally include fragments of ramose bryozoans (probably mainly *Acanthocladia*) and of the small pedunculate brachiopod *Dielasma*.

Close inspection of the rock face shows that the saccoliths comprise 5–?25% of a twig-like framework of branching *Acanthocladia* colonies (with some possible *Thamniscus*) spread unevenly throughout a dense, fine-grained dolomite matrix. Thin sections (Smith, 1981b, figs 14 and 17) reveal that the matrix is of patchily turbid dolomite microspar and dolomicrite and that the rock has undergone a complex history of diagenesis and cavity-fill. Early cementation is suggested by a general lack of crushing of the skeletal remains, and this may have been initiated by the formation of fibrous isopachous fringes (0.05–0.25 mm thick) that coat and line most of the bryozoan frame elements and also many other organic remains.

An additional feature of interest in the reefy 'tors' of Wood Lee Common is the presence of well-developed honeycomb weathering on some faces, and the more restricted occurrence of narrow linenfold-like vertical dissolutional fluting.

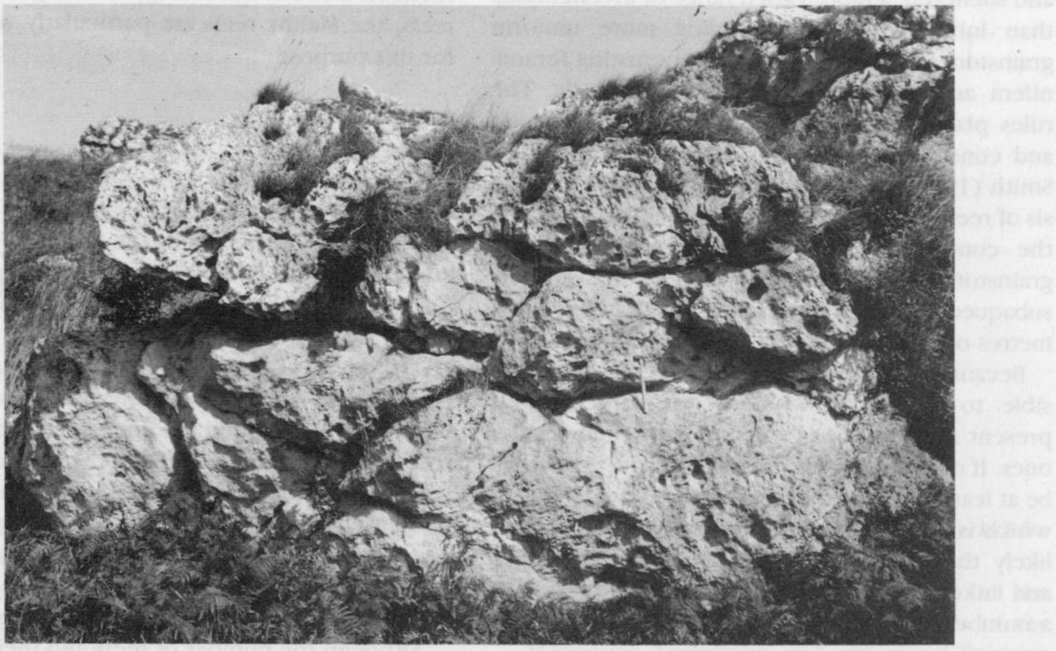


Figure 4.28 Reef 'tor' in the central part of Wood Lee Common GCR site, showing the characteristic subdivision into 'saccoliths'. Hammer (centre-right): 0.33 m. (Photo: D.B. Smith.)

Interpretation

Patch-reefs in the Wetherby Member of the Cadeby Formation in Yorkshire are featured in five GCR sites and display different features in each; those at Wood Lee Common are special in that, in addition to being freely and readily accessible, they display *par excellence* the saccolithic structure that typifies the mainly bryozoan reefs in the lower part of the member (Smith, 1981b). Three of the four other reef GCR sites, Newsome Bridge Quarry, South Elmsall Quarry and Ashfield Brick-clay Pit, may have bryozoan saccolithic cores but, if so, this structure has subsequently almost been obliterated by diagenesis; reefs at the fifth site, Cadeby Quarry, have a rather different structure and biota from the other three. Additional places where a pronounced saccolithic reef structure in bryozoan reefs may be seen include an old quarry (SE 488176) on the northern fringes of Wentbridge and the many exposures in Hooton Pagnell village (SE 4808) where reef/grainstone contacts and relationships are also well exposed (Smith, 1981b, fig. 4); others were noted by Edwards *et al*. (1947) at Aberford (SE 4337) and Boston Spa (SE 4245). Upstanding crags of reef limestone, not unlike those at Maltby, have been reported at Minney Moor (SK 519989), Conisbrough by Mitchell (1932a) and near South Anston (SK 525838), east of Sheffield, by Eden *et al*. (1957).

The distribution and general characteristics of patch-reefs in the Wetherby Member have been investigated by Smith (1974b, 1981b, 1989) and are summarized in the account on South Elmsall Quarry. They lie at all levels in the Wetherby Member between the top of the Bakevellia Bed (commonly 1–3 m above the base) and the Hampole Discontinuity, and range from scattered to abundant in an 8–12 km wide belt that coincides roughly with the outcrop between Brearton (SE 322610, near Harrogate) and Barlborough (SK 4777, near Sheffield). Most simple reefs are a few metres thick and 10–25 m across (although some exceed 100 m), but closely-spaced reefs locally merged to form complexes more than 20 m thick and 120 m across.

Although Mitchell (1932a) was the first to apply the word 'reef' to unbedded or 'brecciated' bryozoan rock in the Wetherby Member, it is clear that Kirkby (1861, p. 315) recognized that the 'polyzoan beds' probably formed part of a sessile, organic community built up by and around ramose cryptostome bryozoans such as *Acanthocladia*. By their growth, the bryozoans gave rise to a variety of minor sub-environments that were occupied by, and sheltered, a more varied range of invertebrates than inhabited the surrounding more uniform grainstones; such forms include encrusting foraminifera and pedunculate small brachiopods. The roles played by the various organisms in the life and construction of the reefs were discussed by Smith (1981b), together with a preliminary analysis of reef diagenesis. It was concluded, partly from the contributary evidence of the surrounding grainstones, that the reefs were formed entirely subaqueously on an open marine shelf under a few metres of water of slightly above-normal salinity.

Because no margins are exposed, it is not possible to determine whether one large reef is present at Wood Lee Common or several smaller ones. If only one reef is present, however, it would be at least 150 m across and more than 20 m thick, which is very large for a single reef; it seems more likely therefore, and taking the several separate and linked reefs at Hooton Pagnell as a guide, that a number of reefs is present rather than one large one.

Future research

The main features of the patch-reefs in the Wetherby Member of the Cadeby Formation are now reasonably well documented and understood, but there remains much scope for detailed research on both the ecology and diagenesis of the reefs; the Maltby reefs are particularly well suited for this purpose.

Conclusions

This site is one of the best localities for the study of bryozoan patch-reefs in the Cadeby Formation. Such reefs are seen in several localities in Yorkshire, notably Cadeby, Newsome Bridge and South Elmsall Quarries. The exposures at Wood Lee Common allow easy access, and as natural outcrops, have undergone differential weathering which has highlighted the internal structure of the reef. The exposures reveal that the reefs are mainly composed of dense masses of bryozoan-rich rock known as 'saccoliths', which are elongate structures that are piled one on another so as to impart a bedded appearance to the rock. The saccoliths are separated by irregular patches of shelly debris.

Although the number of reefs and their relationship to surrounding strata is not known at site, this locality is significant in that its well-developed weathering allows details of the reef to be studied which cannot readily be seen in the fresher quarry faces of most other patch-reef sites.