British Upper Jurassic Stratigraphy (Oxfordian to Kimmeridgian)

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Chapter 4

Upper Jurassic stratigraphy in North Yorkshire

INTRODUCTION

J.K. Wright

The region covered by this chapter extends from the coast at Scarborough westwards through the Tabular Hills to the Hambleton Hills, and then south-west into the Howardian Hills, incorporating the low-lying Vale of Pickering (Figure 4.1). It broadly coincides with the southern half of the Jurassic depositional area known as the 'Cleveland Basin' (Rawson and Wright, 2000, fig. 2). The southern limit of the basin is defined by the Market Weighton High (= Market Weighton Block; BGS, 1996), a positive area that was repeatedly uplifted during the Mesozoic Era, so that the thick sequence of Oxfordian and Kimmeridgian sediments of the Cleveland Basin thins and is eventually overstepped by Lower Cretaceous sediments as Market Weighton is approached.

The basic subdivisions of the Oxfordian and Kimmeridgian are shown in Figure 4.2. At the base there is a comparatively thin representative of the Oxford Clay Formation. As in southern England, the overlying Corallian Group is well developed as a varied clastic–carbonate sequence. It is divided into three formations, the Lower Calcareous Grit and the Upper Calcareous Grit, separated by the Coralline Oolite. The succeeding Ampthill and Kimmeridge Clay formations make up over three-quarters of the Oxfordian–Kimmeridgian time interval, as estimated by the number of ammonite zones, and they are as thickly developed in proportion to time as the Corallian strata.

Most of the GCR sites display strata within the Corallian Group. This is basically the result of the limited exposure of clay formations in north-east Yorkshire, particularly the Kimmeridge Clay. In marked contrast to Dorset, where there are magnificent cliff exposures of Kimmeridge Clay (see cover photo), in north-east Yorkshire coastal exposures of Kimmeridge Clay are minimal, the outcrop being covered by a thick blanket of glacial drift. Occasional abandoned clay

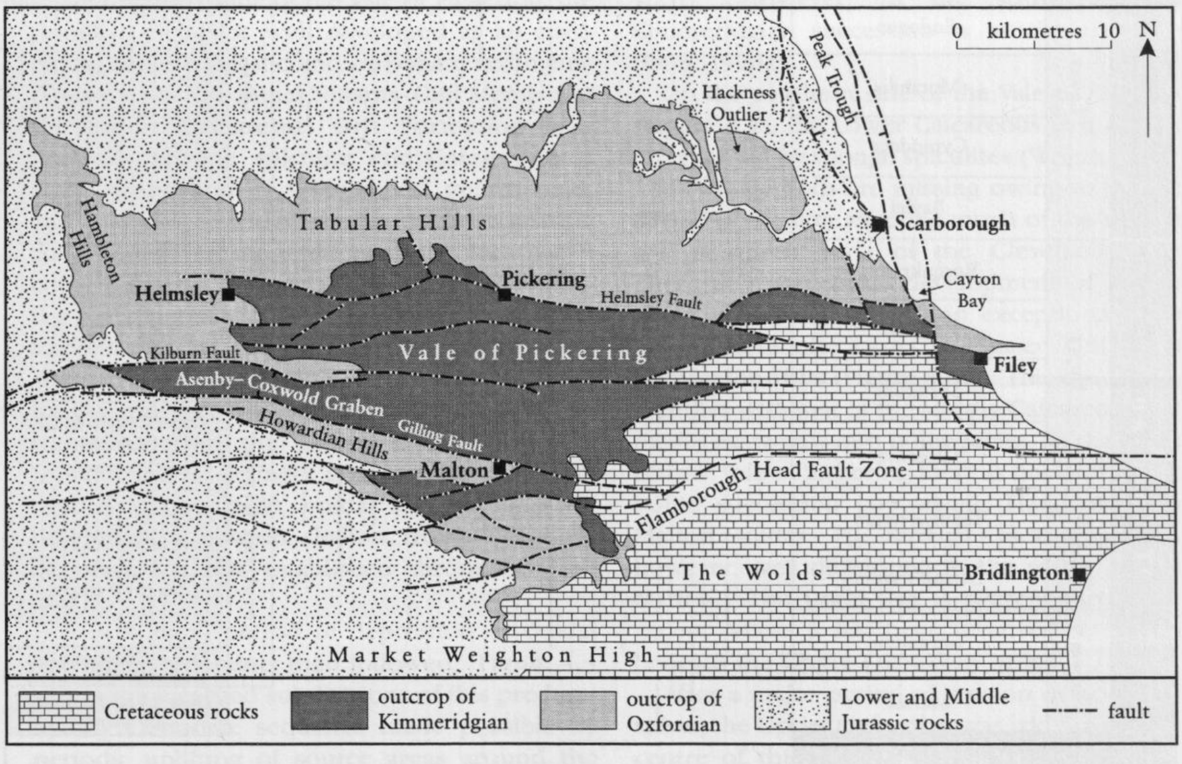


Figure 4.1 Map showing the solid geology of the Oxfordian and Kimmeridgian beds in the Cleveland Basin, with the principal stuctural and geographical features. (Based on Versey, 1929, fig. 1; BGS 1:250 000 Solid Sheet 54N 02W (Tyne-Tees) (1981); BGS 1:1 500 000 Tectonic map of Britain, Ireland and adjacent areas (1996) and BGS 1:50 000 Sheet 54 (Scarborough) (1998)). In the Vale of Pickering there is a thick cover of Quaternary lacustrine deposits.

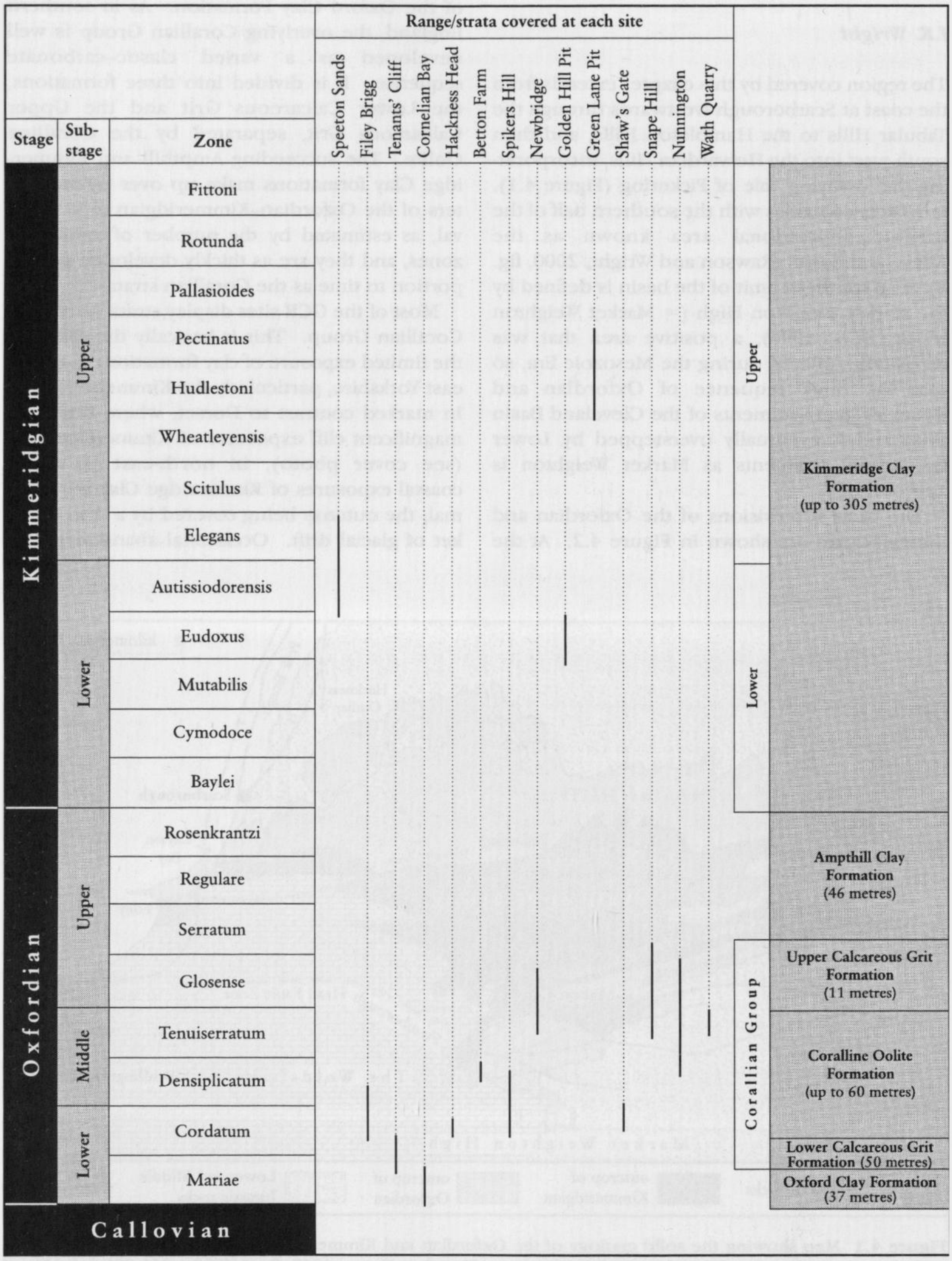


Figure 4.2 Zones of the Oxfordian and Kimmeridgian stages, showing the stratigraphical ages of each of the formations present in the Cleveland Basin, and the age range of the exposure at each GCR site.

pits reveal some Ampthill and Kimmeridge Clay, but much of the uppermost Oxfordian and Kimmeridgian sequence has no exposures, natural or man-made, and some parts have only been seen in borehole cores. In contrast, there are numerous excellent cliff and quarry exposures of Corallian Group strata.

In the Cleveland Basin, as elsewhere in Britain, the Oxfordian Age began with clay sedimentation, represented by the Weymouth Member of the Oxford Clay Formation. The facies of the Weymouth Member in this area is that of a proximal, silty clay with influxes of clastic sediment derived from the Mid North Sea High (Figure 1.2D). There was a gradual tendency for the Cleveland Basin to infill with shallow-water sediments, so that the Weymouth Member becomes increasingly silty upwards. This comparatively short argillaceous episode was then succeeded by deposition of the Corallian Group, a thick sequence of shallow marine sandstones and limestones that form an extensive, horseshoe-shaped outcrop round the north, west and south-west sides of the Vale of Pickering, itself a broad, synclinal structure (Figure 4.1).

On the north side of the Vale of Pickering, the Corallian Group is well developed as an alternating series of clastic and carbonate sediments (Figure 4.3). The initial Tenants' Cliff Member of the Lower Calcareous Grit Formation is a *Rhaxella* sponge spiculite containing only a small proportion of fine-grained quartz sand, and laid down under gentle, offshore marine conditions. The succeeding Saintoft Member in contrast is a fine-grained, shelly sandstone marking a distinct shallowing. A phase of very shallow-water sedimentation then began, with deposition of the Coralline Oolite Formation. The lowest member, the Passage Beds, marks the transition from the Lower Calcareous Grit. Initial medium-grained quartz sands are succeeded by bioclastic, ooidal and coralliferous limestones, as a warm, shallow, tropical, carbonate shelf sea was established throughout the area.

A prolonged period of deposition of ooidal and shelly sediments then followed. Figure 4.3 shows the localized subdivisions of this predominantly carbonate sequence made possible by periodic uplifting of source areas around the margins of the basin. Lenses of siliclastic sediments identified as local members (Birdsall and Middle Calcareous Grits) divide the ooidal carbonate succession into Hambleton and Malton Oolites, and the Hambleton Oolite into Upper and Lower Leafs. The close of carbonate sedimentation was marked by deposition of the Coral Rag, a transgressive sequence, with shelly, coral-rich bioclastic limestone overlain by a complex of coralliferous limestones and muddy, lagoonal sediments laid down in an extensive coral reef complex.

After a major erosive episode, there followed the transgression of predominantly clastic sediment, the Upper Calcareous Grit Formation, over much of the basin. The initial sedimentation was argillaceous (Newbridge Member), succeeded by shelly, fine-grained shelf sandstones (Spaunton Member). The youngest Upper Calcareous Grit sediments (Snape Member) comprise very fine-grained sandstones laid down under more gentle, offshore shelf conditions. There followed a major marine transgression, which led to the deposition of the fine-grained mudstones of the Ampthill and Kimmeridge Clays over the whole area. In the central part of the Vale of Pickering, the thickness of the Kimmeridge Clay is substantially greater than that of the Oxfordian strata (Figure 4.2). However, in the south-east, the Kimmeridgian succession is much attenuated (BGS, 1998a).

On the southern side of the Vale of Pickering (Figure 4.4), the Lower Calcareous Grit is again represented by sponge spiculites (Wright, 1983). The Passage Beds are missing owing to a major period of erosion affecting much of the western and southern parts of the Cleveland Basin. There is a substantial development of Birdsall Calcareous Grit, yielding an exceptionally preserved ammonite fauna at Flassen Gill in the Hambleton Hills (Figure 4.5I). This sand facies, together with that of the Middle Calcareous Grit, passes eastwards into oolite facies, so that in the central Vale of Pickering there is one continuous oolite succession comprising Hambleton and Malton Oolites. The Birdsall Calcareous Grit is, however, well developed in the south, around Malton. The Coral Rag is present throughout except where it has been removed by erosion beneath the Upper Oxfordian beds.

After a major period of erosion or non-deposition, the Upper Oxfordian was laid down in the centre of this strip as a predominantly clastic sequence. The succession here is similar to that seen in the north; however, Spaunton Sandstone is transgressive across Newbridge Member silts in the Nunnington and Oswaldkirk areas.

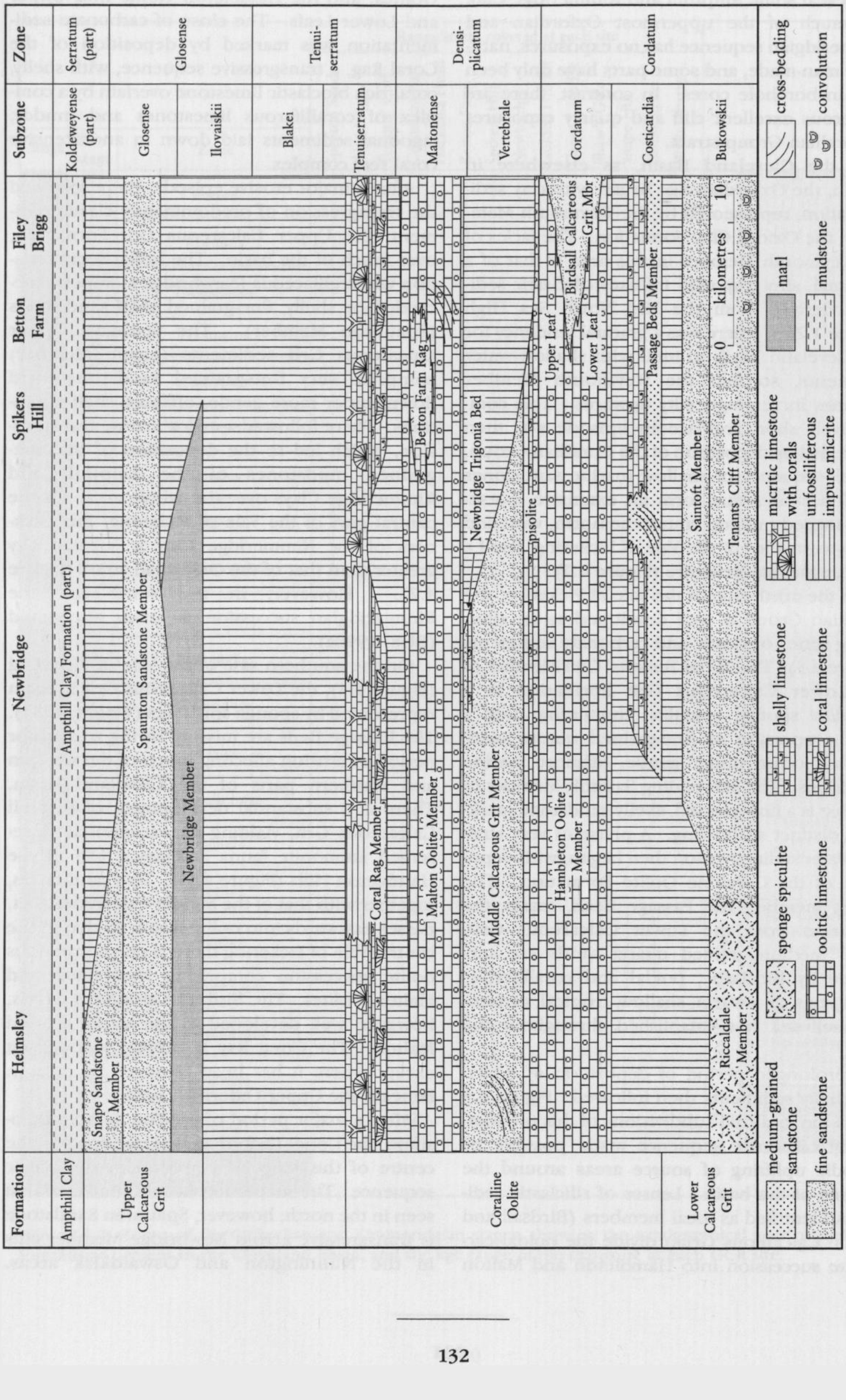


Figure 4.3 Stratigraphical cross-section of the Yorkshire Corallian Group on the north side of the Vale of Pickering from Helmsley to Filey (after Rawson and Wright, 1995, fig. 15).

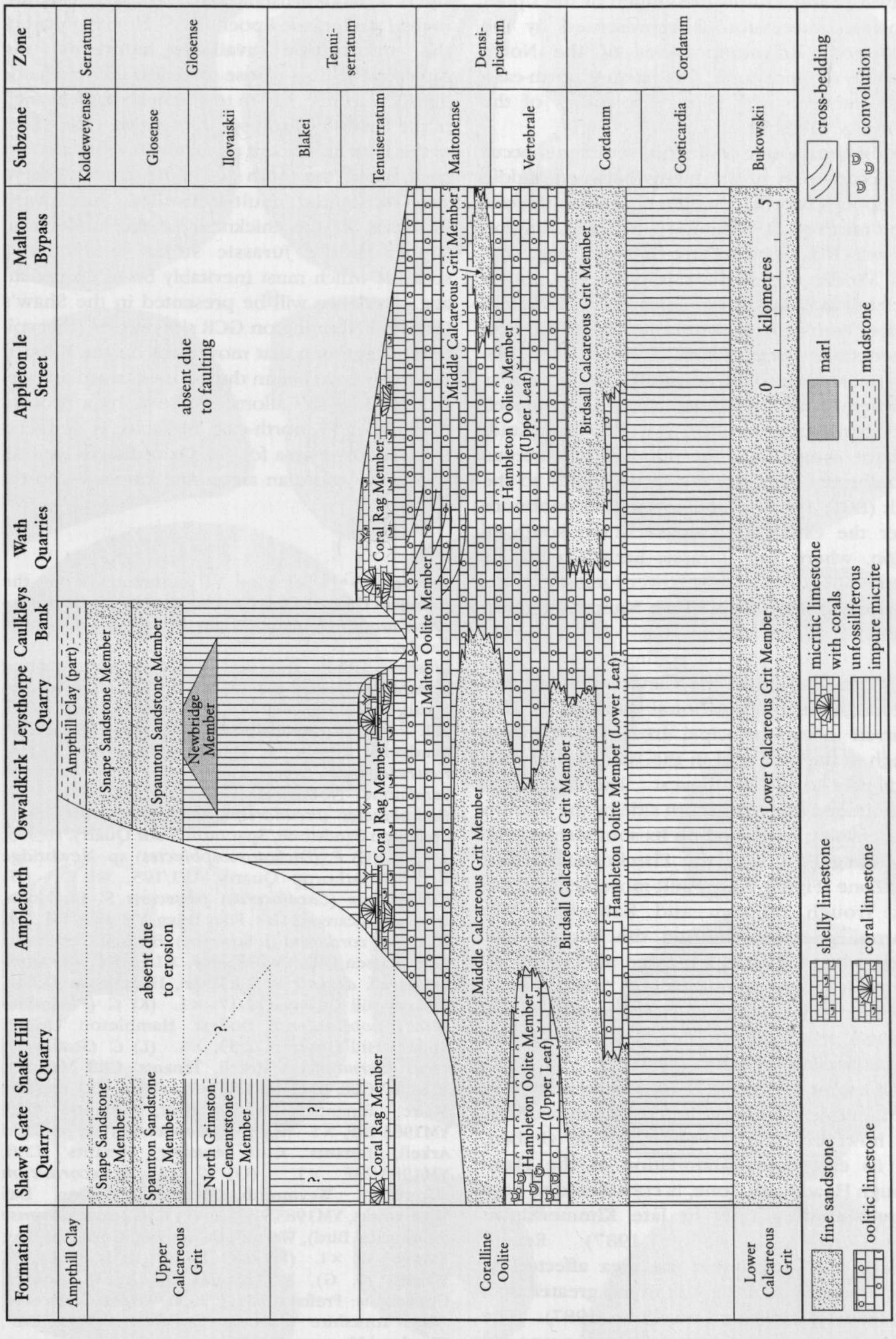


Figure 4.4 Stratigraphical cross-section of the Yorkshire Corallian Group on the south-west side of the Vale of Pickering from the Hambleton Hills to Malton.

Westwards and southwards, much of the Upper Oxfordian succession is represented by the argillaceous limestone facies of the North Grimston Cementstone, this passing north-eastwards into the silty sponge spiculites of the Newbridge Member.

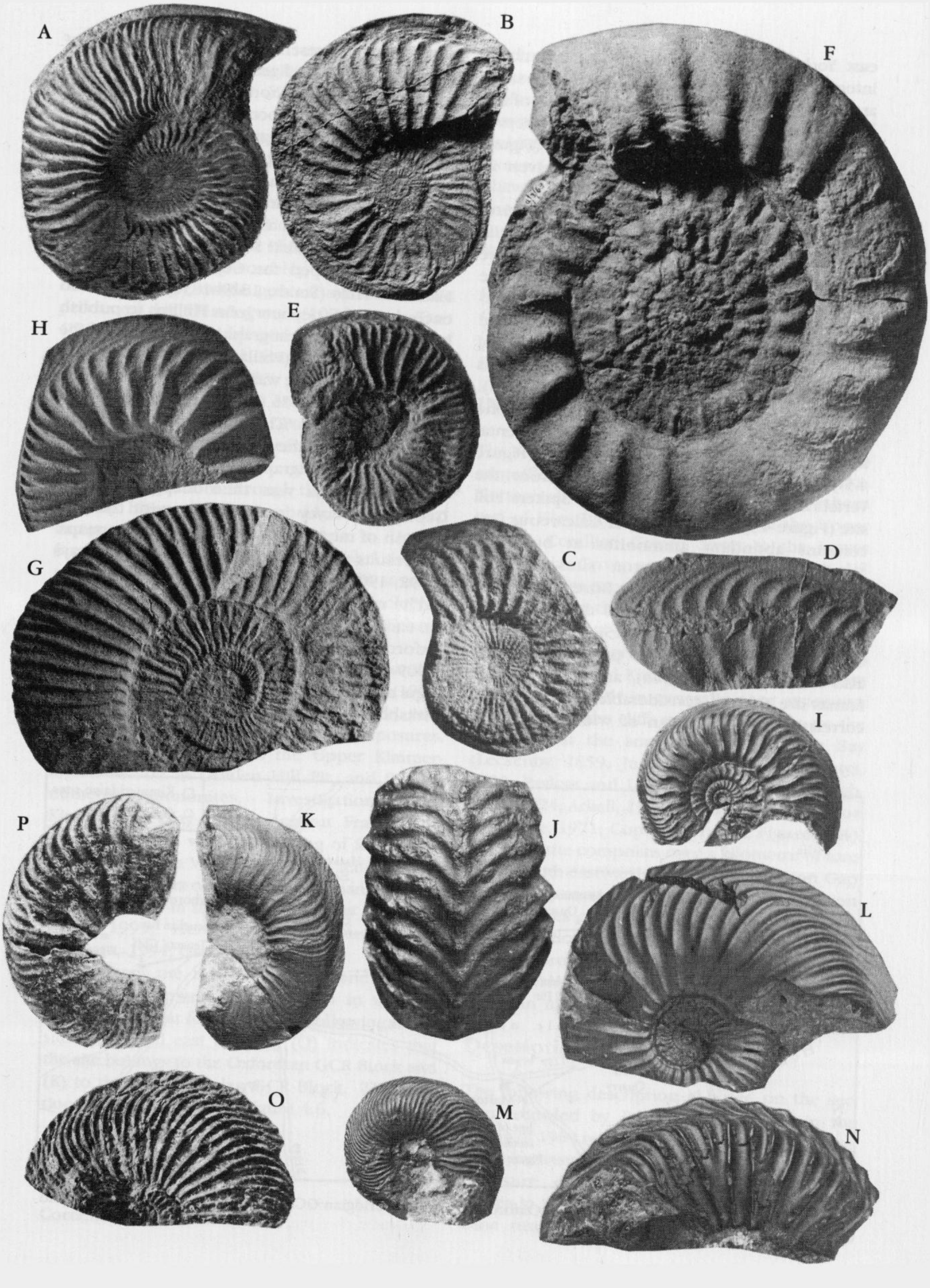
In the area south of Malton, sediments occur that occupy part of the hiatus between Middle and Upper Oxfordian sediments that is present to the north (C.D. Wright, 1976). The Langton Clay, which appears to rest on Coral Rag, contains Middle Oxfordian cardioceratids, and is overlain by the silty, calcareous Limekiln Member coming in beneath the North Grimston Cementstone (see Wright, 1980, col. O15). Uppermost Oxfordian Ampthill Clay occurs as elsewhere, and the Kimmeridge Clay is well developed south of Malton as well. Recent studies have shown that the sub-Late Cretaceous unconformity does not cut down gently to the south (BGS, 1993). Kimmeridge Clay continues under the Chalk to a point 12 km south of Malton, where Late Jurassic–Early Cretaceous movement faults it against Lower Jurassic Redcar Mudstone at the margin of the Market Weighton 'Block'.

As in southern England, sedimentation during the Jurassic Period in the Cleveland Basin was affected by syndepositional faulting. This occurred in two principal areas: in the Peak Trough in the east, and in the Vale of Pickering/Wolds area to the south-west. This latter area was bounded on its northern side by the Kilburn and Helmsley Faults and on its southern side by the Gilling Fault and the Flamborough Head Fault Zone (Figure 4.1). Fault movements in the Peak Trough (Milsom and Rawson, 1989) occurred principally during the Mid Jurassic Epoch, when they had a marked affect on sedimentation (Rawson and Wright, 2000). Fault movements in the Vale of Pickering/Wolds area occurred principally in the Late Jurassic and Early Cretaceous epochs.

The extent of the effect on sedimentation of fault movements during the Oxfordian is uncertain, however. The Asenby–Coxwold Graben, with its eastwards continuation as the Flamborough Head Fault Zone, is considered to have begun subsiding only in late Kimmeridgian times (Kirby and Swallow, 1987). Recent research has shown that the area affected by synsedimentary faulting was much greater than envisaged by Kirby and Swallow (1987). The whole of the eastern Vale of Pickering was the site of a major synsedimentary graben structure in the Late Jurassic Epoch (BGS, 1998a). Most of the information available concerns the Kimmeridge Clay, whose thickness increases, for instance, from *c.* 320 m to 410 m across a branch of the Helmsley Fault south of Ayton. The effect of this fault movement on Oxfordian strata is less clear, but on the south side of the structure there are substantial fault-controlled northward increases in the thickness of the underlying 'Upper–Middle Jurassic strata (undivided)', some of which must inevitably be of Oxfordian age. Evidence will be presented in the Shaw's Gate and Nunnington GCR site reports (this volume) suggesting that movement on the Kilburn Fault may have begun during the Oxfordian Age.

According to Callomon (1964), by a process of elimination, north-east Yorkshire is deduced to be the type area for the Oxfordian Stage. As such, the Oxfordian ammonite faunas of north-

Figure 4.5▸ Selection of ammonites from the Corallian Group of the Cleveland Basin. (A) *Amoeboceras nunningtonense* Wright (holotype), Spaunton Sandstone, Leysthorpe Quarry, m27, ×1. (B) *A. glosense* (Bigot and Brasil), Newbridge Member, Leysthorpe Quarry, U/1/14, ×1. (C) *A. transitorium* Spath, Newbridge Member, Leysthorpe Quarry, U/1/5, ×1. (D) *A. ilovaiskii* (M. Sokolov), Spaunton Sandstone, Newbridge Quarry, U/2/38, ×1. (E) *A. newbridgense* Sykes and Callomon, Spaunton Sandstone, Newbridge Quarry, U/2/20, ×1. (F) *Perisphinctes* (*Pseudarisphinctes*) *pachachii* Arkell, Spaunton Sandstone, Spaunton Moor Quarry, U/3/63, ×0.33. (G) *P.* (*Dichotomosphinctes*) sp. Newbridge Beds, Leysthorpe Quarry, U/1/103, ×0.7. (H) *Cardioceras* (*Cardioceras*) *persecans* S. Buckman, Birdsall Calcareous Grit, Filey Brigg, YM1983/45F, ×1. (I) *C.* (*C.*) *cordatum* (J. Sowerby), Birdsall Calcareous Grit, Flassen Gill, YM1983/36F, ×1. (J) *C.* (*Vertebriceras*) aff. *dorsale* S. Buckman, Hambleton Oolite, Spikers Hill Quarry, C/2/17, ×1. (K) *C.* (*Plasmatoceras*) *popilaniense* Boden, Hambleton Oolite, Spikers Hill Quarry, C/2/59, ×1. (L) *C.* (*Scarburgiceras*) *harmonicum* Arkell, Tenants' Cliff Member, Tenants' Cliff, YM1983/17F, ×1. (M) *C.* (*S.*) *reesidei* Maire, Tenants' Cliff Member, Tenants' Cliff, YM1983/20F, ×1. (N) *C.* (*Vertebriceras*) aff. *phillipsi* Arkell, Tenants' Cliff Member, Tenants' Cliff, YM1983/23F, ×1. (O) *C.* (*S.*) *praecordatum* (Douvillé), Weymouth Member, Cayton Bay Waterworks, YM1983/9F, ×1. (P) *C.* (*S.*) *scarburgense* (Young and Bird), Weymouth Member, Cornelian Bay, YM1983/3F, ×1. (Photos: (A–E), (H, I), (L–P), J.K Wright; (F, G), K. D'Souza; (J, K) K. Denyer. Collections: Prefixes 'U', 'C', J.K. Wright Collection; 'YM', Yorkshire Museum Collection, York; 'm', Woodend Museum, Scarborough.)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east Yorkshire have considerable international interest. The zones and subzones of the stage are listed in Figure 4.2, with an indication of the range of strata present at each site, and representative ammonites are also figured (Figure 4.5). The locations of the sites are given in Figure 4.6.

The Cornelian Bay site has yielded well-preserved *Cardioceras* belonging to the initial Scarburgense Subzone of the Oxfordian (Figure 4.5P), and both here and at the Tenants' Cliff site there are representative ammonites of the overlying Praecordatum Subzone (Figure 4.5O). An exceptionally well-preserved ammonite fauna of the Bukowskii Subzone of the Cordatum Zone is present at the Tenants' Cliff site (Figure 4.5L–N). The Filey Brigg site yields a Cordatum Subzone fauna (Figure 4.5H), though the best representatives are found in the Hambleton Hills (Figure 4.5I). A Middle Oxfordian fauna from the Vertebrale Subzone is found at the Spikers Hill site (Figure 4.5J, K). The Upper Calcareous Grit contains abundant ammonites at both the Newbridge and Nunnington sites. These ammonites belong both to the Boreal cardioceratid family (Figure 4.5A–E) and the Sub-Boreal perisphinctid family (Figure 4.5F, G). Traces of Sub-Mediterranean province perisphinctids are also found (Wright, 1996a), and the Yorkshire faunas are thus of considerable importance in correlating the Oxfordian of widely separated areas where representatives of one or other of these families are indigenous.

Research on the Yorkshire Oxfordian and Kimmeridgian strata occurred in four phases. The initial work was begun early in the 19th century by Young and Bird (1822). These authors collected and figured many Oxfordian ammonites, and their names are still in use today. William Smith also became involved. He lived at Hackness, near Scarborough, during the 1820s and mapped the Corallian beds in the Hackness Hills (Smith, 1829–1830). Smith also encouraged his nephew John Phillips to publish his (Smith's) full stratigraphical synthesis of the Yorkshire Corallian (Phillips, 1829).

The second phase was ushered in by the work of Hudleston (1876, 1878) and Blake and Hudleston (1877). These authors carried out a detailed study of the Corallian beds and set up many of the stratigraphical subdivisions still in use. The area was then mapped by the Geological Survey in the 1880s, with the production of meticulous, beautifully drawn maps. The results were summarized by Fox-Strangways (1892, 1904).

The major phase of work carried out during the early years of the 20th century on the English Oxfordian and Kimmeridgian by Buckman (1909–1930) and Arkell (references listed in Cope *et al.*, 1980) was in southern England. The Yorkshire succession had been so well mapped

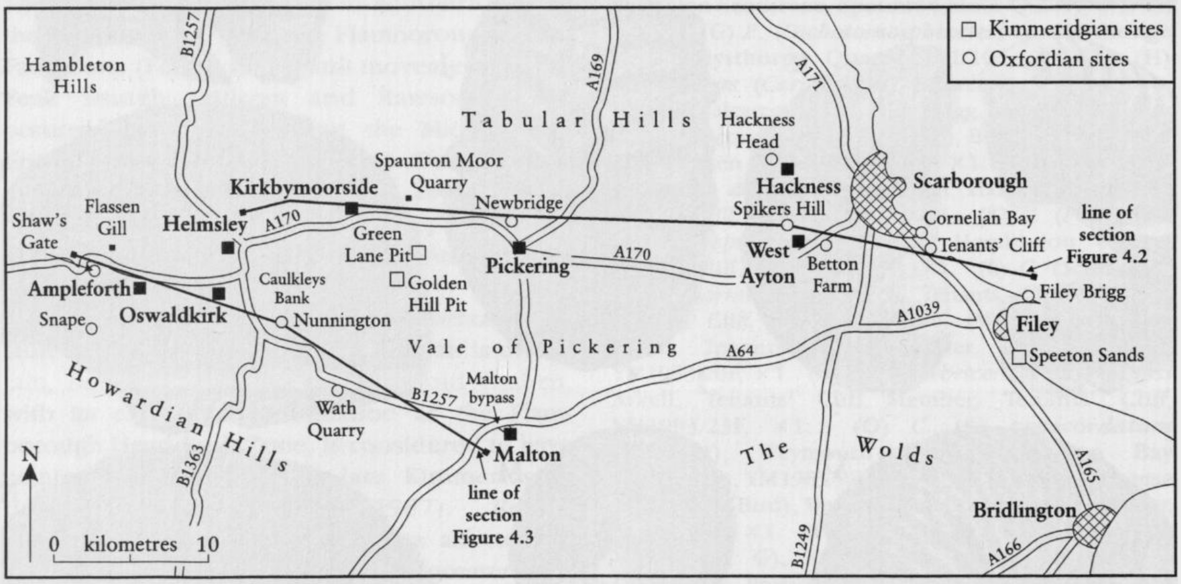

Figure 4.6 Map showing the locations of Oxfordian and Kimmeridgian GCR sites in north-east Yorkshire, and other localities mentioned in the text.

and described that there seemed to be little more to do. However, Wilson (1933, 1949) refined the stratigraphy and carried out detailed palaeontological studies.

The fourth phase of study, which is still ongoing, was initiated by Wright (*in litt*, 1960), who mapped Corallian rocks at the western end of the Vale of Pickering, and subsequently produced a synthesis of Corallian stratigraphy (Wright, 1972). Several PhD theses were completed in the area (Twombley, 1965; Lee, 1971; Hitchins, 1983), while general syntheses were produced by Hemingway (1974) and Kent (1980b). Wright published detailed studies of the stratigraphy and faunas of the Lower Oxfordian (Wright, 1983, 1992), the Middle Oxfordian (Wright, 1997) and Upper Oxfordian (Wright, 1996a, b) strata. Powell *et al.* (1992) provided a detailed study of the Corallian beds in the Hambleton Hills, while Coe (1995) redescribed sections through the Corallian beds at Filey Brigg and at Newbridge Quarry, and compared these with successions in Dorset. Boreholes drilled in the 1970s enabled the first recognition of the youngest Oxfordian strata in clay facies (Richardson in Institute of Geological Sciences, 1974; Pyrah, 1977; Cox and Richardson, 1982).

Study of the Kimmeridge Clay Formation has suffered from lack of exposure. Cope (1974) produced a synthesis of previous work, with some new records from temporary exposures. Wignall (1993) described the Upper Kimmeridgian section at Golden Hill Pit, and figured numerous ammonites. Investigation of the Kimmeridge Clay by the Institut Français du Pétrole in 1987, with the drilling of four cored boreholes in the Vale of Pickering, led to a succession of papers on the Kimmeridgian stratigraphy and fauna in that area (Herbin *et al.*, 1991, 1993, 1995; Herbin and Geyssant, 1993; Geyssant, 1994; Oschmann, 1994).

Details of the main lithologies and depositional environments are included in the site descriptions that follow. In the following list of sites (arranged east to west) (O) indicates that the site belongs to the Oxfordian GCR Block and (K) to the Kimmeridgian GCR Block. The location of sites is shown in Figure 4.6.

Speeton Sands (K)
Filey Brigg (O)
Tenants' Cliff (O)
Cornelian Bay (O)
Hackness Head (O)
Betton Farm (O)
Spikers Hill (O)
Newbridge (O)
Golden Hill Pit (K)
Green Lane Pit (K)
Shaw's Gate Quarry (O)
Snape Hill (O)
Nunnington (O)
Wath Quarry (O)

SPEETON SANDS (TA 142 764)

B.M. Cox

INTRODUCTION

The Yorkshire coast has long been known for its magnificent exposures of Jurassic rocks. Northwards from Filey Brigg, at the northern end of Filey Bay, Jurassic beds from the Upper Jurassic Corallian Group down to the Lower Jurassic Lias Group are displayed in superb cliff and foreshore exposures giving an unprecedented insight into the Hettangian to Oxfordian geological history of the Cleveland Basin. South of Filey Brigg, younger Jurassic beds are much less well exposed, and Kimmeridgian strata are seen only intermittently in generally poor exposures at the base of the cliffs and, occasionally, on the foreshore at the southern end of Filey Bay (Leckenby, 1859; Judd, 1868; Fox-Strangways, 1892; Pavlow and Lamplugh, 1892; Lamplugh, 1896, 1924; Arkell, 1933; Callomon in Callomon and Cope, 1971; Cope, 1974) (see Figure 4.26). The GCR site comprises over a kilometre of foreshore south-eastwards from near Reighton Gap. It is usually covered by beach sand but occasional exposures of the underlying strata have provided sections of the Lower Kimmeridgian Autissiodorensis Zone and Upper Kimmeridgian Elegans Zone; these zones are not exposed elsewhere in Yorkshire.

Description

The following description is based on the section recorded by Prof. J.H. Callomon in the spring of 1964 near Reighton Gap when the foreshore between tide-marks was free of sands and exposure exceptionally good; the outcrop occurs in a small planed-off, south-pitching anticline near an old concrete gun-emplacement bunker (TA 143 764) (Callomon in Callomon and Cope, 1971). No new stratigraphical data have since been added to this original record because of the rare and largely unpredictable availability of these exposures.

	Thickness (m)
Kimmeridge Clay Formation	
Shales, black, hard, crowded with layers of crushed but otherwise complete *Pectinatites (Virgatosphinctoides) elegans* Cope and *P. (Arkellites)* spp.	seen *c.* 6
Shales, black, more or less hard, with calcareous bands; numerous crushed ammonites often concentrated in shell beds; 'pectinatitids' fairly abundant in top *c.* 1.5 m; concretionary horizons with large, uncrushed ammonites seen in lowest beds at low tide; *Aulacostephanus autissiodorensis* (Cotteau), *A. kirghisensis* (d'Orbigny), *A. volgensis* (Vischniakoff); *Sphinctoceras* sp. and abundant *Subdichotomoceras* cf. *lamplughi* Spath	seen *c.* 6

The cliffs adjacent to the GCR site are mainly of slumped Quaternary till. At their base, exposures of the underlying Speeton Clay (Lower Cretaceous) and Kimmeridgian strata vary with the state of the beach and cliff, but the Wheatleyensis, Hudlestoni and Pectinatus zones of the Upper Kimmeridgian have been recorded from time to time (Cope, 1974, emend. 1980; Wignall, 1990a, 1993; Rawson and Wright, 2000) and, in recent years, have been regularly exposed. Younger Kimmeridgian and Portlandian strata are cut out by the unconformity, marked by the Coprolite Bed, at the base of the Speeton Clay. Cored boreholes through the Kimmeridge Clay have been drilled for the British Geological Survey (Gallois, 1979a) and the Institut Français du Pétrole (Herbin *et al.*, 1991; Oschmann, 1994) on or near the cliff top here.

Interpretation

The two units into which Callomon (in Callomon and Cope, 1971) divided his section were separated on the basis of a sharp faunal break rather than a marked lithological change. The ammonite fauna of the upper unit, comprising species of *Pectinatites*, indicates the Upper Kimmeridgian Elegans Zone, and the more varied ammonite assemblage, including *Aulacostephanus*, of the lower unit indicates the Lower Kimmeridgian Autissiodorensis Zone. The section thus shows the Lower–Upper Kimmeridgian substage boundary. Callomon (in Callomon and Cope, 1971) referred the 'pectinatitids' of the lower unit to *Pectinatites (Arkellites)* but Cope (1974), on the basis of material seen by him on a subsequent visit to the site, believed they belonged to the genus *Propectinatites*, including forms apparently intermediate between *Propectinatites websteri* Cope and early *P. (Arkellites)*; according to Cope (1974), true *Pectinatites* had yet to be recorded from the Lower Kimmeridgian strata.

The concretionary horizons with uncrushed ammonites recorded in the lower unit are almost certainly the source of many museum specimens, marked 'Filey Bay' or 'Speeton', which probably came from material washed up on the shore in the past (Callomon in Callomon and Cope, 1971). These include species figured and described by Pavlow (in Pavlow and Lamplugh, 1892), Spath (1925) and Ziegler (1961, 1962), amongst which are the type specimens of *Aulacostephanus fallax* Ziegler, *A. rigidus* Ziegler and *Subdichotomoceras lamplughi* Spath (Figure 4.7). According to Callomon (in Callomon and Cope, 1971), this latter genus, together with *Sphinctoceras*, is definitely more abundant here than in southern England and, because these genera are also known from East Greenland, he suggested that they represented a genuinely Boreal group.

Conclusions

The elusive exposures on the foreshore near Reighton Gap in Filey Bay provide an occasional opportunity, depending on the erosional state of the beach, to observe the Lower–Upper Kimmeridgian substage boundary succession, including diagnostic ammonite faunas. This interval is not exposed elsewhere in the Cleveland Basin where it is otherwise known only from cored boreholes. Although ammonites are the only fauna to have been reported from here, these show a more Boreal aspect than those of southern England (see also

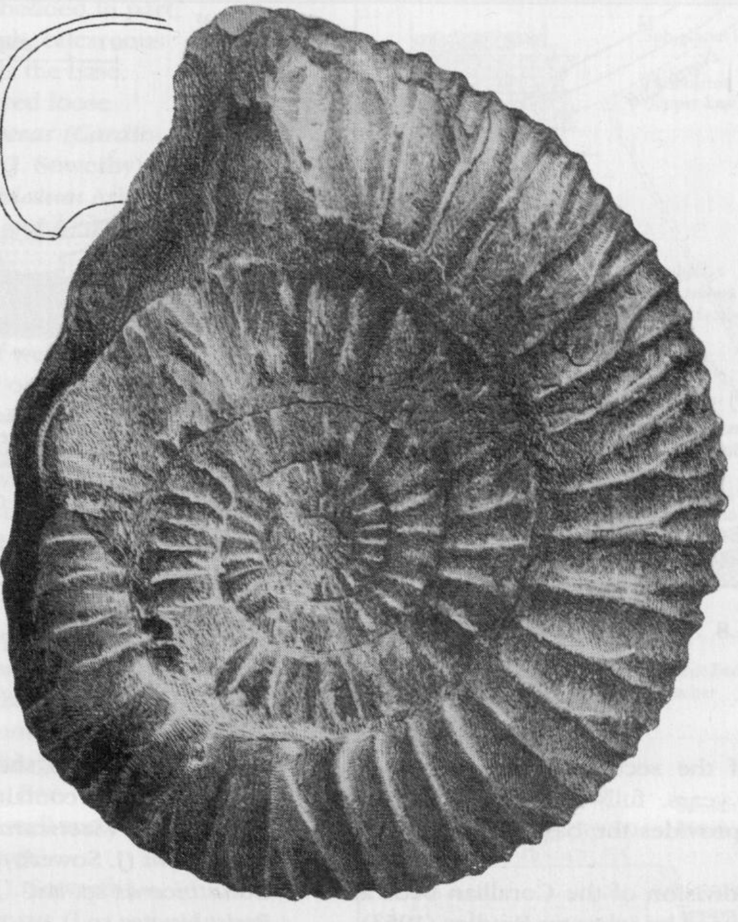

Figure 4.7 The type specimen of ***Subdichotomoceras lamplughi*** Spath, type species of the genus, from the Eudoxus Zone at Speeton, as figured by Pavlow and Lamplugh (1892, p. 111). Approximately natural size.

the 'Description' section for Golden Hill Pit, this volume), including relatively abundant *Sphinctoceras* and *Subdichotomoceras*. Material from these rarely seen exposures near low water mark are almost certainly the source of ammonite material, including type and figured specimens, found in many museum collections. Younger Kimmeridgian strata can usually be seen at the base of the slumped cliffs adjacent to the site.

FILEY BRIGG (TA 126 817–TA 139 814)

J.K. Wright

Introduction

The rocky, E–W-trending coastal promontory of Filey Brigg extends for nearly 1.5 km along the north side of Filey Bay and lies some 1 km north-east of the town of Filey (Figure 4.8). It provides a continuous section from the top of the Lower Calcareous Grit Formation through 14 m of the Coralline Oolite Formation. Much of the latter is present in a sandy facies transitional from Hambleton Oolite into Birdsall Calcareous Grit. It is easily accessible, and this enables a continuous bed-by-bed examination of the whole sequence to be made (see Figure 4.10).

The presence of Oxfordian strata at Filey Brigg was first recorded by Phillips (1829). Pioneer studies were carried out by Hudleston (1876), Blake and Hudleston (1877) and Fox-Strangways (1892), each providing a sound framework for the later researches of the 20th century. Arkell (1933, 1945) made significant contributions to the stratigraphy of the succession. However, it was Wilson's comprehensive

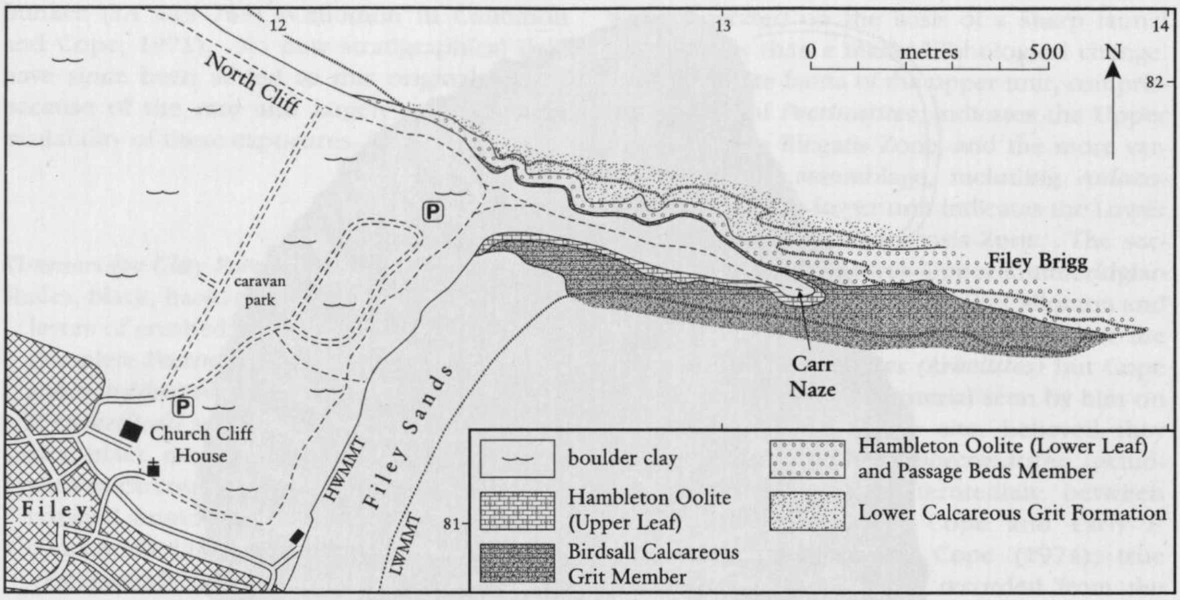

Figure 4.8 Sketch map of the geology of Filey Brigg (after Rawson and Wright, 2000, fig. 33).

investigation of the section over a period of more than 30 years, fully detailed in Wilson (1949), which provides the basis for most later studies.

Wilson's subdivision of the Corallian beds at Filey Brigg was used by Sylvester-Bradley (1953), but subsequent authors (i.e. Lee, 1971; Hemingway, 1974; Kent, 1980b) have not adopted Wilson's scheme, preferring to use the stratigraphical subdivisions of Wright (1972). However, Wright's scheme was subsequently shown to be in need of amendment (Wright, 1983), and this later version is used by current workers (Coe, 1995; Rawson and Wright, 1995, 2000).

Description

Filey Brigg exposes a fine section through almost 24 m of Lower and Middle Oxfordian strata, which range in age from the early Cordatum Zone to the early Densiplicatum Zone. The following section is taken from Wright (1983):

	Thickness (m)
Coralline Oolite Formation	
Hambleton Oolite Member, Upper Leaf, Vertebrale Subzone	
14. Loose limestone rubble	
13. Flaggy, argillaceous, shelly, sandy limestone containing *Cardioceras (Scoticardioceras) excavatum* (J. Sowerby), *Goliathiceras* sp. and *Perisphinctes* sp.	seen to 0.75
12. Argillaceous, shelly, sandy limestone containing *Cardioceras (Subvertebriceras) densiplicatum* Boden and *Perisphinctes* sp.	0.75
Birdsall Calcareous Grit Member, Cordatum Subzone	
11. Soft-weathering, fine-grained laminated sandstone	0.6
10. Sandy limestone, sporadically shelly, and frequently with a sand parting in the middle. *Rhaxella* spicules are abundant. The ammonite fauna comprises *Cardioceras (Cardioceras)* aff. *persecans* (S. Buckman), *C. (Plasmatoceras)* aff *plasticum* Arkell and *Peltoceras* sp.	0.9
9. Soft-weathering, fine-grained sandstone	0.45
8. Shelly, sandy, spicular limestone, somewhat lenticular	0.25
7. Brown-weathering, shelly, fine-grained sandstone, well-bedded	

to massive, cross-bedded in part, with a bed of tough, calcareous sandstone towards the base. Ammonites collected loose comprise *Cardioceras (Cardioceras) cordatum* (J. Sowerby), *C. (C.) angusticordatum* Arkell, *C. (C.) persecans* and *C. (C.) ashtonense* Arkell — 4.6

Hambleton Oolite Member, Lower Leaf

6. Two sequences of well-bedded to massive, shelly oolitic limestone containing profuse *Thalassinoides* burrow networks and numerous bivalves and brachiopods, separated by sporadically oolitic, calcareous sandstone — 3.7

Passage Beds Member, Costicardia Subzone

5. Variably sandy, non- or sporadically oolitic, white, shelly limestone with numerous bivalves and brachiopods — 1.9
4. Softer-weathering, fine- to medium-grained, well-sorted sandstone with large *Nanogyra nana* (J. Sowerby) and *Chlamys fibrosus* (J. Sowerby) — 0.6

Lower Calcareous Grit Formation

Saintoft Member, Bukowskii Subzone

3. Massive, fine- or fine to medium-grained sandstone forming three roughly equal beds, each with two rows of large calcareous concretions or 'cannon balls' — 2.75
2. Massive, very tough fine-grained calcareous sandstone forming a long promontory — 0.6

Tenants' Cliff Member

1. Yellow, spicular sandstone with occasional beds of grey, sandy limestone — seen to 6

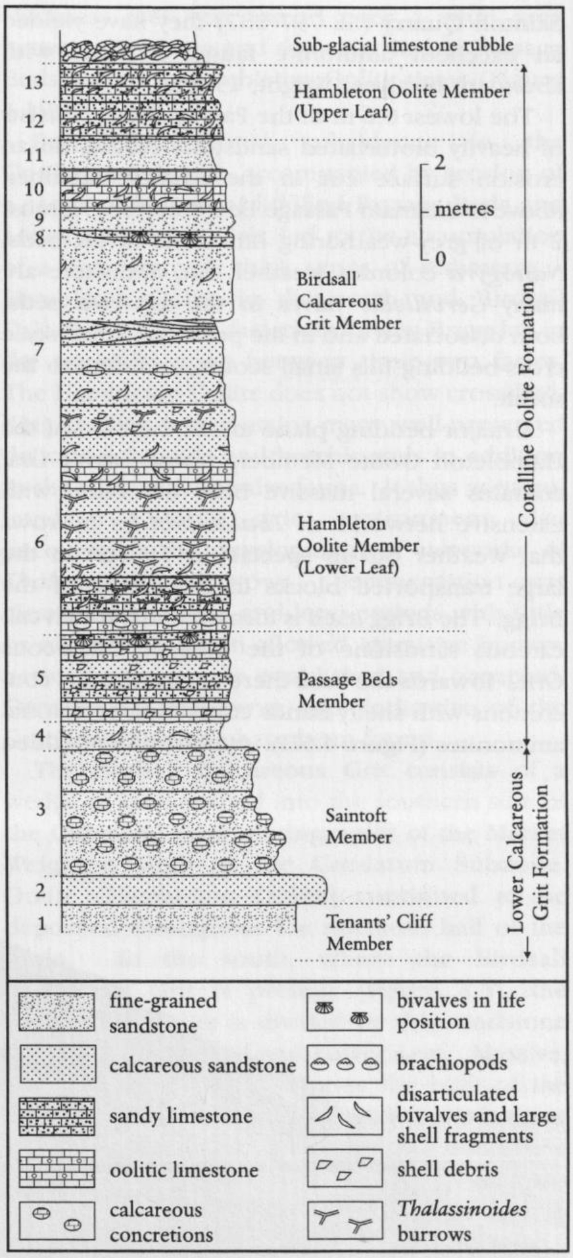

Figure 4.9 Log of the Corallian succession at Filey Brigg (after Rawson and Wright, 2000, fig. 34).

A log of the Corallian succession at Filey is given in Figure 4.9. The Tenants' Cliff Member of the Lower Calcareous Grit is present here as a tough, thick-bedded, calcareous sandstone. Though well exposed, it is only seen at low tide at the base of the precipitous cliffs. Further description and discussion is given in the Tenants' Cliff site report (this volume), where the section is more accessible.

The Saintoft Member displays the regular rows of large calcareous concretions resembling cannon balls from which the original name 'Ball Beds' came. The concretions are not particularly fossiliferous on the coast, but inland at

Saintoft Quarry (SE 797 887) they have yielded an excellent ammonite fauna, together with abundant bivalves (Wright, 1983).

The lowest 0.6 m of the Passage Beds consists of heavily bioturbated sandstone resting on an erosion surface cut in the Saintoft Member. Above is the main Passage Bed limestone: almost 2 m of grey-weathering limestone in six beds. *Nanogyra* colonies weather out, and there are many *Gervillella* valves in the top two beds, both dissociated and in life position. Small-scale cross-bedding fills small scours, and dips to the south.

A major bedding plane marks the base of the Hambleton Oolite Member, whose Lower Leaf contains several massive beds of oolite, with extensive networks of *Thalassinoides* burrows that weather out in spectacular fashion in the large transported blocks in the centre of the Brigg. The Brigg itself is formed of the tough calcareous sandstone of the Birdsall Calcareous Grit. Towards the base there are calcareous concretions with shelly bands containing occasional ammonites (Figure 4.5H). Massive cross-bedded sandstone forms the bulk of the unit, with two tough calcareous beds towards the top (Bed 8 and Bed 10).

The Upper Leaf of the Hambleton Oolite is seen excellently in the low cliff on the southern side of the Brigg (Figure 4.10). Numerous limestone-infilled *Thalassinoides* burrows descend from the base of the Upper Leaf (Bed 12) into the soft sandstone of the Birdsall Calcareous Grit (Bed 11). The tough, impure limestone contains well-preserved bivalves and ammonites. The higher beds are cut out by ice action at the base of the glacial till.

Wilson (1949) published a detailed measured section of the Coralline Oolite Formation at Filey Brigg, dividing the succession into 34 beds. Extensive fossil lists were given for each bed. The correlation of Wilson's bed numbers with those of Wright (1983) is given by Coe (1995). Wilson (1949) discussed at length the palaeoecology of the faunas, and also the conditions of sedimentation and the local palaeogeography. Further observations on the faunas were made by Wright (1972).

Figure 4.10 View of the southern side of Filey Brigg showing fossiliferous Hambleton Oolite (Upper Leaf) overlying Birdsall Calcareous Grit in the rock platform. The junction is where the figure is pointing with the hammer. (Photo: J.K. Wright.)

Interpretation

The Coralline Oolite Formation is present in an attenuated sequence, but the re-interpretation of the section by Wright (1983) shows that there is much less attenuation than formerly thought, and that this is confined to the Passage Beds. These are only 2.5 m thick at Filey, in contrast to 10–12 m in the Tabular Hills. The Hambleton Oolite, including the Birdsall Calcareous Grit, is 12.2 m thick, with the top not seen. This thickness is comparable with that measured in the Cayton Carr Borehole (Wright, 1972). Filey now fits much better into the regional pattern of sedimentation, with the Cordatum Subzone sediments thickly developed as they are elsewhere in the Cleveland Basin (Wright, 1983).

The Passage Beds can be divided into a sandstone unit (Bed 4) followed by limestone (Bed 5) as is typical over the Scarborough–Hackness area. Near-shore marine sandstone is thus followed by fine bioclastic limestone. The latter, with its gentle cross-bedding combined with the preservation of delicate fossils, seems to have formed in a series of storm surges that washed shell debris from shallower water existing in the area of the Hackness Coral–Sponge Bed to the north-west (Figure 4.19). Small clasts of the corals *Thamnasteria* and *Fungiastraea*, 2–3 mm in diameter, derived from the reef margin south-west of Hackness, occur sporadically in the Passage Beds limestones. Sedimentation was thus intermittent in this area. Throughout most of the time interval occupied by the Passage Beds, little or no sedimentation seems to have been taking place, and substantial networks of *Thalassinoides* burrows were constructed within the stable sediment. Much of the fauna is allochthonous, though in the highest bed *Gervillella* occurs in life position.

The erosion surface that separates the Passage Beds from the Hambleton Oolite can be traced throughout the whole Cleveland Basin (Wright, 1983). Particularly in the Hambleton Hills (Wright, 1983, fig. 3), erosion was accompanied by considerable uplift. The implication is that subsequent to the deposition of the Passage Beds the whole Cleveland Basin was uplifted and became land or an intertidal rock platform for a period of time. Erosion of the Hackness Coral–Sponge Bed may have given rise to the presence of the sponges *Enaulofungia* and *Corynella* found by Wilson (1949) in the overlying Hambleton Oolite at Filey. Debris from the Hackness reef was spread over a wide area between Pickering and the coast in late Passage Beds and early Hambleton Oolite times (Figure 4.19).

Renewed regional subsidence in the Cordatum Subzone, accompanied by erosion of a series of islands of lithified Passage Beds and Lower Calcareous Grit, led to the accumulation of a comparatively thick series of sediments – Hambleton Oolite in the north and Birdsall Calcareous Grit in the south. Filey Brigg lay in the transition zone between these two facies. The Hambleton Oolite does not show cross-bedding at Filey, and contains many well-preserved delicate echinoids and brachiopods in addition to the substantial bivalve fauna. It thus accumulated in a stable, quiet environment, also encouraging the development of networks of *Thalassinoides* burrows. Sedimentation was clearly intermittent, and long periods with little or no sedimentation allowed extensive burrow networks to become established and occupied. Occasional *Cardioceras* spp. indicative of the Cordatum Subzone have been found.

The Birdsall Calcareous Grit consists of a wedge of sand poured into the southern side of the Cleveland Basin during uplift of the Market Weighton High in the Cordatum Subzone. Oolite (Hambleton Oolite) continued to be deposited throughout the northern half of the basin. In the south, where the Birdsall Calcareous Grit is present (Figure 4.3), the Hambleton Oolite is divided by this sandstone unit into Upper Leaf and Lower Leaf. Massive, cross-bedded sandstone forms the bulk of the Birdsall Calcareous Grit at Filey, with, at bottom and top, beds of tough calcareous sandstone that have yielded most of the fossils. Conditions favoured the deeper-burrowing bivalves, such as *Pholadomya* and *Goniomya*, as well as *Pinna* – forms that do not occur in the Hambleton Oolite. Numerous Cordatum Subzone *Cardioceras* have been collected from this unit (Figure 4.5H).

Arkell (1935–1948) recorded *Perisphinctes plicatilis* (J. Sowerby) and *Cardioceras excavatum* from the Upper Leaf of the Hambleton Oolite, and this unit thus belongs to the overlying Densiplicatum Zone. The impure limestone contains excellently preserved fossils, though many shells are broken or have the valves dissociated. Again, these appear to have been swept from a shelf area into deeper water.

Higher Corallian beds are not seen at Filey

Brigg. Wilson (1949) suggested that this was due to the beds being cut out by a fault immediately south of the Brigg. However, the absence in the coastal section of the Malton Oolite, Coral Rag and the Upper Calcareous Grit, all of which were seen in a borehole at Filey gasworks 1.3 km to the south-west (Fox-Strangways, 1904), is better explained by the erosion of a large valley, subsequently filled with drift, through the Filey area. A complete, dipping sequence of upper Corallian beds is thus thought to lie beneath glacial drift in the Filey area. Solid rock (basal Kimmeridge Clay), overlain by drift, was met with at a depth of 25 m below sea level in the Filey gasworks borehole.

Conclusions

Filey Brigg is a key Corallian site showing the most extensive exposures in the Cleveland Basin through the Lower Calcareous Grit, the Hambleton Oolite and Birdsall Calcareous Grit. Of exceptional interest is the very fossiliferous Hambleton Oolite, which is normally present in Yorkshire in a poorly fossiliferous, ooid shoal facies. Here, it formed in a shallow, offshore shelf where shelly life proliferated. The comparatively thin development of the Passage Beds, and the facies transition into the sands of the Birdsall Calcareous Grit, are of significance in regional palaeogeographical and facies studies.

TENANTS' CLIFF, CAYTON BAY (TA 065 847)

POTENTIAL GCR SITE

J.K. Wright

Introduction

The Tenants' Cliff site is situated in the central and northern parts of Cayton Bay, south of Scarborough (Figure 4.11). The site comprises a faulted area of rock platform and cliff exposures in the triangle covered by TA 062 850, TA 065 850 and TA 067 845. Its distinctive feature is the occurrence of outcrops of the Lower Calcareous Grit Formation containing calcareous concretions that yield a prolific, exceptionally well-preserved fauna of cardioceratid ammonites. The fauna of the concretions has been known since Victorian times, and numerous examples of ammonites from museum collections were figured by Arkell (1935–1948). The museum labels simply said 'Low Calc. Grit, Scarborough', and Arkell had to attempt to identify a horizon from which these specimens had been collected. The obvious choice was the Ball Beds, a series of concretionary beds within the Lower Calcareous Grit well exposed at Filey Brigg (see site report for Filey Brigg, this volume), and at Castle Hill, Scarborough. However, only later did it become evident that the fauna had been collected from Tenants' Cliff, Cayton Bay, a locality where the Ball Beds concretions are not exposed. The fauna had been collected from an older series of concretionary beds in the Lower Calcareous Grit sequence, a unit that Wright (1983) named the 'Tenants' Cliff Member'. The Ball Beds were renamed the 'Saintoft Member' (Figure 4.3).

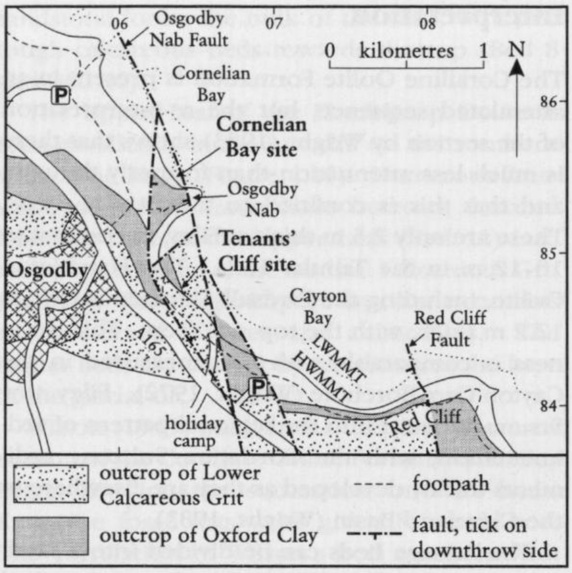

Figure 4.11 Locality map of the Tenants' Cliff and Cornelian Bay GCR sites. Outcrop of the Oxford Clay and Lower Calcareous Grit from Wright (1968, fig. 9).

Description

The following section was measured by the present author in 1983:

	Thickness (m)
Lower Calcareous Grit Formation	
Saintoft Member, Bukowskii Subzone	
6. Fine-grained, brown, very spicular sandstone	seen to 0.9

5. Fine-grained, sandy micritic limestone passing up from fine-grained sandstone 0.80

Tenants' Cliff Member

4. Massive, fine-grained, sporadically spicular sandstone with many infilled *Thalassinoides* burrows 2.36
3. Massive argillaceous, sandy spicular siltstone with the frequent development of small, very fossiliferous, calcareous concretions 7.97
2. Moderately well-bedded, slightly sandy, spicular siltstone with argillaceous partings, and weathering quite readily. Fossiliferous calcareous concretions 1 m in diameter and 0.5 m thick are developed in four distinct rows 2.15

Praecordatum Subzone

1. Soft-weathering, argillaceous sandy siltstone, becoming slightly tougher and spicular above seen to 3.63

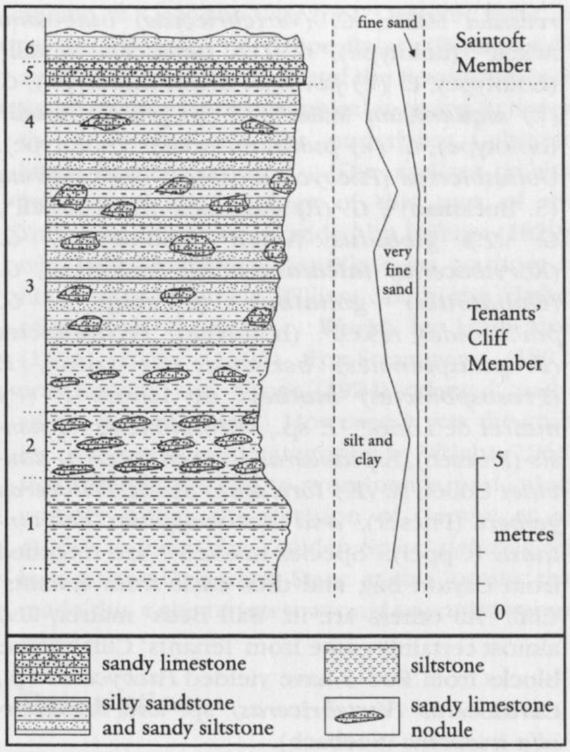

Figure 4.12 Log of the Lower Calcareous Grit succession at Tenants' Cliff, as measured by J.K. Wright in 1982.

The section was measured in the cliff that forms the western side of the site, and a log of this section is given in Figure 4.12. The cliff forms a stable feature, despite its being marked on BGS Sheet 54 (Scarborough) as landslip overlying Oxford Clay. The map of Wright (1968, fig. 9), partially reproduced in Figure 4.11, interprets the area as one of solid geology broken up by faults.

Samples from Bed 1 collected at the base of the cliff break down readily in water, containing 73% silt and clay, and thus this unit might be grouped with the Oxford Clay, though it weathers yellow/brown as does the Lower Calcareous Grit and cannot be distinguished from calcareous grit in the field. The incoming of *Rhaxella* spicules at the top of this bed marks the more typical calcareous grit facies. There is then an obvious, though irregular, increase in the quartz sand content upwards, though all beds of the Tenants' Cliff Member except Bed 4 are technically sandy siltstones. Beds 5 and 6 (Saintoft Member) mark the incursion of slightly coarser grained sand, still with much silt and clay.

Bed 1 contains frequent *Cardioceras (Scarburgiceras) praecordatum* Douvillé and is thus allocated to that subzone. The concretions of beds 2 and 3 have a very similar matrix, and fossils collected loose cannot be allocated to individual beds. Concretions are present both in the cliff section and boulders beneath, and in the large area of rock platform extending northwestwards from the cliffs. Many concretions are barren, or contain bivalves: *Chlamys fibrosus* (J. Sowerby), *Nanogyra nana* (J. Sowerby), *Anisocardia minina* (J. Sowerby), *Modiola bipartita* (J. Sowerby), *Pleuromya uniformis* (J. Sowerby), *P. alduini* (Brongniart), and *Pseudomonotis* sp.. Nests of *Rhynchonelloidella thurmani* (Phillips) and *Alaria* cf. *laevigata* Morris and Lycett are also common. Perhaps one in twenty concretions contains ammonites, all indicating the lower part of the Bukowskii Subzone. Arkell (1935–1948) recorded from the matrix of beds 2 and 3: *Cardioceras (Scarburgiceras) harmonicum* Maire, *C. (S.) excavatoides* Maire, *C. (S.)* aff. *alphacordatum* Spath, *C. (S.) gloriosum* Arkell (holotype), *C. (S.) leckenbyi* Arkell (holotype), *C. (S.) bukowskii* Maire, *C. (S.)* cf.

reesidei Maire, *C. (Vertebriceras) bulbosum* Arkell* (holotype), *C. (V.) tumescens* Arkell* (holotype), *C. (V.) phillipsi* Arkell (holotype), *C. (V.) sequanicum* Maire*, *C. (V.) gracile* Arkell* (holotype), *C. (V.) pumilum* Arkell* (holotype), *Goliathiceras (Pachycardioceras) anacanthum* (S. Buckman)*, *G. (P.) magnacanthum* Arkell*, *G. (P.) globulus* Arkell* (holotype), *G. (Korythoceras) falcatum* Arkell (holotype), *G. (Goliathites) goliathus* (d'Orbigny), *G. pavlovoides* Arkell* (holotype), *Perisphinctes (Properisphinctes) bernensis* de Loriol, *P. (Prososphinctes) matheyi* de Loriol, *P. (P.) mairei* de Loriol*, *P.* sp., *Mirosphinctes frickensis* (Moesch), *Aspidoceras (Euaspidoceras) douvillei* Collot, *A. (E.) loricatum* Spath, *Peltoceras gerberi* (Prieser), *and Neocampylites delmontanus* (Oppel). Species marked * are recorded from Cayton Bay, and thus came from Tenants' Cliff. All others are in 'Ball Beds' matrix, and almost certainly came from Tenants' Cliff. Loose blocks from Bed 5 have yielded *Pachyceras* sp., *Cardioceras (Vertebriceras)* sp. and *Myophorella triquetra* (Seebach).

Interpretation

The Tenants' Cliff Member was laid down during a period when subsidence of the Cleveland Basin failed to keep pace with the accumulation of sediment. The result was a gradual shallowing producing the transition from Oxford Clay into the spiculites of the Tenants' Cliff Member. These were laid down in a gentle, offshore marine environment that was favourable to the growth of siliceous sponges, most of whose spicules are now calcified. Evidence suggests that the Yorkshire spiculites were deposited in a regime of gentle to moderate agitation, as unrecrystallized *Rhaxella* spicules with well-preserved internal structure show signs of substantial abrasion in thin section (Wright, 1983). The well-preserved bivalve fauna of the Lower Calcareous Grit is an early variant of the *Pleuromya uniformis* association of Fürsich (1977). The gentle accumulation of fine-grained sand with minimal current winnowing results in the burrowing *Pleuromya uniformis* and *Myophorella triquetra* (Seebach) and free-swimming *Chlamys* spp. frequently being found with the two valves attached.

Ammonites that originated in the Tethyan Realm seem to have found such conditions inimical as they comprise only 5–6% of the fauna (Figure 4.13A, B), whereas during accumulation of the Oxford Clay they had dominated the fauna (Wright, 1983). Boreal cardioceratids (Figure 4.13C) seem to have thrived on and above a sea floor carpeted with sponges. Thus, the three units where *Rhaxella* is prolific – Lower Calcareous Grit, Birdsall Calcareous Grit and Upper Calcareous Grit – also have prolific cardioceratid faunas (Wright, 1983, 1996b). However, though ammonites undoubtedly thrived in these periods, it was vital to have the correct conditions for preservation, particularly the growth of calcareous concretions soon after the sediment had been laid down. Only three sites in Yorkshire are known to yield such concretions (Wright, 1983), and of these, Tenants' Cliff has by far the most varied and prolific fauna. The exceptional preservation of the Tenants' Cliff fauna is illustrated in Figure 4.13 and Figure 4.5 L–N, the cardioceratids figured here being representative of the *Cardioceras* fauna cited by Arkell (1941a) in the definition of the Bukowskii Subzone.

Arkell (1935–1948) described the ammonites of Bed 2 and Bed 3 as 'massed together and superbly preserved in hard grey, non-oolitic limestone. Many were obtained by the early collectors, and are to be seen in many museums'.

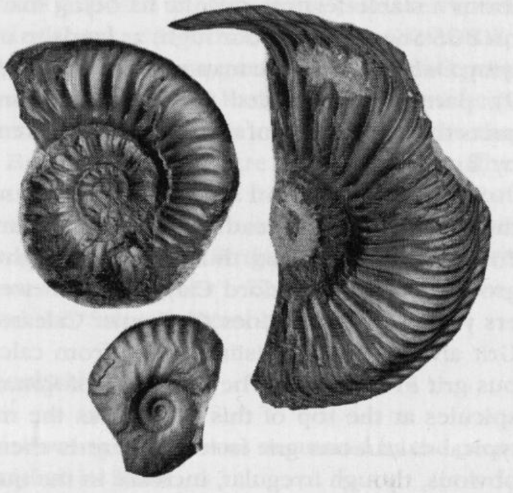

Figure 4.13 Exceptionally well-preserved ammonites from the Tenants' Cliff Member. (A) *Mirosphinctes frickensis* (Moesch) (Tethyan), LG744; (B) *Neocampylites delmontanus* (Oppel) (Tethyan), LG742; (C) *Cardioceras (Scarburgiceras) bukowskii* Maire (Boreal), LG736. (Photos: K. D'Souza. Specimens in the J.K. Wright Collection. Natural size.)

Arkell figured many of the ammonites, despite the fact that no one, at the time of his writing, had any real idea where this fauna had been collected, other than in the Scarborough district. Arkell visited Scarborough several times (Arkell, 1936b), but was unable to discover the site. His failure to do so can be attributed to the fact that the exposures at Tenants' Cliff had been virtually ignored in descriptions of Yorkshire Jurassic geology until the map of the area was published by Wright in 1968. Thus, for example, as recently as 1949, Wilson stated that there are no exposures of Corallian beds between Red Cliff, Cayton Bay, and Scarborough Castle Hill. However, the site was rediscovered during a Geologists' Association visit in 1967, Penney and Rawson (1969) recording '*Cardioceras* nucleii' from the site.

Conclusions

The distinctive feature of the site is the occurrence of the prolific Bukowskii Subzone ammonite–bivalve–gastropod–brachiopod fauna beautifully preserved in calcareous concretions. The moderate amount of coastal erosion present here means that new exposures of fossiliferous concretions are continually becoming available. Tenants' Cliff is the type locality for the Bukowskii Subzone, and hence for the definition of the base of the Cordatum Zone. The importance of this zone was emphasized by Arkell (1956). It can be recognized over a large part of the northern hemisphere and the typical cardioceratid genera and subgenera have been found as far apart as Alaska, Canada, Idaho and Wyoming in the west and Moscow, Siberia, the Caucasas, Poland, Saxony and France. Southwards across France, the cardioceratids disappear, but the characteristic *Perisphinctes, Peltoceras* and *Aspidoceras* of the Tenants' Cliff section can be found at many places in the Tethyan Realm, including North Africa, and as far afield as Madagascar.

CORNELIAN BAY (TA 064 854)

J.K. Wright

Introduction

The cliff section at the southern end of Cornelian Bay, 50 m due west of the headland known as 'Osgodby Nab' (not 'Osgodby Point' as on the OS map) or 'Knipe Point' (Figures 4.11 and 4.14), represents one of the few localities in Britain where a stratigraphical junction between the Oxfordian and the underlying Callovian Stage is well exposed. The earliest reliable account of the geology of this part of the Yorkshire coast was provided by Phillips (1829), who based his stratal identifications on those of his prestigious uncle William Smith, the 'Father of English Geology'. Works by Hudleston (1876), Blake (1891), Fox-Strangways (1892) and Kendall and Wroot (1924) referred to the site in general terms. However, it was the studies of the regional stratigraphy by Wright (1968) that brought the site to prominence, and subsequently it was the decision of George *et al.* (1969) to insert the 'Golden Spike' defining the base of the Oxfordian Stage at this locality that made this a site of international scientific importance.

Description

The Cornelian Bay exposure shows a continuous section through 8 m of Callovian strata and some 10 m of Oxfordian strata, which dip gently south-eastwards at the base of the low cliff. The basal Scarburgense Subzone of the Oxfordian Stage is present in very condensed facies (Figure 4.14), as is evident from the following measured section adapted from Wright (1968). Bed numbers continue up from the Callovian section below.

	Thickness (m)
Oxford Clay Formation	
Weymouth Member, Praecordatum Subzone	
14. Grey, silty clay containing, in a thin band 1 m up, *Cardioceras (Scarburgiceras) praecordatum* Douvillé, *Peltoceras (Peltoceratoides) arduennensis* (d'Orbigny) and fossil wood	seen to 9
Scarburgense Subzone	
13. Tough, medium-grey, fine silty clay with abundant black chamosite ooliths. Scarce ammonites include *C. (S.) praecordatum* and *C. (S.) scarburgense* (Young and Bird)	0.10
12. Sticky, black clay	0.02

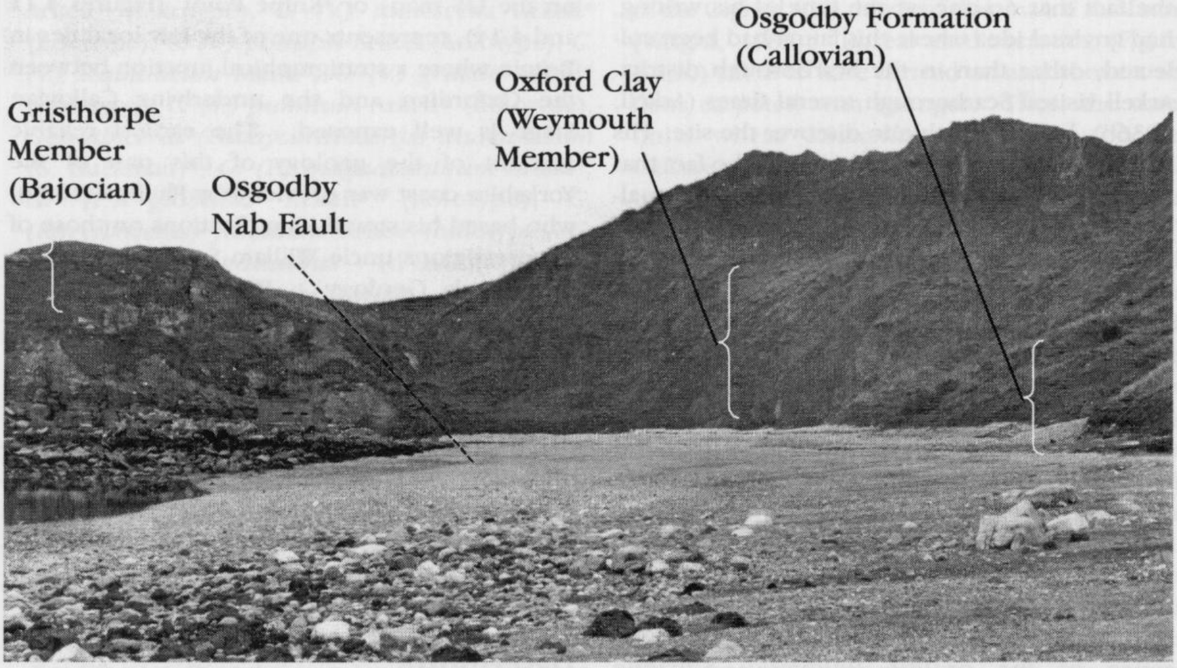

Figure 4.14 General view of the southern end of Cornelian Bay showing the Middle Jurassic Ravenscar Group (on the left) faulted against easterly dipping Osgodby Formation sandstones (Callovian) overlain by Weymouth Member Oxford Clay. (Photo: J.K. Wright.)

11.	Tough, medium-grey, fine silty clay with abundant black chamosite ooliths and a line of calcareous nodules containing well-preserved ammonites 0.05 m up. Contains *Quenstedtoceras omphaloides* (J. Sowerby), *C. scarburgense*, etc.	0.18
10.	Grey, slightly sandy shale with scattered green chamosite ooliths and a line of calcareous nodules 0.08 m up. Just below this occurs a band with frequent excellently preserved ammonites: *C. (S.) scarburgense, Q. mariae* (d'Orbigny), *Q.* aff. *macrum* (Quenstedt); also *Gryphaea dilatata* J. Sowerby, *Chlamys fibrosus* (J. Sowerby) and *Pleuromya* sp.	0.20

Osgodby Formation
Hackness Rock Member, Lamberti Zone

9.	Green, chamositic sand	0.10

A log of the section is given in Figure 4.15. The attenuation of the basal Lower Oxfordian is more marked on the Yorkshire coast than in any other area in Britain. At Cornelian Bay evidence of slow sedimentation is abundant, the Scarburgense Subzone comprising only 0.4 m of fine, nodular, chamositic clays (beds 9–13). (In comparison, this subzone has its thickest development (37.5 m) in the Warlingham Borehole in Surrey; Callomon and Cope, 1971). The ammonites are preserved uncrushed, as phosphatic internal moulds (Figure 4.5P). A facies change then occurs, with the deposition of the tough, silty clays of the Praecordatum Subzone. Sedimentation was much more rapid, and the ammonites are crushed, though the preservation can still be quite good (Figure 4.5O).

Interpretation

The ammonites of Bed 10 consist solely of Boreal cardioceratids with no Tethyan forms present. Connections with the Tethyan seas to the south had yet to be established. The bivalves *Gryphaea*, *Chlamys* and *Pleuromya* indicate

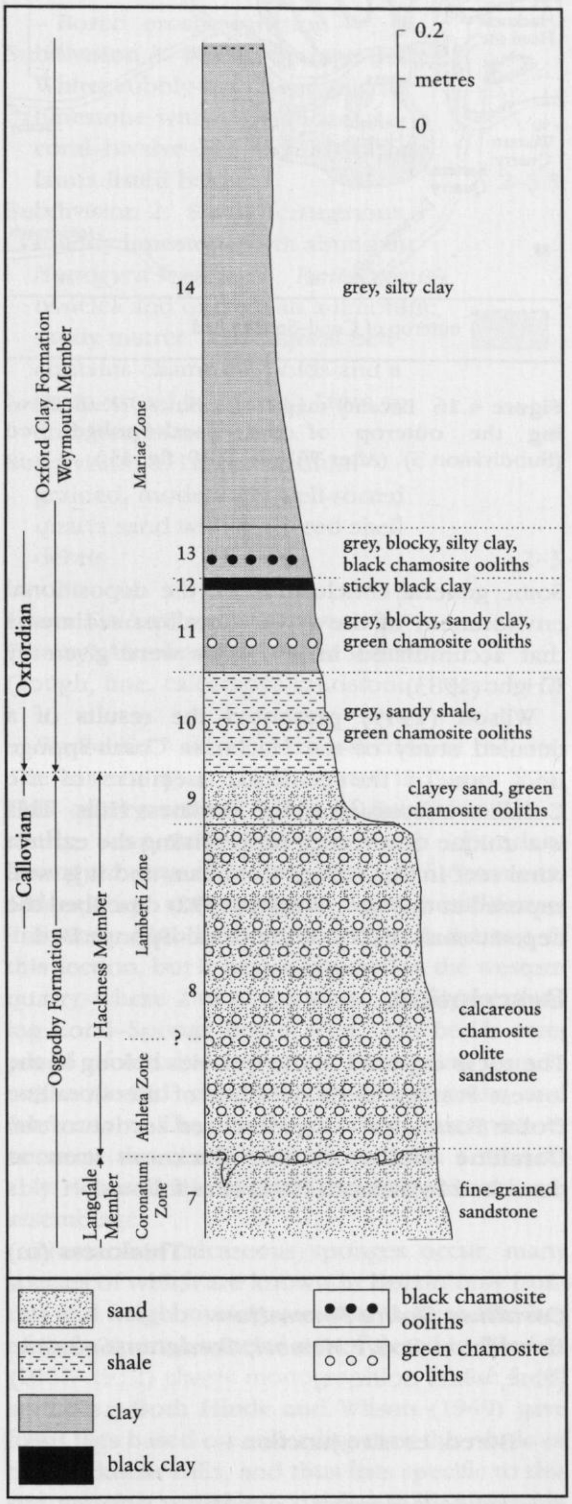

Figure 4.15 Log of the Upper Callovian–Lower Oxfordian sequence at Cornelian Bay (after Wright, 1969, fig. C4).

non-toxic bottom conditions favouring both infaunal and epifaunal suspension feeders. Sedimentation appears to have been in restricted basins, preventing ingress of clastic sediment. The silty clays of the overlying Praecordatum Subzone (Bed 14) represent the establishment of more open-water conditions over the whole area. Offshore shelf conditions predominated, with a limited benthic fauna but numerous free-swimming ammonites. Tethyan and Boreal forms are found in roughly equal proportions, *Peltoceras, Aspidoceras* and *Taramelliceras* representing the aforementioned, while the Boreal *Cardioceras* and *Quenstedtoceras* were joined by *Goliathiceras*.

Attenuation of the basal strata of the Oxfordian sequence on the Yorkshire coast probably represents a response to the effects of deep-seated tectonic movements affecting deposition near to the Market Weighton High, the northern edge of which lies only 15 km to the south (Kent, 1980a). The basal Oxfordian in much of north-west Europe is either thin or absent, there being a regional hiatus or lacuna at this horizon. In those areas affected by episodes of still-stand and erosion, the earliest Scarburgense Subzone faunas occur in small pockets of sediment found in hollows, and have been overlooked until recently (Wright, 1983).

The junction between the Oxfordian and Callovian stages was taken by George *et al.* (1969) between beds 9 and 10. However, subsequent to the choice of Cornelian Bay as the British stratotype section for the base of the Oxfordian, it has become apparent that the succession here may not be entirely complete. Wright (1983) records silty, sandy beds containing *Quenstedtoceras paucicostatum* (Lange) overlying the Lamberti Zone Hackness Rock at Gristhorpe Cliffs (TA 095 833). When first described by Marchand (1979), the *Q. paucicostatum* fauna was considered to be the earliest fauna of the Oxfordian. However, subsequent work (Callomon and Cope, 1995) has shown that the *Q. paucicostatum* fauna is the highest fauna of the Callovian Stage. The *C. scarburgense* silts appear to have overstepped the *Q. paucicostatum* silts at Osgodby Nab. This evidence of a non-sequence or non-sequences at this site, and the problem that the site is occasionally covered by slipped clay (Figure 4.14), has led Marchand and Fortwengler (1995) to propose a French locality as the international standard for the Callovian–Oxfordian boundary.

This action does not detract from the importance of the Cornelian Bay site as one of the best localities in Britain at which the Callovian–Oxfordian junction can be examined.

Conclusions

The Cornelian Bay site provides one of the few sections in Britain where the comformable contact between basal Oxfordian Scarburgense Subzone rocks and the underlying Lamberti Zone beds of the Callovian sequence is well exposed and can be studied in detail. The base of the Weymouth Member of the Upper Oxford Clay is thinly developed, there being a regional hiatus present at the level of the highly condensed Scarburgense Subzone, which is only half a metre in thickness. This locality is important in palaeogeographical studies of this heavily faulted region north of the Market Weighton High, and is essential in elucidating the complex biostratigraphy of the Oxfordian of the Sub-Boreal Province.

HACKNESS HEAD (SE 964 905 AND SE 966 904)

J.K. Wright

Introduction

The Hackness Head locality is a composite site, comprising two adjacent disused quarries about 100 m apart, and is situated approximately 0.5 km due west of Hackness village (Figure 4.16). Costicardia Subzone limestones are preserved here on the southern side of the Hackness Outlier, a large dissected area of Corallian rocks north-east of the main Corallian outcrop and separated from it by the valley of the River Derwent.

The Corallian rocks of the Hackness Hills were first studied and mapped by William Smith whilst he was employed on the Hackness Estate (Smith, 1829–1830). Hudleston (1876, 1878) and Blake and Hudleston (1877) gave general accounts, and detailed mapping and a study of the stratigraphy was carried out by Fox-Strangways (1892). Arkell (1933) and Wilson (1934) both based their accounts on Fox-Strangways' work. The rocks of the Hackness Outlier were referred to in general terms by Wright (1972), who gave a revised stratigraphy, and this scheme was adopted by Kent (1980b).

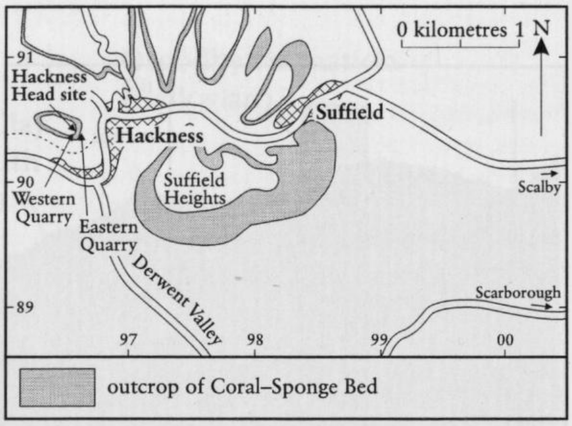

Figure 4.16 Locality map for Hackness Head showing the outcrop of the Coral–Sponge Bed (Subdivision 3). (After Wilson, 1949, fig. 43.)

Some general conclusions on the depositional environment of the lower Corallian sediments that accumulated in this area were given by Wright (1983).

Wilson (1949) presented the results of a detailed study of the Hackness Coral–Sponge Bed, one of the principal members of the Corallian succession in the Hackness Hills. This is a unique occurrence representing the earliest coral reef in the British Corallian, and it is well exposed at this site. Wright (1992) described the depositional history of the Coral–Sponge Bed.

Description

The rocks exposed in the quarries belong in the lowest Passage Beds Member of the Coralline Oolite Formation. A generalized section of the Coralline Oolite in the Hackness area as described by Wright (1992) is as follows:

Thickness (m)

Coralline Oolite Formation
Hambleton Oolite Member, Cordatum Subzone
(Fine, white oolite 9)

– Bored, erosive junction –

Passage Beds Member, Costicardia Subzone
Subdivision 4. Biosparite containing abundant large coral fragments, limestone clasts and '*Pentacrinus*' ossicles in a shelly matrix with

much medium-grained quartz sand	0.15–0.20
– Bored, erosive junction –	
Subdivision 3. (Coral–Sponge Bed). White, rubbly-weathered micritic limestone with an abundant coral–bivalve–brachiopod–sponge fauna listed below	2–3.5
Subdivision 2. Shelly, ferruginous, muddy limestone with abundant *Nanogyra* fragments, '*Pentacrinus*' ossicles and oncoids in a limonitic, sandy matrix. The highest bed contains chamosite ooids and a more varied fauna with *Lima* sp. and *Pleurotomaria* sp.	4
Subdivision 1. Loose, medium-grained, moderately well-sorted quartz sand with scattered shell debris	2–3

Lower Calcareous Grit Formation
Saintoft Member, Bukowskii Subzone
(Tough, fine, calcareous sandstone — seen to 5)

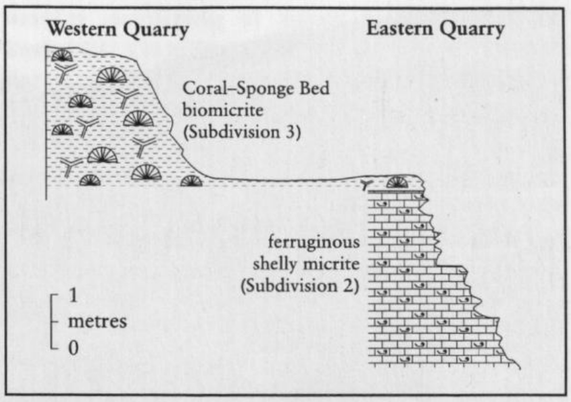

Figure 4.17 Cross-section of Hackness Head showing the two quarry sections, as measured by J.K. Wright in 1991.

Figure 4.17 shows a cross-section of the site. The eastern quarry is illustrated in Figure 4.18. This quarry reveals 3.7 m of Subdivision 2, a shelly, iron-rich limestone with abundant *Nanogyra nana* (J. Sowerby), and occasional *Chlamys* sp. and sponges. Some coralliferous limestone (Subdivision 3) occurs at the top of this section, but is better exposed in the western quarry, where 2 m of the white, rubbly-weathering Coral–Sponge Bed is seen. The bed is composed of micritic limestone containing numerous rounded colonies of *Fungiastraea* and *Isastraea*. The shelly, micritic limestone in between the coral colonies contains a remarkably rich and diverse reef-dwelling invertebrate assemblage.

Numerous calcareous sponges occur, many species of which are known in Britain only from this and neighbouring quarries. A large number of these sponge species were figured in Hinde's (1887–1912) classic monograph on British fossil sponges. Both Hinde and Wilson (1949) gave fossil lists based on collecting over the whole of the Hackness Hills, and thus lists specific to this site are not available. Hinde (1887–1912) initially recorded seven species of calcareous sponge from the Hackness Coral–Sponge Bed. Wilson (1949), who made a collection of over 300 specimens from the Hackness area, amended this to 11 species. The complete list of fossil sponges recorded from the Hackness Outlier is as follows: *Enaulofungia floriceps* (Phillips), *E. polita* (Hinde), *E. bernensis* (Etallon), *E. bella* (Hinde), *E. smithi* (Wilson), *E. hindei* (Wilson), *E. suffieldensis* (Wilson), *Peridonella recta* Hinde, *P. hacknessi* Wilson, *Blastina aspera* Hinde and *Corynella chadwicki* Hinde.

The calcareous sponge assemblage occurring in the Hackness Coral–Sponge Bed is found in association with a coral fauna rich in numbers, and consisting of *Fungiastraea arachnoides* (Parkinson), *Isastraea explanata* (Goldfuss) and *Thamnasteria concinna* (Goldfuss). These occur in lenses, colonies and isolated masses or 'roundheads', along with numerous often fragmentary branching corals such as *Thecosmilia annularis* (Fleming) and *Rhabdophyllia phillipsi* Edwards and Haime. Hitchins (1980) found within sheltered pores in corals and sponges small foraminifera belonging to a new genus *Tentilenticulina*. Other foraminifera such as *Placopsilina* occur fixed to coral surfaces.

Large numbers of terebratulid brachiopods along with numerous bivalve, echinoid, serpulid worm and bryozoan species fill other ecological niches in the rich palaeontological community of the Coral–Sponge Bed. The full list of brachiopod, bivalve and echinoid species, based on Wilson (1949) and Kent (1980b), is as follows:

Bivalves:
Lopha gregarea (J. Sowerby)
Nanogyra nana (J. Sowerby)
Lithophaga inclusa (Phillips)

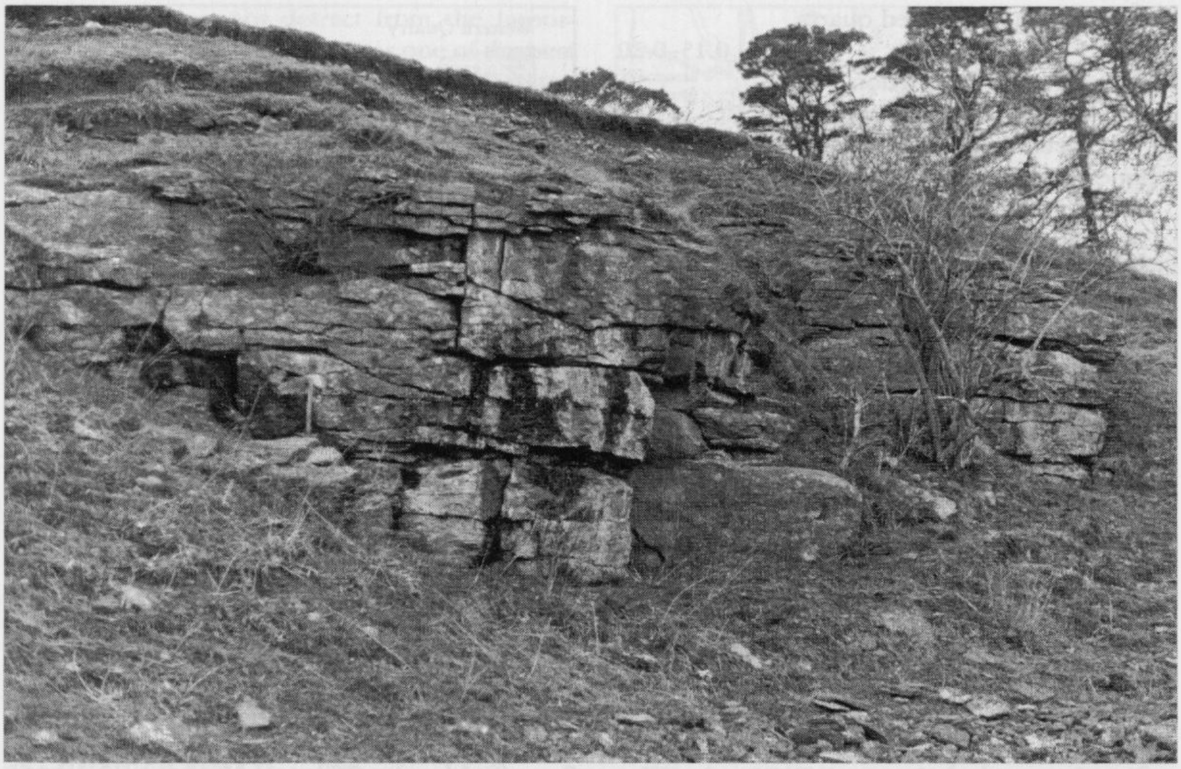

Figure 4.18 View of the eastern quarry at Hackness Head, showing the massive, bioclastic limestones of Subdivision 2 overlain by coral rubble (Subdivision 3) just below the grass at the top. Hammer shaft (mid-left of picture) is 30 cm. (Photo: J.K. Wright.)

Liostrea quadrangularis Arkell
Chlamys nattheimensis (de Loriol)
Chlamys fibrosus (J. Sowerby)
Lima zonata Arkell
Lima rigida (J. Sowerby)
Astarte ovata Smith
Camptonectes lens (J. Sowerby)
Pleuromya uniformis (J. Sowerby)
Ctenostreon proboscideum (J. Sowerby)
Praeconia rhomboidalis (Phillips)
Ostrea sp.
Velata anglica Arkell
Gervillella aviculoides (J. Sowerby)

Echinoids:
Hemicidaris intermedia (Fleming)
'Cidaris' smithi Wright

Brachiopods:
'Terebratula' fileyensis Walker
'Terebratula' kingsdownensis auctt
Zeilleria hudlestoni Walker
Terebratulina substriata auctt

Interpretation

Subdivision 1

Wright (1992) deduced that the unit had been laid down as part of a terrigenous sand sheet. The medium grain size and moderate-to-good sorting suggests that the Hackness area was occupied by a barrier sand extending across a predominantly westerly current that was gradually transporting terrigenous sediment from the Market Weighton uplift to the south. Both east and west of Hackness, the equivalent sands are fine grained, offshore marine in nature (see site report for Filey Brigg, this volume).

Subdivision 2

Conditions do not seem to have been favourable for life, with the exception of *Nanogyra*. This was almost certainly a shallow, tidal, lagoonal area prone to the influx of ferruginous mud from a nearby landmass to the north. In the deeper parts of the lagoon, '*Pentacrinus*' thickets flourished, along with thin-shelled bivalves and *Nanogyra*, in conditions sheltered from wave action. Around the margins of the lagoon, freshly broken bivalve shells provided an abundant supply of nucleii for oncoids to grow in the intertidal zone.

The highest bed in this ferruginous sequence, a chamosite oolite crowded with green ooids, is also the most varied as far as the fossil content is concerned. Conditions for the formation of this iron silicate mineral, initially as berthierine (see site report for Westbury, this volume), cannot have been toxic to living organisms, and the berthierine almost certainly formed diagenetically within the sediment (Donaldson *et al.*, 1999).

Subdivision 3

Wilson (1949) described the Coral–Sponge Bed at the Hackness site as a heterogeneous mass of lenses of compound corals, calcareous sponges and a host of other fossils in a matrix of calcilutite and detrital reef carbonate. He regarded the corals, sponges and other organisms as having lived in shallow, warm, fully marine waters that were agitated and current swept, and in which little deposition was taking place.

Growth banding shows that the average growth rate for the Hackness corals was only 2 mm per year, as against an average of 10 mm for corals growing in the Bahamas today. Britain in the Late Jurassic Epoch was at a similar latitude to that of the Bahamas, and initially, this slow growth rate seems puzzling. Such rates of growth of 1.5–3 mm per year are in fact quite typical throughout the British Corallian, and the explanation is simply that Jurassic corals grew at a slower rate than do modern ones (Ali, 1984), and had much denser skeletons.

Insalaco (1996) has noted that there is a marked difference in growth rates between Jurassic corals from the Yorkshire reefs and corals of a similar age from central Europe. In Yorkshire the growth rate was on average 1.5 mm per year less than that in central Europe. The climate in both areas seems to have been equable and similarly suited to coral growth. Insalaco proposed that the reduction in growth of the Yorkshire corals was due to the lesser amount of solar radiation reaching these northerly latitudes (39°N at this time).

The massive corals from Hackness are quite small (*c.* 150 mm) compared with the large coral masses occurring at other horizons in the Yorkshire Corallian (see site report for Betton Farm, this volume), and some special factor appears to have inhibited their growth. One possibility is an influx of clay washed in from the low-lying landmass to the north (Rawson and Wright, 2000). Equally likely, Hackness was situated in a lagoonal area away from the reef front (Figure 4.19), and growth of coral here would be inhibited by a reduced food supply.

Thus, with its abundance of lime mud and only slightly broken and abraded shell debris, the Hackness area appears to have been a quiet, lagoonal area in the centre of a reef complex. There was prolific growth of the delicate, branching *Rhabdophyllia*, and the more sporadic growth of massive corals. The abundance of robust globate terebratulids and the presence of sponges support the view that these deposits were formed near land and in shallow water. Palmer and Fürsich (1981) studied a Bathonian sponge reef in Normandy and suggested a similar shallow, protected, low-energy environment.

Studied as a whole, the coraliferous sequences within the Yorkshire Passage Beds fulfil many of the criteria of a coral reef complex (Figure 4.19). To the south-west of Hackness, at Basin Howe, coralliferous micrite with large coral masses reaching 250 mm in diameter occurs (Wright, 1992). The larger size of the corals, plus the abundance of broken coral and the coarser matrix, suggests that this area was close to the nutrient-supplying currents. As the coral reef built up here into the surf zone, coral growth was at its maximum, but erosion was equally at a maximum. Thus, in all directions to west, south and east of Basin Howe, the Coral–Sponge Bed passes laterally into a coral–shell bed consisting of a chaotic jumble of abraded coral fragments, sponges, echinoids and bivalves.

Slightly further west, south and east (i.e. to the south at Spikers Hill, see site report, this volume), the coral fragments are more rounded and fragments of reef rock more numerous. As the clasts were transported longer distances they became more and more abraded, and those in the long tail of coral–shell sand extending towards Filey consist almost entirely of 2–3 mm fragments of *Thamnasteria* and *Fungiastraea* (see site report for Filey Brigg, this volume).

It is clear that in the area south of Hackness the Coral–Sponge Bed formed a solid reef front that was attacked by wave action and the coral

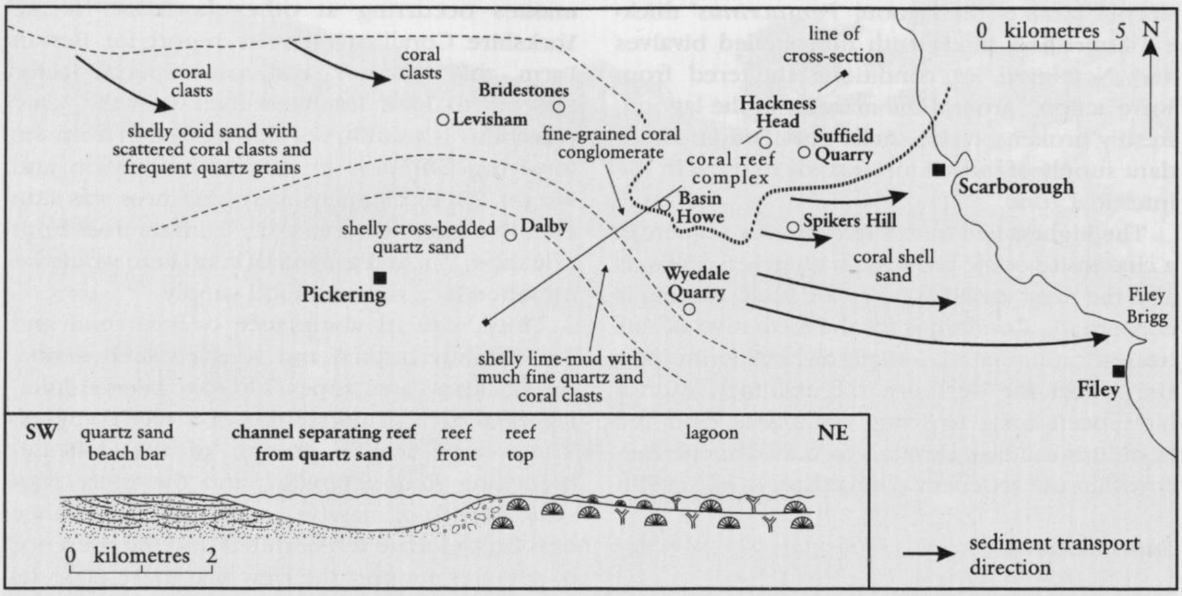

Figure 4.19 Facies distribution across the central and eastern parts of the Cleveland Basin during deposition of the Hackness Coral–Sponge Bed (after Wright, 1992, fig. 10).

fragments broken off and incorporated into the surrounding sediments. An irregular reef margin is indicated in Figure 4.19, based on detailed mapping of clast sizes. Coral conglomerate with clasts 5–10 mm in diameter formed in a narrow zone close to the reef. Coral fragments averaging 2–3 mm are scattered through the fringing sediments away from the reef, and can be prolific (see site report for Spikers Hill, this volume). The long tail of coral–shell sand extending eastwards to Filey demonstrates the west–east transport direction. The lessening in the energy of transport of this finer-grained sediment is shown by the occurrence of large, complete bivalves in life position, i.e. *Gervillella aviculoides* (J. Sowerby) at Filey Brigg. This is the dominant bivalve of a community that seems to have thrived in a relatively high-energy environment.

The conditions suitable for the association of corals and sponges at Hackness were unique in Britain, and were not repeated in later Corallian times. During the main episode of coral reef development in the Coral Rag of Yorkshire, Cambridgeshire, Oxfordshire and Wiltshire there is a virtual absence of calcareous sponges and terebratulids. The Hackness Coral–Sponge Bed formed relatively soon after the end of the sandy conditions of the Lower Calcareous Grit and early Passage Beds, and it appears that the continued influx of very fine clastic sediment affected the palaeoenvironment, encouraging the growth of sponges, and slightly inhibiting that of corals.

Subdivision 4 – the Pentacrinus biosparite

This thin, oobioclastic limestone rests erosively on the coral reef throughout the Hackness area. It is not exposed at the Hackness Head site, but it is seen particularly well at Spikers Hill. The conditions of deposition will thus be dealt with below in the Spikers Hill GCR site report.

Conclusions

Hackness Head is a key stratigraphical and palaeontological site for Upper Jurassic British rocks. The locality shows two metres of coral–sponge bed belonging to the Passage Beds Member at the base of the Coralline Oolite Formation. This accumulation of colonial corals of both massive and phaceloid forms is the earliest known in the British Oxfordian record, and its association with a wide variety of fossil sponges is unique.

BETTON FARM (TA 0020 8565 AND TA 0015 8555)

J.K. Wright

Introduction

The Betton Farm site comprises two adjacent disused quarries situated either side of the A170, approximately 1 km north-east of East Ayton (Figure 4.20). The exposures occur at the south-eastern extremity of the Tabular Hills, and were first described by Blake and Hudleston (1877) and Hudleston (1878). The site has been visited twice during Geologists' Association field meetings (Wilson, 1934, 1954) and is listed in a field guide by Sylvester-Bradley (1953). These exposures figure conspicuously in the valuable thesis of Lee (1971) concerning the 'Coralline Oolite Formation east of Newtondale', and are discussed in the overall review of Corallian stratigraphy in Yorkshire by Wright (1972). Brief mention of the exposures also occurs in Hemingway (1974) and Kent (1980b), and descriptions of one of the sections were given by Rawson and Wright (1995, 2000).

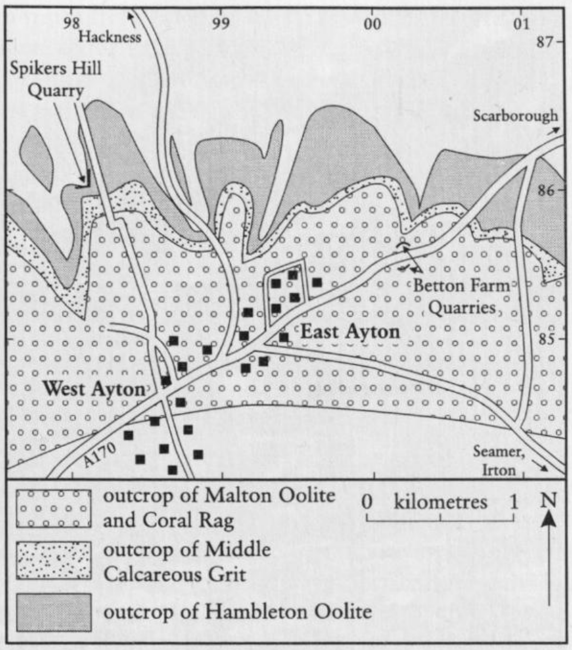

Figure 4.20 Locality map of the Betton Farm and Spikers Hill GCR sites. Geological outcrops from BGS Sheet 54 (Scarborough) (1998).

Description

The quarry north of the road has recently been cleaned up, while that south of the road remains overgrown at the time of writing. This account is thus largely based on the exposures in the northern quarry. The following section is taken from Rawson and Wright (2000).

	Thickness (m)
Coralline Oolite Formation, ?Maltonense Subzone	
Malton Oolite Member	
2. Shelly oomicrite containing fragmentary corals, echinoid spines, bivalves and gastropods, and with large isolated masses of *Thamnasteria* up to 1 m across (= Betton Farm Rag, Figure 4.3)	1.5
1. Well-bedded to massive, very poorly sorted oolite containing *Bourguetia striata* (J. Sowerby)	2.2

The chief interest of the exposure is in Bed 2 (Figure 4.21), which is extremely variable in nature. Around the outside of the masses of *Thamnasteria* is a densely packed oolite–coral–shell sand with abundant abraded fragments of massive corals. In between the coral stacks is a shelly, coralliferous oomicrite with abundant delicate coral fragments including *Rhabdophyllia*, together with delicate bivalves, and abraded coral fragments. The oomicrite of Bed 2 is thinly bedded, and is seen to pass laterally into massive coral, which was growing as the sediment around it accumulated. The coral masses are then overlain by poorly sorted oosparite that infills borings and crevices in the top surface of the corals. Wilson (1934) recorded from this quarry *Thamnasteria concinna* (Goldfuss), *Lithophaga inclusa* (Phillips), *Chlamys nattheimensis* (de Loriol), *Nanogyra nana* (J. Sowerby), *Bourguetia striata* and '*Cidaris*' *smithi* Wright.

Coralliferous facies very similar to that of the shelly limestones surrounding the coral stacks at Betton Farm can be traced from Seamer to Brompton, and have been envisaged as filling a 'channel' (Wilson, 1934; Kent, 1980b). Blake and Hudleston (1877) gave a comprehensive faunal list from the half dozen or so quarries that formerly exposed this bed, including Betton

Figure 4.21 View of Betton Farm Quarry (north) showing rounded masses of Thamnasterian reef coral above the hammer (30 cm) resting on oolite (Malton Oolite). (Photo: J.K. Wright.)

Farm. An updated version of this list is as follows:

Bivalvia:
Liostrea sp.
Nanogyra nana
Lopha gregarea (J. Sowerby)
Chlamys nattheimensis
Camptonectes lens (J. Sowerby)
Velata anglica Arkell
Lima rigida (J. Sowerby)
Isognomon promytiloides Arkell
Navicula quadrisulcata (J. de C. Sowerby)
Barbatia pectinata (Phillips)
Cucullea contracta Phillips
Astarte subdepressa Blake and Hudleston
Astarte ovata Smith
Myochoncha texta (Buvignier)
Pseudomonotis ovalis (Phillips)
Lithophaga lycetti (Whiteaves) (holotype)
Lithophaga inclusa

Gastropoda:
'Natica' arguta Phillips
Cerithium inornatum Buvignier
Cerithium limaeformis Roemer
Cerithium humbertinum Buvignier
Nerinea fusiformis d'Orbigny
Nerinea fasciata Voltz
Nerinea visurgis auct. *non* Roemer
'Littorina' muricata (J. Sowerby)
Turbo funiculatus Phillips
Pseudofissurella corallensis (Buvignier)
Trochus aytonensis Blake and Hudleston
Bourguetia saemanni
Ditremaria tornatilis (Phillips)
Pseudomelania heddingtonensis (J. Sowerby)

Brachiopoda:
'Terebratula' kingsdownensis auctt

Echinodermata:
'Cidaris' smithi
Hemicidaris intermedia (Fleming)

Anthozoa:
Thamnasteria concinna
Rhabdophyllia phillipsi Edwards and Haime

Interpretation

It has been a matter of contention for 120 years whether the Betton Farm section lies within the Malton Oolite, or whether it represents the true Coral Rag. Stratigraphically, all that can be said of the exposure is that it occurs somewhere in the upper part of the Coralline Oolite Formation, between the Middle and Upper Calcareous Grits, neither of which is exposed in the vicinity. The Betton Farm Rag must be correlated with exposures elsewhere by means of its fauna and lithology. Hudleston (1878) was the first to compare critically the faunas and lithologies at Betton Farm with those seen in the Coral Rag throughout the Cleveland Basin. The arguments can be presented as follows.

In the western, southern and eastern parts of the Cleveland Basin, the true Coral Rag consists of a framework of massive and phaceloid corals preserved in a shelly, micritic matrix. This reef facies frequently rests on a coral–shell bed, and this on Malton Oolite (see site report for Wath Quarry, this volume). There was no return to oolitic facies, and Upper Calcareous Grit rests on a bored, erosive surface of Coral Rag at several localities (see site report for Newbridge, this volume). The principal developments of corals in Yorkshire are in the Coral Rag and in the Hackness Coral–Sponge Bed. Frequently during deposition of the Hambleton and Malton Oolites, however, there was a localized development of coralliferous horizons resulting in masses of *Thamnasteria* up to 1 m across being preserved in oolite. One such structure in the Hambleton Oolite is described by Rawson and Wright (2000, pp. 86, 87). In these beds the fauna other than corals is reduced compared with the true Coral Rag. In particular, spines of the echinoid *Paracidaris florigemma* (Phillips) are absent. These are so common in the true Coral Rag that Hudleston (1878) used the term *florigemma*-Rag, and proposed a zone of *Cidaris florigemma*. *Paracidaris florigemma* has not been recorded at Betton Farm, leading to the conclusion that the 'Coral Rag' at Betton Farm does not represent the true Coral Rag, but is simply a coralliferous facies of the Malton Oolite.

The idea, first put forward by Hudleston (1878), that the Antecedens Subzone Malton Oolite passes into coralliferous facies in the Seamer–Ayton–Brompton area now seems firmly established. Wright (1972) suggested on ammonite evidence that the Betton Farm Rag was older than Coral Rag elsewhere. Evidence from the Betton Farm section supports this view, in particular the fact that oolite overlies the coral masses. True Coral Rag should be sought higher up (Figure 4.3), and, in fact, 6 m of massive thamnasterian reef were recorded by Wilson (1931) from the Irton Borehole only 1.5 km away. This lay immediately beneath the Upper Calcareous Grit, and was clearly the Coral Rag *sensu stricto*, coming in at a horizon some distance above the present section.

Conclusions

The Betton Farm quarries show the best example of *Thamnasteria* patch reefs in the Yorkshire Corallian, with a rich associated molluscan fauna, notably gastropods, occurring both in and around the reefs. This is an important palaeoecological locality in the classic Yorkshire Corallian.

SPIKERS HILL (SE 980 863)

J.K. Wright

Introduction

Spikers Hill Quarry is a large limestone quarry currently being operated by Marshall's Stone Company Ltd. It lies about 6 km west of Scarborough and 1.5 km north of the village of West Ayton (Figure 4.20). It occupies a narrow spur of rising ground separating Forge Valley from Yedmandale. The principal area of interest is in the most recently worked southern part of the quarry where there is a roughly E–W-trending vertical face, with stepped ledges above (Figure 4.22). Though the quarry is clearly marked on maps dated 1950 and earlier, the first description of this site was published by Wright (1972). The quarry figured prominently in the thesis of Lee (1971), and reference has been made to the section in Hemingway (1974) and Kent (1980b). A revised description was given by Rawson and Wright (1995). Several ammonites from the quarry were figured by Wright (1997), and see Figure 4.5J, K.

Description

The quarry, when first opened, revealed a small

Figure 4.22 The main east–west face in the Hambleton Oolite at Spikers Hill Quarry. The dark, pisoidal 'Blue Band' (Bed 2) is clearly seen towards the top of the quarry, overlain by beds 3 to 7, which are more thinly bedded than those below. Since this photo was taken, the quarry has been deepened to reveal part of the Passage Beds, Bed '0'. (Photo: J.K. Wright.)

section in white, unfossiliferous oolite. However, when Wright and Lee visited the site in the late 1960s, the operations had expanded and deepened the pit considerably to expose a fine section through more than 19 m of Lower and Middle Oxfordian strata belonging to the Cordatum and Densiplicatum zones, and Wright (1972) published a measured section. The quarry has been extended and deepened further in recent years, revealing previously unexposed strata at both top and bottom of the section. The revised section given below is from Rawson and Wright (1995), these authors introducing Bed '0' to encompass the newly exposed lowest beds.

Thickness (m)

Coralline Oolite Formation

Malton Oolite Member, ?Maltonense Subzone

7. White, flaggy oolite — seen to 1.0
6. Flaggy, shelly oolite, largely oosparite but passing into oomicrite. Contains many whole bivalves and gastropods, including *Gervillella aviculoides* (J. Sowerby), *Myophorella* sp., *Chlamys* sp., *Nanogyra nana* (J. Sowerby), *Pseudomelania heddingtonensis* (J. Sowerby), *Nucleolites scutatus* Lamarck and *Cardioceras* sp. — 0.25

– erosion surface –

Middle Calcareous Grit Member, Vertebrale Subzone

5. Fine-grained, argillaceous sandstone, thick bedded below, becoming flaggy, calcareous and oolitic above. Occasional bivalve fragments present — 1.17

Hambleton Oolite Member

4. Flaggy, impure, sandy oomicrite with an abundant fauna: *Cardioceras (Cardioceras)* aff. *cordatiforme* (S. Buckman), *C. (Scoticardioceras) excavatum* (J. Sowerby) (common), *C. (Subvertebriceras) zenaidae* Ilovaisky (common), *C. (Vertebriceras)* ex gr. *vertebrale* , *C.*

(Plasmatoceras) popilianiense Boden and *Aspidoceras* sp., with *Pleuromya uniformis* J. Sowerby, *Trichites ploti* (Lluyd), *Lopha gregarea* (J. Sowerby), *G. aviculoides*, *Isognomon* sp., *Camptonectes lens* (J. Sowerby), *Cerithium* sp. and *N. scutatus* 0.15

3. White, micritic oolite containing small colonies of *Thamnasteria concinna* (Goldfuss) 0.9
2. Blue, unoxidized, non-oolitic limestone with algal pisoids (oncoids), abundant abraded shell fragments and occasional *Perisphinctes (Arisphinctes)* aff. *cotovui* Simionescu 2.45

Cordatum Subzone

1B. Thick-bedded, white oolite, with two, minor, blue-grey bands at 4 m and 9.5 m. The fauna, apart from frequent *G. aviculoides*, is sporadic: *Thamnasteria* sp., *Cardioceras* sp. and *Goliathiceras (Pachycardioceras) nitidum* Arkell 12.7

Passage Beds Member, Costicardia Subzone

1A. Fine-grained, very poorly sorted, shelly oolite containing '*Pentacrinus*' ossicles and *Perisphinctes* sp. 1.8

'0' Massive, bioclastic limestone in three beds separated by iron-rich bands. *Chlamys fibrosus* (J. Sowerby), *Liostrea* sp. and *G. aviculoides* are common. The limestone becomes increasingly coarse grained and shelly upwards, with nests of *N. nana*, and numerous abraded fragments of massive and solitary corals and sponges seen to 2.1

A log of the quarry face is given in Figure 4.23. The Passage Beds (Bed '0' and Bed 1A) are very fossiliferous, with fragments of *Fungiastraea, Thecosmilia* and *Rhabdophyllia* recognizable among the coral debris, though the clasts rarely exceed 3 mm. Bed 1A is a poorly sorted, immature oolite, with scattered coral fragments and '*Pentacrinus*' ossicles, and is coarsely shelly at the base; it was grouped with the Passage Beds by Wright (1992). The 16 m thick Hambleton Oolite succession is largely represented by

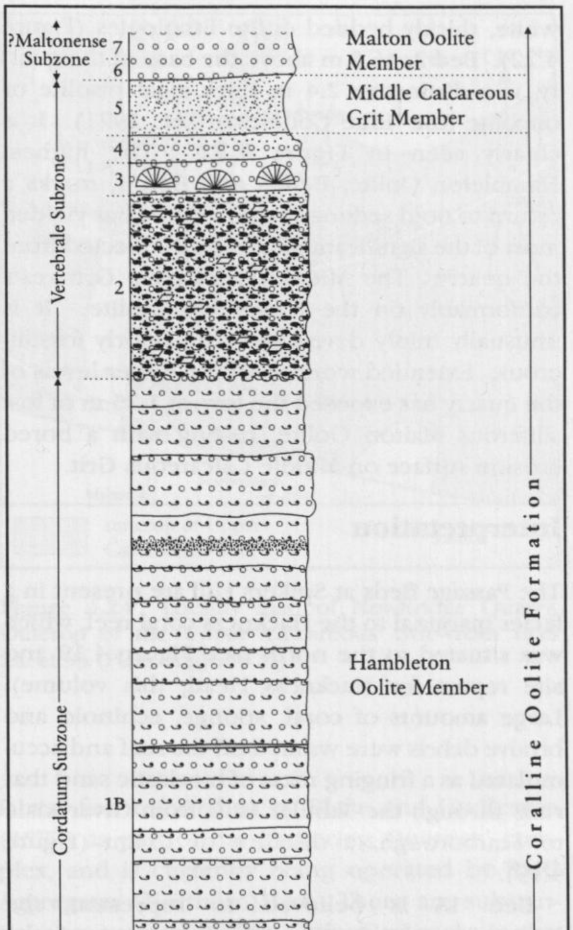

Figure 4.23 Log of the Corallian succession at Spikers Hill Quarry, as measured by J.K. Wright in 1991.

white, thickly bedded oolite lithologies (Figure 4.22). Bed 2, 16.5 m above the base of the quarry, is a distinctive 2.4 m thick algal pisolite or oncolite (the 'Blue Course' of Lee, 1971). It is clearly seen in Figure 4.22. The highest Hambleton Oolite, Bed 3 and Bed 4, marks a return to ooid sedimentation. Bed 4 has yielded most of the significant ammonites collected from the quarry. The Middle Calcareous Grit rests conformably on the Hambleton Oolite. It is unusually thinly developed, and poorly fossiliferous. Extended working of the upper levels of the quarry has exposed the lowest 1.25 m of fossiliferous Malton Oolite, resting with a bored erosion surface on Middle Calcareous Grit.

Interpretation

The Passage Beds at Spikers Hill are present in a facies marginal to the Hackness coral reef, which was situated to the north (see Figure 4.19 and site report for Hackness Head, this volume). Large amounts of coral, sponge, echinoid and bivalve debris were washed off the reef and accumulated as a fringing mass of bioclastic sand that runs through the Tabular Hills from Giverndale to Scarborough, a distance of 15 km (Figure 4.19).

Bed 1A is believed to represent the *Pentacrinus* biosparite (Subdivision 4 of the Passage Beds) of Wright (1992). A common feature of almost all specimens from this unit is that they are very poorly sorted, forming a chaotic jumble of shell fragments, coral clasts and '*Pentacrinus*' ossicles both abraded and unbroken, with ooids and oncoids of all sizes. The constituents that make up this sediment came into existence in a variety of separate environments. '*Pentacrinus*' attached itself to a hardground with clasping cirri as part of the fixosessile benthos. The ooids formed on turbulent beaches or in tidal channels, and the oncoids in gently agitated, shallow-water conditions. The bivalves would have lived both here and on the stable shelf away from the surf zone. The coral fragments and clasts formed in the surf zone fringing relict masses of reef rock.

Elements from all these varying facies have been brought together to rest upon the hardground that forms the top of the Coral–Sponge Bed and surrounding sediments. The bringing together of all these disparate elements into one ill-sorted bed can best be explained as the result of a major storm sweeping together this mass of clasts and bioclasts into one storm deposit or tempestite. Such beds are best recognized by their internal structures, seen particularly well at Spikers Hill. Typical grading is present, with coarse, shelly oolite overlain by finer-grained oolite. Infiltration fabrics in the shelly oolite show sparry calcite infilling voids beneath upturned bivalve shells, a very typical tempestite feature (Kreisa and Bambach, 1982).

The pure, white oolite of the Hambleton Oolite contrasts with the 10.5 m equivalent sequence at Filey Brigg, which is markedly arenaceous there due to the incursion of the Birdsall Calcareous Grit. There is no indication of this sandy facies at Spikers Hill. A small amount of cross-bedding suggests the presence of nearby intertidal ooid shoals.

The oncolite or 'Blue Course' (Lee, 1971, Bed 2) is not only laterally persistent within the quarry, but also maintains the same stratigraphical position (basal Vertebrale Subzone) over a distance of 40 km across the Corallian outcrop from Helmsley in the west to Spikers Hill in the east (Hemingway and Twombley, 1964; Wright, 1972). The unit represents an excellent marker band, and is considerably thicker at this site than elsewhere. The fine-grained nature of the matrix of this bed has led some authors to propose a lagoonal origin for such oncolites. However, the frequent occurrence of ammonites implies a good connection to open marine conditions.

The Middle Calcareous Grit is more thickly developed between Helmsley and Pickering in the west, where it consists of 12–14 m of largely decalcified sandstone with an ooidal bed, the Newbridge Trigonia Bed (Coe, 1995), near the top. The member is thinly developed throughout the Yedmandale and Forge Valley areas, consisting of 1.2 m of yellow sandstone both at Spikers Hill and at White Quarry, 1 km ESE of Spikers Hill (Wright, 1972). The Irton Borehole, 4 km to the south-east, revealed only 0.3 m of sandstone between the Hambleton Oolite and the Malton Oolite (Wilson, 1931). The bored surface below the Malton Oolite at Spikers Hill suggests that the reduction in thickness of the Middle Calcareous Grit eastwards from Pickering is due to erosion beneath the Malton Oolite, and not to lateral facies change as was previously thought (Wright, 1972).

Ammonites are rare in the lower beds, but the *Goliathiceras nitidum* from Bed 1B is characteristic of the Cordatum Subzone. Bed 2 has yielded two valuable perisphinctids, and these, together with a specimen of *Cardioceras (Subvertebriceras) densiplicatum* Boden, the lowest Boreal Middle Oxfordian zonal index, found at nearby Wykeham Quarry (Wright, 1972), firmly date Bed 2 as Vertebrale Subzone.

Bed 4 has yielded an excellent cardioceratid fauna (Figure 4.5J, K), with only one perisphinctid, and marks a revival of the Cardioceratidae. This bed also lies within the early Vertebrale Subzone, however, because the cardioceratids predominate: in the later Vertebrale Subzone of the Oxford area (see site report for Dry Sandford, this volume), perisphinctids and cardioceratids are roughly equal in number. At Pickering, the highest Middle Calcareous Grit (Newbridge Trigonia Bed) has yielded an Antecedens (Maltonense) Subzone fauna (Wright, 1972). The basal Malton Oolite also belongs to this subzone and at Spikers Hill comes above a non-sequence omitting early Maltonense Subzone Middle Calcareous Grit.

Conclusions

Spikers Hill is of key importance in elucidating the stratigraphy and palaeogeography of the Cleveland Basin in Early and Mid Oxfordian times. The quarry exposes the most comprehensive section through the Passage Beds–Hambleton Oolite–Middle Calcareous Grit–Malton Oolite sequence seen in inland north-east Yorkshire. Coral fragments eroded from the Hackness reef to the north are prolific. Valuable ammonite evidence for the position of the Cordatum–Vertebrale Subzone boundary (and thus the Lower–Middle Oxfordian boundary) has been obtained here. The quarry displays excellently a laterally persistent algal pisolite bed that is a stratigraphically important marker horizon over 40 km of Corallian outcrop. The thin development of Middle Calcareous Grit reveals evidence of an important erosive phase affecting Middle Oxfordian sediments at the eastern end of the Vale of Pickering.

NEWBRIDGE (SE 800 860)

J.K. Wright

Introduction

Newbridge Quarry is a large limestone quarry situated 2 km north of Pickering (Figure 4.24).

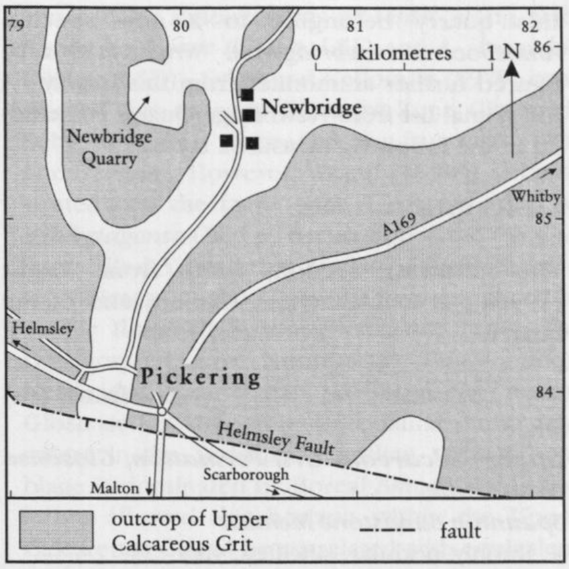

Figure 4.24 Locality map of Newbridge Quarry. Outcrop of the Upper Calcareous Grit from BGS Sheet 53 (Pickering) (1973).

It was first referred to by Blake and Hudleston (1877) as part of the 'Pickering Quarries' complex, and is currently being operated by RMC Aggregates (Northern) Ltd. There are substantial exposures of Middle Oxfordian rocks in this quarry (Coe, 1995), while Upper Oxfordian rocks are seen in the western and southern faces of the pit. In these areas, Upper Calcareous Grit is stripped off as overburden, leaving easily accessible graded ledges and ramps above the vertical working face of the quarry.

Blake and Hudleston (1877) gave a detailed measured section of the Middle and Upper Oxfordian strata seen in the Pickering Quarries, though they do not state precisely where within the complex their section was measured. Fox-Strangways (1892), Arkell (1933) and Sylvester-Bradley (1953) described the quarry only in general terms. The detailed researches of Hemingway and Twombley (1964), Twombley (1965), Lee (1971) and Coe (1995) were concerned almost entirely with the Middle Oxfordian rocks. Wright (1972) recognized the importance of this exposure for stratigraphical and palaeontological studies of the Upper Oxfordian rocks, and designated Newbridge Quarry the type locality of the Newbridge Member of the Upper Calcareous Grit Formation. Sykes and Callomon (1979) subsequently figured six ammonites from this quarry belonging to a new species, *Amoeboceras newbridgense*. Wright (1996a, b) figured further ammonites from this quarry. A full faunal list from Newbridge Quarry is included in the following measured section.

Description

The following section, taken from Wright (1996a), is visible at the southern end of the quarry:

Thickness (m)

Upper Calcareous Grit Formation, Glosense Subzone

Spaunton Sandstone Member

4. Rubbly, nodular, silicified, very fossiliferous sandstone containing *Amoeboceras newbridgense* Sykes and Callomon, *A. nunningtonense* Wright, *A. glosense* (Bigot and Brasil), *A. ilovaiskii* (M. Sokolov), *A. shuravskii* (D. Sokolov), *Microbiplices* sp., *Perisphinctes* sp., *Myophorella clavellata* (Parkinson), *Pleuromya uniformis* (J. Sowerby), *Chlamys midas* (Damon), *C. fibrosus* (J. Sowerby), *Lucina lirata* Phillips, *Nanogyra nana* (J. Sowerby), *Camptonectes lens* (J. Sowerby), *Pseudomonotonis ovalis* (Blake and Hudleston), *Goniomya literata* (J. Sowerby) and *Pentacrinus* sp. seen to 0.63
3. Fairly tough, flaggy sandstone, strongly bioturbated towards the top. Contains *Amoeboceras* sp., *Perisphinctes (Perisphinctes) cautisnigrae* Arkell, *P. (Pseudarisphinctes) pachachii* Arkell, *Decipia decipiens* (J. Sowerby), *D. lintonensis* Arkell and *Modiolus pulchrum* Phillips 1.5

Newbridge Member, ?Ilovaiskii Subzone

2. Very shaly siltstone with occasional *Decipia ravenswykensis* Wright 1.26
1. Shaly, sandy, sporadically oolitic marl, with numerous bored pebbles of blue–grey, fine-grained limestone containing *Rhabdophyllia*. *Chlamys* sp. is rare 2.1

– Prominent, bored erosion surface –

Coralline Oolite Formation

Coral Rag Member ?Tenuiserratum Subzone

(Blue–grey, fine-grained, laminated limestone with sporadic *Rhabdophyllia phillipsi* Edwards and Haime 6.8)

Fox-Strangways (1892) also recorded '*Liostrea bullata*' (a synonym of *Gryphaea dilatata* J. Sowerby), *Perna* sp., *Protocardia* sp. and *Thracia* sp. from this section.

A log of the section is given in Figure 4.25. The Newbridge Member beds are soft, weathering readily, and forming sloping ledges. Bored pebbles of Coral Rag encrusted by *Nanogyra*

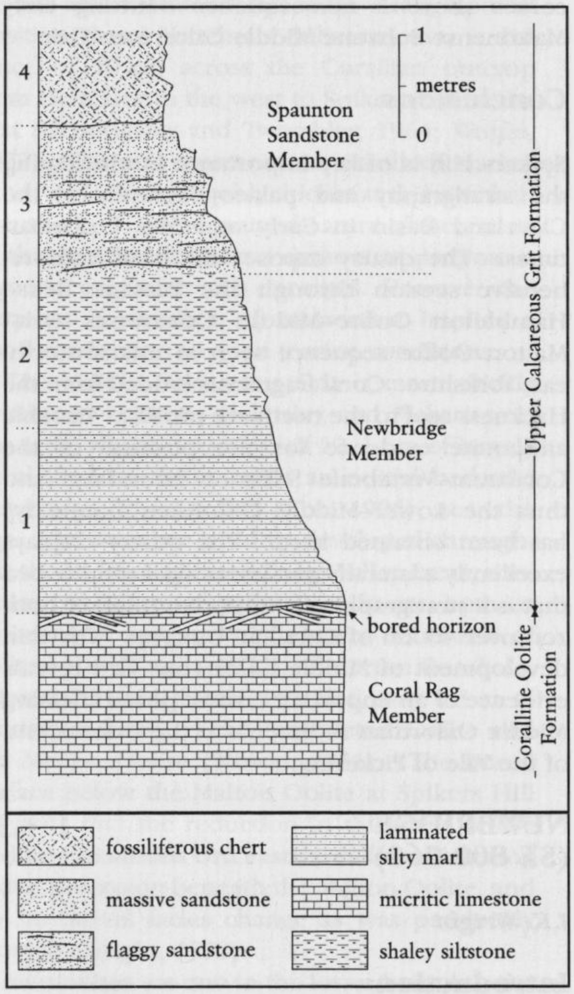

Figure 4.25 Log of the Upper Calcareous Grit at Newbridge Quarry, as measured by J.K. Wright in 1998.

nana are common. The Spaunton Sandstone is tough and forms vertical faces at the top of the quarry. *Thalassinoides* burrowing is intense. The highest bed (Bed 4) contains silicified masses of chert. The silica was introduced into the bed by *Rhaxella*, spicules of which are readily visible in thin section. Ammonites and bivalves are abundant in this bed, the shells gently washed together so that breakage is frequent. Distortion has also occurred during compaction.

Interpretation

The facies of the Coral Rag is unusual here: a grey, sparsely fossiliferous, laminated limestone. As this splintery, flaggy, series of beds is traced westwards it takes on its normal coralliferous shelly micrite facies as seen in quarries at Wrelton and Spaunton (Wright, 1972). This was thus a lagoonal back-reef area with stagnant, muddy conditions.

There was a considerable period of non-deposition between the Coral Rag and the Newbridge Member, allowing the Coral Rag to be lithified and gently planed off in a marine bench. The bored erosion surface is seen particularly well at Newbridge, and also in nearby Wrelton Quarry, where Wright (1980) described an undulating bored erosion surface cut in micritic Coral Rag. The change from marine erosion to marine sedimentation was sluggish. The lowest beds thus consist of pebbly marl. Periodic surges apparently swept pebbles of limestone from beaches fringing low cliffs into the shallow, muddy sea.

Source areas were rejuvenated now, and quantities of sand and silt were brought into the area, forming Bed 3 of the Spaunton Sandstone. The fauna consists of scattered *Nanogyra* and frequent perisphinctids, with very rare *Amoeboceras*. Offshore marine shelf conditions were then established as the spicular sands of the upper Spaunton Sandstone were laid down (Bed 4). The association of prolific sponge growth with a prolific cardioceratid–bivalve fauna, seen previously in the Lower Calcareous Grit at the Tenants' Cliff site, was repeated, though whether this is an ecological or a preservational association, or a combination of the two, is not clear.

This exposure is relevant to both the Boreal and the Sub-Boreal ammonite zonal schemes. In the former case, the exposure has yielded numerous specimens of the Upper Oxfordian zonal index *Amoeboceras glosense*, along with *A. newbridgense* (Figure 4.5E) and *A. ilovaiskii* (Figure 4.5D). Sykes and Callomon (1979) considered this an early Glosense Zone (Ilovaiskii Subzone) fauna, succeeded by a fauna with prolific *Decipia*. However, Wright (1996b) demonstrated that the fauna with *A. glosense* and *A. newbridgense* (Bed 4) occurs above the *Decipia* fauna (Bed 3), and that *A. newbridgense* is here an indicator of the Glosense Subzone, not the earlier Ilovaiskii Subzone (see site report for Leysthorpe Quarry, Nunnington, this volume). Newbridge Quarry has produced the richest Glosense Subzone ammonite fauna found anywhere in the Yorkshire Corallian. The assemblage is dominated by Boreal *Amoeboceras* and it has allowed this horizon within the Upper Calcareous Grit to be correlated with equivalent beds not only on Skye and in Greenland (Sykes and Callomon, 1979), but also in Canada, Alaska and Russia.

In the Sub-Boreal subzonal scheme, the type perisphinctid fauna of the Cautisnigrae Subzone lies in the Clavellata and Sandsfoot Clay Members in Dorset (see site report for Osmington, this volume). At Osmington, however, the Cautisnigrae Subzone fauna occurs in isolation, with non-sequences above and below, whereas at Newbridge the fauna occurs in the Spaunton Sandstone (Bed 3) above the Newbridge Member (Bed 2), which has yielded a slightly older fauna including an early variety of *Decipia, D. ravenswykensis* (Wright, 1996a). Correlation between several Upper Oxfordian sections in the Cleveland Basin, including Newbridge Quarry and Leysthorpe Quarry (see site reports, this volume), suggests that the Newbridge Member represents the Ilovaiskii Subzone (Wright, 1996a).

Conclusions

This locality is one of the key sections in dating the final phase of Corallian sedimentation in the Cleveland Basin. Resting non-sequentially on the Coral Rag is one of the richest ammonite-bearing Upper Calcareous Grit successions in the area. The quarry contains the stratotype section for the Ilovaiskii Subzone Newbridge Member, which is here overlain by highly fossiliferous and bioturbated Glosense Subzone Spaunton Sandstone. The species of *Decipia* and *Amoeboceras* present here allow correlations with both the Clavellata Formation of

Dorset and with parts of the upper Staffin Shales of Skye, and are consequently of great significance in correlation between faunal provinces.

GREEN LANE PIT AND GOLDEN HILL PIT (SE 732 837 AND SE 724 827)

B.M. Cox

Introduction

The Jurassic clays that mainly floor the Vale of Pickering beneath a blanket of Quaternary deposits crop out only sporadically around the edge of the Vale and as scattered 'islands' within the Vale, for example at Kirby Misperton, Great Barugh, Salton, South Holme, Normanby, Great Edstone, near Sinnington and near Helmsley (Hudleston, 1876, 1878; Fox-Strangways, 1881; Arkell, 1933, 1945). In the 19th century, the clays were excavated in a number of small brickpits such as at Kirbymoorside, Newton Grange, Wass Grange, Hildenley, Scagglethorpe and Knapton (Blake and Hudleston, 1877; Fox-Strangways, 1881, 1892; Lamplugh, 1896) (Figure 4.26). No measured sections are available for these old brickpits, and records of fossils, some of which may be substantiated by material in museum collections, provide the only evidence of the strata that they exposed. From just before World War I, Jurassic clays were again worked at Kirbymoorside where they were used for making drainpipes and tiles. When production changed to the manufacture of bricks in the 1950s, it was found that the clays from further south in the Vale were more suitable and, from 1964, clay was brought instead from two pits near Marton. A section through the clays at Kirbymoorside was recorded by Pyrah (1977) but, in recent years, the two brickpits at Marton (Green Lane and Golden Hill) have provided the only significant inland exposures of Upper Jurassic clays in the Cleveland Basin (Hemingway and Twombley, 1964; Callomon in Callomon and Cope, 1971; Cope, 1974, 1980; Wignall, 1993).

Description

Green Lane Pit

According to Cope (1974), the then already disused Green Lane Pit exposed *c.* 12 m of fissile,

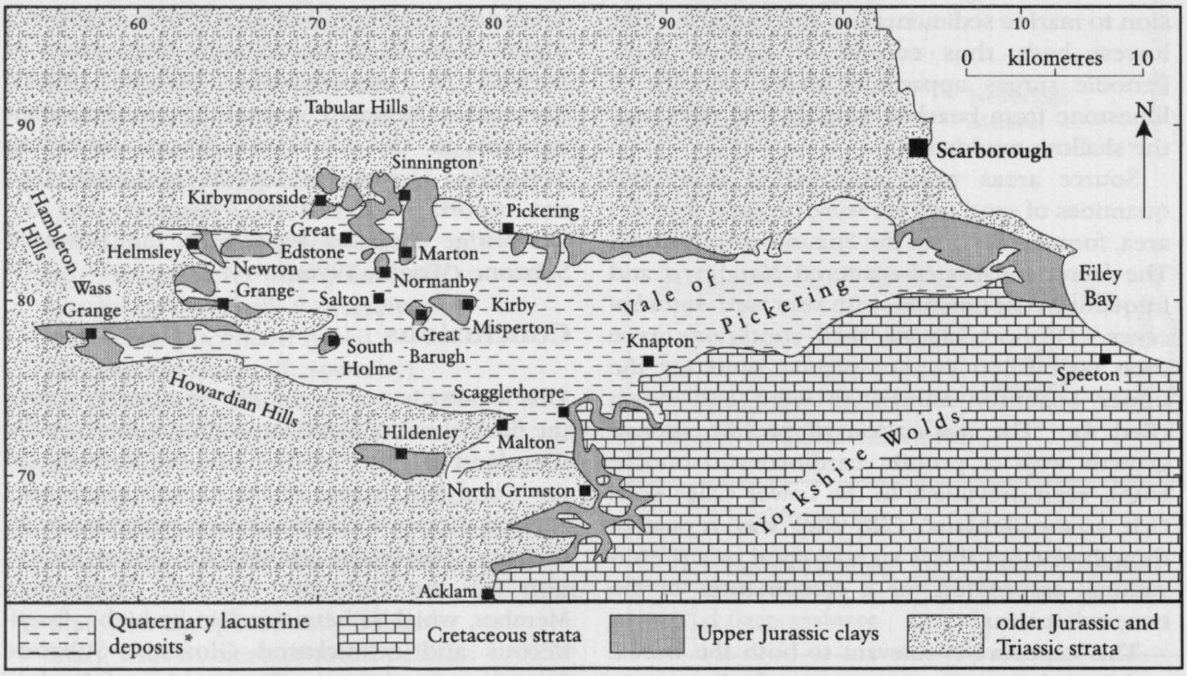

Figure 4.26 Simplified geological drift sketch map of the Vale of Pickering showing localities cited in the text (based on Geological Survey 1:50 000 sheets 53 and 54). The Green Lane Pit and Golden Hill Pit GCR sites are located at Marton. *Other drift deposits are omitted for clarity.

organic-rich ('bituminous') shales, generally too weathered (with bedding planes covered with selenite crystals) to yield identifiable fossils. A discontinuous bed of ferruginous, calcareous siltstone (ankeritic concretions), at *c.* 4 m above the base of the pit, yielded various species of the ammonites *Amoeboceras (Amoebites)*, *Amoeboceras (Hoplocardioceras)* and *Aulacostephanus*, including *A. (Aulacostephanoceras) eudoxus* (d'Orbigny), *A. (Aulacostephanoceras) pusillus* Ziegler and *A. (A.)* cf. *pseudomutabilis anglicus* (Steuer) (Callomon in Callomon and Cope, 1971). Blocks of this bed, breaking with a conchoidal fracture, littered the pit floor. A hard, silty shale, up to 0.03 m thick, *c.* 6 m higher in the pit face, yielded the diminutive ammonite *Amoeboceras (Nannocardioceras)*. The only other fauna that has been noted is Hemingway and Twombley's (1964) record of 'other molluscs and fish remains', and Wignall's (1990a) record of a few scattered specimens of *Protocardia* and *Liostrea*.

Golden Hill Pit

Cope (1974) provided a measured section through *c.* 15 m of interbedded, grey, calcareous mudstones and organic-rich shales at a time when the pit was still being worked intermittently. Since then, the pit has seen some activity and Wignall (1993) provided additional data based on newly cleaned sections. His composite section for the pit, based on three separate but nearly overlapping faces (A, B, C), is shown in Figure 4.27 together with both Wignall's (1993) and Cope's (1974) bed numbers. The strata, totalling *c.* 25 m, dip gently north so that Face A, in the southern half of the pit, exposes the oldest beds; Wignall's bed numbers begin at the base of that face, which is dominated by silty mudstones with four horizons of indurated, yellow-weathering siltstones capping poorly developed coarsening-upwards cycles. The top part of Face A includes two thin shales that weather to a brown colour and 'leathery' texture, indicating their high organic content. A slight stratigraphical gap (probably little more than a metre) exists between the top of Face A and the base of the 100 m long Face B. The lowest two-thirds of Face B consist of weakly developed alternations of organic-rich shale and mudstone capped by a distinct, blocky marl (Bed 29 of Wignall) overlain by an organic-rich shale (Bed 30 of Wignall), which weathers to form a prominent overhang.

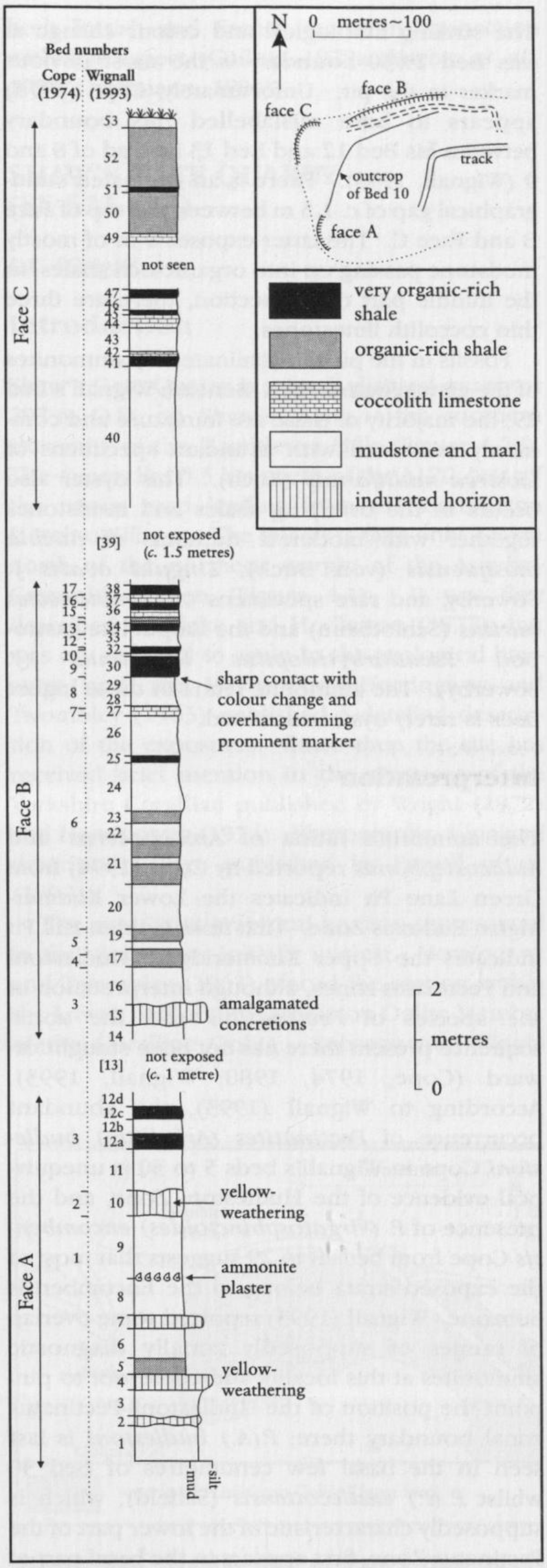

Figure 4.27 Composite graphic log of the section at Golden Hill Pit (after Wignall, 1993, fig. 3).

The striking lithological and colour change at this Bed 29/30 boundary is the most obvious marker in the pit. Unfortunately, Cope (1974) appears to have mislabelled this boundary between his Bed 12 and Bed 13 instead of 8 and 9 (Wignall, 1993). There is an estimated stratigraphical gap of *c.* 1.5 m between the top of Face B and Face C. The latter exposes 8 m of mostly mudstone passing up into organic-rich shales; in the middle part of the section, there are three thin coccolith limestones.

Fossils in the pit are dominated by ammonites of the genus *Pectinatites*. Beneath Wignall's Bed 29, the majority of these are immature and commonly encrusted with abundant specimens of *Liostrea multiformis* (Koch). This oyster also occurs in the overlying shales and mudstones together with moderate numbers of *Buchia mosquensis* (von Buch), *Lingula ovalis* J. Sowerby, and rare specimens of *Camptonectes auritus* (Schlotheim) and the limpet-like gastropod *Pseudorhytidopilus latissimus* (J. Sowerby). The ammonite fauna in these higher beds is rarely oyster-encrusted.

Interpretation

The ammonite fauna of *Amoeboceras* and *Aulacostephanus* reported by Cope (1974) from Green Lane Pit indicates the Lower Kimmeridgian Eudoxus Zone. That from Golden Hill Pit indicates the Upper Kimmeridgian Hudlestoni and Pectinatus zones, although interpretation of the species of *Pectinatites* and the zonal sequence present there has not been straightforward (Cope, 1974, 1980; Wignall, 1993). According to Wignall (1993), the abundant occurrence of *Pectinatites (Arkellites) hudlestoni* Cope in Wignall's beds 5 to 30 is unequivocal evidence of the Hudlestoni Zone, and the presence of *P. (Virgatosphinctoides) encombensis* Cope from beds 8 to 29 suggests that most of the exposed strata belong to the Encombensis Subzone. Wignall (1993) reported some overlap of ranges of supposedly zonally diagnostic ammonites at this locality and chose not to pinpoint the position of the Hudlestoni–Pectinatus zonal boundary there; *P.(A.) hudlestoni* is last seen in the basal few centimetres of Bed 30 whilst *P. (P.) eastlecottensis* (Salfeld), which is supposedly characteristic of the lower part of the Pectinatus Zone, first appears in the basal part of Bed 29. No such overlap in the ranges of these two ammonite taxa has been noted in the Dorset coastal sections (see site report for Tyneham Gap–Hounstout, this volume) where the Upper Kimmeridgian ammonite zonation was established; in fact, in Dorset no ammonites have been documented from the 10 m of strata across this zonal boundary, which is there defined at the base of the White Stone Band (Cope, 1967; Wignall, 1993). However, in terms of the lithological succession, the section at Golden Hill Pit is generally closely comparable with that on the Dorset coast. Indeed, Gallois (in Cope, 1980) already drew attention to this when he refuted Cope's (1974) earlier assertions that the Hudlestoni Zone was absent at Golden Hill Pit and that the Pectinatus Zone there directly overlaid the Wheatleyensis Zone. Both Gallois and Medd (1979) and Wignall (1993) reckoned that the coccolith-rich Bed 16 of Cope (1974)/Bed 37 of Wignall (1993) was probably the correlative of the White Stone Band of the Dorset coast. According to Bailey *et al.* (1997), ranges of key dinoflagellate cysts at Golden Hill can be clearly related to those elsewhere in north-west Europe and particularly in Dorset. They placed the Hudlestoni–Pectinatus zonal boundary somewhere between Bed 8 and Bed 15 of Cope (1974) and probably at his 'abrupt lithological change' (= base Bed 30 of Wignall, 1993). Unfortunately, they appear to have been unaware of this latter author's work.

Wignall (1990a) suggested that the dearth of benthic fauna in the organic-rich shales and mudstones at Green Lane Pit indicated that anoxic bottom waters had prevailed for considerable periods of time and that the sediments had accumulated in fairly deep waters. Similar depositional conditions were suggested by Wignall (1993) for the beds below his Bed 29 at Golden Hill Pit where he interpreted the oysters that encrust the ammonites as probably pseudoplanktonic 'parasites' attached to living ammonites in the water column. The oysters appear to have outlived the ammonites in only a few cases because there are relatively few examples of oysters that have grown beyond the ammonite shell on to the sediment surface. According to Wignall (1993), the rarity of ammonites encrusted with oysters at higher levels at Golden Hill Pit indicated, perhaps, that *Pectinatites (Pectinatites)* was able to defend itself from the unwanted ballast of an oyster epifauna. The non-ammonite faunal assemblage recorded from these higher beds is unequivocally benthic and testifies to slightly improved oxygen levels in the bottom waters (Wignall, 1993). Described by Wignall (1990a) as the 'E13 *Buchia mosquensis*: *Liostrea multiformis* Association', it differs greatly from that of equivalent organic-rich shale associations in southern England; the normally ubiquitous *Protocardia morinica* (J. de C. Sowerby) and *Corbulomima suprajurensis* (d'Orbigny) are replaced by a number of forms typical of more northern waters, such as *Buchia mosquensis*. Wignall (1990a) deduced that, in the Late Kimmeridgian, a divide existed between Boreal and Sub-Boreal faunal provinces along the line of the Market Weighton High; this prohibited the northward migration of Sub-Boreal forms, whilst Boreal forms were able to spread progressively southwards. A typically Boreal taxon is also amongst those recorded from Green Lane Pit; the main areas of occurrence of *Amoeboceras (Hoplocardioceras)* are central and northern East Greenland, Franz Josef Land and the Ust'–Yenisei region of Siberia (Birkelund and Callomon, 1985).

According to Cope (1974), a strike fault, running approximately through Marton village and with a minimum downthrow to the south of 30 m, has to be envisaged in order to explain the relative stratigraphy of the two pits. Green Lane Pit is sited on high ground (presumed by Cope to be due to the resistance of the organic-rich shales to erosion) but the beds exposed further south at Golden Hill Pit are younger, although there is no strong dip in that direction.

Conclusions

Cored boreholes in the Vale of Pickering indicate that there is a thick sequence (over 300 m) of Upper Jurassic clays flooring the Vale (Cox *et al.*, 1987). However, these remain largely unseen because of an extensive cover of Quaternary deposits. Green Lane Pit and Golden Hill Pit expose, respectively, clays of Early and Late Kimmeridgian age, and together with the transitory exposures on the coast at Filey Bay (see site report for Speeton Sands, this volume), offer the only exposures of these youngest Jurassic rocks in the Cleveland Basin. The sites are therefore important not only for basic stratigraphy but also for regional geology, palaeogeography and palaeobiogeography. Their proximity to the North Sea, where the Kimmeridge Clay, at depth, is an important source rock for oil and gas, gives the sites some additional significance; cored boreholes have been drilled at Golden Hill Pit by both British and French teams in connection with this aspect (Gallois, 1979a; Herbin *et al.*, 1991; Oschmann, 1994).

SHAW'S GATE QUARRY (SE 523 823)

J.K. Wright

Introduction

Shaw's Gate Quarry is a small disused quarry at 297 m O.D. on Shaw's Moor at the southern extremity of the Hambleton Hills (Figure 4.28). The quarry lies 0.5 km south of the A170, just off the minor road leading from the Hambleton Hotel to Kilburn. The quarry is thus only 2.5 km north of the northern margin of the Asenby–Coxwold Graben (Figure 4.1). It was first described by Blake and Hudleston (1877), but was not referred to again in the geological literature until the 1960s when Hemingway and Twombley (1963) published a detailed description of the exposures. Since then the site has received brief mention in the synopses of the Yorkshire Corallian published by Wright (1972) and Hemingway (1974). Photographs, a log and description were published by Powell *et al.* (1992).

The exact stratigraphical horizon represented in the quarry was initially unclear. Hemingway and Twombley (1963) placed the section within the Lower Leaf of the Hambleton Oolite Member of the Coralline Oolite. Subsequently, Wright

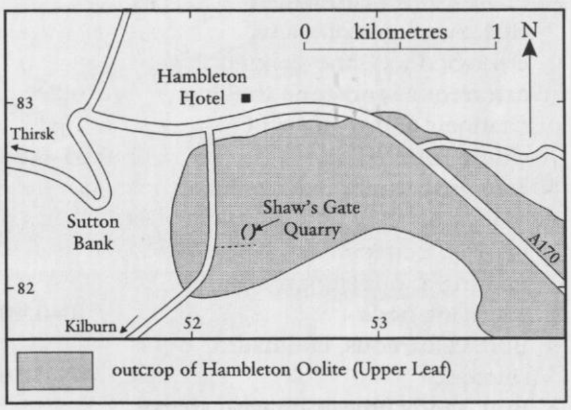

Figure 4.28 Locality map of Shaw's Gate Quarry. Outcrop of the Hambleton Oolite from BGS Sheet 52 (Thirsk) (1992).

(1972, 1983) showed that the Lower Leaf was exposed in the valleys to the south-east and north-east of Shaw's Moor, and that the quarry must lie in the Upper Leaf, probably in the Vertebrale Subzone.

Description

The quarry exposes 6 m of argillaceous oolite, a facies typical of the Hambleton Oolite in this area where oolite passes laterally into Birdsall Calcareous Grit a few kilometres to the south. Penecontemporaneous deformation of the Hambleton Oolite has been detected in at least five sites over a restricted area of about 21 km² at the southern end of the Hambleton Hills. Shaw's Gate Quarry displays by far the best examples of stratal convolution in this area. A log of the section is given in Figure 4.29. The following section is taken from Powell *et al.* (1992).

	Thickness (m)
Coralline Oolite Formation	
Hambleton Oolite Member	
9. Undeformed, oolitic limestone	seen to 1.0
8. Grey, ooidal limestone with small oysters and *Nucleolites* sp. Hemingway and Twombley (1963) saw slump fragments	seen to 0.7
7. Yellow, sandy, sparsely ooidal limestone	0.32
6. Buff, sandy limestone with sparse ooids and contorted, sandy laminae. The base is erosive, with laminated, siliceous limestone and cross-bedded, fine-grained, calcareous sandstone infilling channels and troughs of slump folds	0.65–0.82
5. Pale-grey, laminated, ooidal limestone showing slump folding, penecontemporaneous faulting and injection into the overlying beds	0–0.40
4. Buff, calcareous, laminated siltstone	0–0.50
3. Buff, sandy limestone with sparse ooids and shell fragments. Grey, sandy ooidal limestone is present as slump balls in the upper part	0.55–0.70

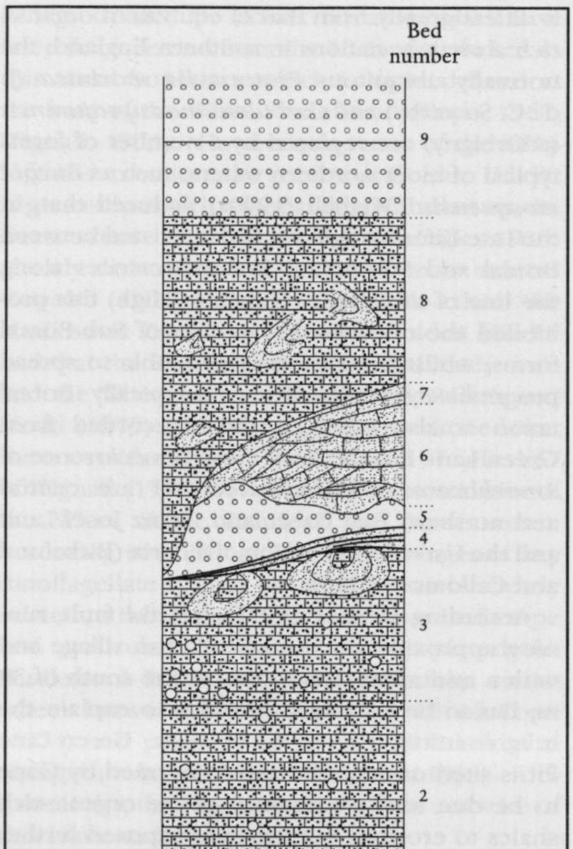

Figure 4.29 Log showing the slump structures at Shaw's Gate Quarry (after Powell *et al.*,1992).

2. Buff, very sandy limestone with shell fragments and sparse ooids 0.70
1. Buff, sandy, ooidal limestone containing large blocks of contorted, siliceous limestone and chert at all angles to the bedding seen to 1.20

The penecontemporaneous deformation structures are best seen in beds 1, 3 and 8, and comprise deformed, disturbed and distorted sedimentary layers. The penecontemporaneous nature of the folding of the limestones is clearly evidenced where the upper surface of a folded bed is cleanly bounded by truncated bedding planes (Figure 4.30). Some down-folds are infilled with laminated limestone. Less marked movements are shown by the occurrences of slump balls within the sediment.

Bed 1 contains slumped blocks characterized by sharp-angled, overturned folds of amplitude greater than the thickness of the bed. Somewhat similar structures, isolated slump balls with sharp boundaries and containing contorted, laminated internal structures, typify the arenaceous carbonates of the second disturbed unit (Bed 3). In contrast to the style of deformation in these lower disturbed beds, two distinct lithologies characterize the third phase of stratal deformation: a basal oolite and an overlying laminated limestone (Bed 5 and Bed 6). Two structures involved in this deformation are particularly well exposed on the west wall of the exposure (Figure 4.30). The folds here are asymmetric towards the north. Associated with these slumps, overlying laminated silts and fine calcarenites fill near-concentric scoured basins displaying dish-like geometry and presenting a form characteristic of festoon bedding. Such features are predominantly compaction or adjustment phenomena.

Hemingway and Twombley (1963) noted that the west face of the quarry displays a fine example of a fluid-escape pipe along which oolite has been extruded through the overlying laminated limestone (Bed 6 to Bed 8). Near to the fissure the laminated limestone can be seen to have lost its original depositional fabric and to have

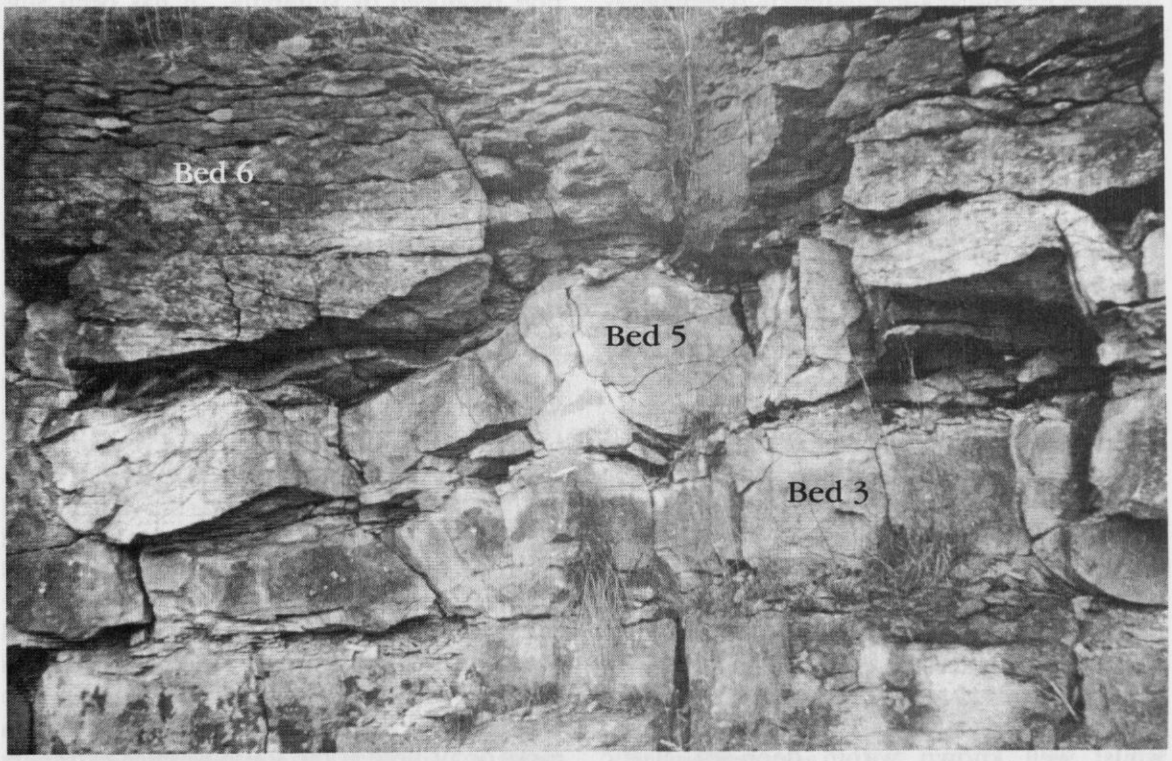

Figure 4.30 View of Shaw's Gate Quarry showing a slump fold in oobiosparite (Bed 5). The flanks of the fold are filled with laminated sandy limestone (Bed 6). A load ball in Bed 3 is visible on the lower right. Height of face 1.5 m. (Photo: J.K. Wright.)

become homogenized. The final convolution phase saw slump fragments incorporated into the calcareous sandstone (Bed 8).

Interpretation

Convolute bedding such as that which occurs at Shaw's Gate consists of structures involving marked crumpling or complicated folding of well-defined sedimentation units. It has been suggested that the presence of two horizons with convolute folding necessitated the impact of sudden shock waves. The practically horizontal bedding pattern prevailing in the vicinity, as throughout the bulk of the Cleveland Basin during the Oxfordian, implies that the submarine slopes were very gentle at the time of deposition. Submarine sliding was thus considered unlikely as an explanation of this phenomenon by Hemingway and Twombley (1963), although Powell *et al.* (1992) suggest that the erosive bases and planar, truncated upper bedding surfaces do indicate deposition as submarine debris flows. Only two other occurrences of convolution phenomena are known from Yorkshire Jurassic deposits, in the Cloughton Formation between Ravenscar and Cloughton (Hemingway, 1974), and in the Lower Calcareous Grit at Cunstone Nab (Wright, 1983). Both these occurrences are close to the Peak Trough (Figure 4.1), a fault system that is known to have been active in the Jurassic Period (Milsom and Rawson, 1989). Shaw's Gate Quarry lies close to the Kilburn Fault, which has a throw of some 300 m to the south and which is the northern representative of the Asenby–Coxwold trough-fault system. Hemingway and Twombley (1963) considered that movement on this fault may have been initiated in Late Jurassic times and may have caused the convolution phenomena.

Early seismicity connected with the Asenby–Coxwold Graben could thus have been the mechanism through which the convoluted bed-forms and dewatering structures were formed. Mobilization of the ooidal bed (Bed 5) is regarded by Hemingway and Twombley (1963) as having preceded its upward extrusion into the overlying strata. This site provides a fine example of the penecontemporaneous liquefaction of unconsolidated sediment. Features such as this, whilst well known within deep-sea clastic sequences, are rarely preserved in the shallow-shelf depositional environment (Reineck and Singh, 1980). Experimental tests on the fluidization of sediment highly charged with water (McKee and Goldberg, 1969) suggest that Bed 5 could have been extruded through liquefaction by several means. An increase in pressure could have been induced by a direct increase in hydrostatic load, a sudden increase in interstitial water, a change in packing of the sediment, or the sudden impact of a shock wave. In general, sedimentation took place under very slow, gentle conditions in the Yorkshire Corallian, and only the shock-wave hypothesis can account for the sudden change in conditions necessary for convolution to be initiated.

Dugué (1995) has described almost identical synsedimentary deformation structures from Late Oxfordian silty, spicular limestone (Calcaire gréseux de Hennequeville) in Normandy. As is the case at Shaw's Gate Quarry, Dugué believed that the formation of these structures was due to liquefaction of unconsolidated sediment during earthquakes.

Conclusions

The Hambleton Oolite at this site is important in showing penecontemporaneous stratal deformation produced by slumping. It has been suggested by Hemingway and Twombley (1963) that the convolution and dewatering features at Shaw's Gate Quarry were the result of mass movements triggered by seismic shocks in heavily water-laden sediments. The shocks were possibly connected with movements on the Asenby–Coxwold trough fault system occurring nearby. Structures such as those present at this site are rare in shallow marine shelf carbonates, which normally become lithified very quickly.

SNAPE HILL (SE 509 787)

J.K. Wright

Introduction

Snape Hill Quarry is a large disused, wooded quarry cut into the steep northern and western flanks of Snape Hill approximately 1 km to the south-west of Kilburn (Figure 4.31). Oxfordian rocks occur here at the south-western extremity of the Yorkshire Corallian outcrop and are preserved within the E–W-trending Asenby–Coxwold Graben (Figure 4.1), bounded to the

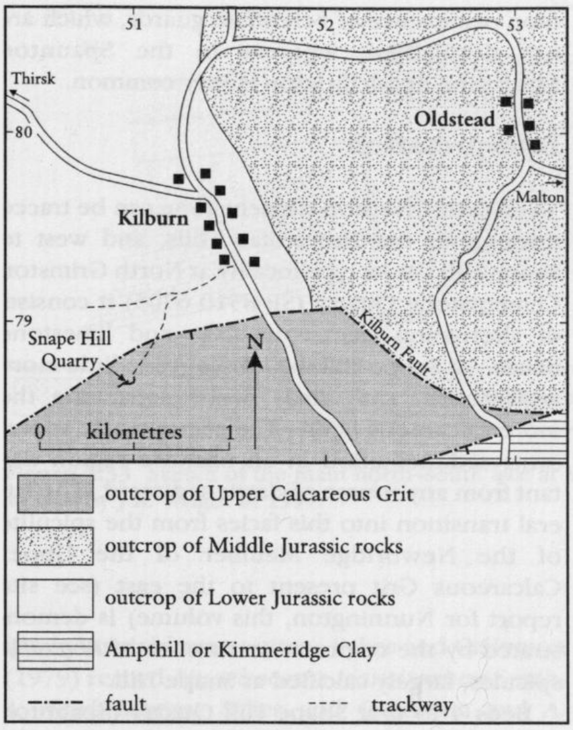

Figure 4.31 Locality map of Snape Hill Quarry. Geological information from BGS Sheet 52 (Thirsk) (1992).

north by the Kilburn Fault. Interest is focussed on the eastern face of the quarry (SE 5090 7870) where a N–S-trending outcrop includes a semi-vertical pitch and weathered-back ledges with talus slopes beneath.

The locality was referred to by Hudleston (1878) and was described by Fox-Strangways (1892). There were at one time several quarry sections available on Snape Hill, and the present section and other exposures now filled in were subsequently described by Wilson (1933) and Arkell (1933). Wright (1972) designated Snape Hill Quarry the stratotype section of the Snape Sandstone Member of the Upper Calcareous Grit Formation. Sykes and Callomon (1979) listed several ammonite species from this quarry, and suggested that several of the beds included by Wright in the Snape Sandstone would be better allocated to the Spaunton Sandstone. Powell *et al.* (1992) published a generalized section of the quarry, adopting Sykes and Callomon's suggested change in nomenclature. The measured section below is as published by Wright (1996a) and takes account of these views.

Description

The following section is currently exposed at Snape Hill Quarry:

	Thickness (m)
Upper Calcareous Grit Formation	
Snape Sandstone Member	
7. Massive, fine-grained *Rhaxella* spiculite, with siliceous or calcified spicules in a calcareous matrix. The unit contains flaggy partings, and distinctive, fine, argillaceous laminae, with distinct lustre mottling. The unit becomes flaggy below with alternations of shale and impure limestone. *Belemnites explanata* Phillips is very common	seen to 4.5
– fault – unknown gap –	
Spaunton Sandstone Member	
6. Blocky, yellow spiculite, very tough although weathered. The spicules are all siliceous. Occasional *Belemnites* sp. and shell fragments occur	seen to 1.5
5. Thin-bedded to flaggy, fossiliferous, sandy argillaceous spiculite containing equal proportions of siliceous and calcified spicules, and siliceous bands. *Chlamys midas* (Damon) and *Decipia* sp. were found loose in this matrix	1.3
4. Rubbly weathering, massive spiculite with siliceous knots containing siliceous spicules in a calcareous matrix. Elsewhere the spicules are completely calcified	1.0
North Grimston Cementstone Member	
3. Light to grey to whitish, fine-grained limestone with delicate, small-scale scour structures. Strongly recrystallized, but scattered calcified spicules in a ?pelletoidal matrix are visible	0.5
2. Grey-brown, impure limestone with intercalations of silty, flaggy limestone	1.0
1. Grey, brown-weathering, silty, shaly flaggy limestone, with	

alternations of more calcareous and less calcareous, flaggy bands. The more calcareous bands contain calcified spicules in a ?pelletoidal matrix — seen to 9.0

The North Grimston Cementstone was seen by Fox-Strangways (1892) to rest on 1.2 m of Coral Rag containing *Thecosmilia annularis* (Fleming), *Lopha gregarea* (J. Sowerby) and *Paracidaris florigemma* (Phillips). Bed 1 is recorded as being 11 m thick when fully exposed (Wilson, 1933), and the upper part is still well seen (Figure 4.32). Most of the bivalves recorded by Wilson (1933) almost certainly came from the brown, flaggy, decalcified Spaunton Sandstone (Bed 5). Bed 7, the Snape Sandstone, is exposed at the very back of the quarry and is downfaulted against beds 1–6, the section thus being discontinuous (Figure 4.33). The Snape Sandstone is a calcareous spiculite containing only a minor proportion of quartz grains. It is readily distinguished by its massive bedding, very characteristic, gently bioturbated lamination, and the common occurrence of belemnite guards, which are not decalcified, whereas in the Spaunton Sandstone decalcification is very common.

Interpretation

The North Grimston Cementstone can be traced throughout the Howardian Hills, and west to Snape Hill. At its type locality at North Grimston Cementstone Quarry (SE 8510 6705) it consists of alternating calcareous flags and limestone bands. At Snape Hill the lithology is a little more argillaceous, with shaly bands separating the more calcareous beds. The cementstone represents sedimentation in an offshore region distant from any source of clastic sediment. The lateral transition into this facies from the spiculite of the Newbridge Member of the Upper Calcareous Grit present to the east (see site report for Nunnington, this volume) is demonstrated by the common occurrence of *Rhaxella* spicules, largely calcified at Snape Hill.

Beds 4 to 6 at Snape Hill Quarry (Spaunton Sandstone) are the only beds exposed within the

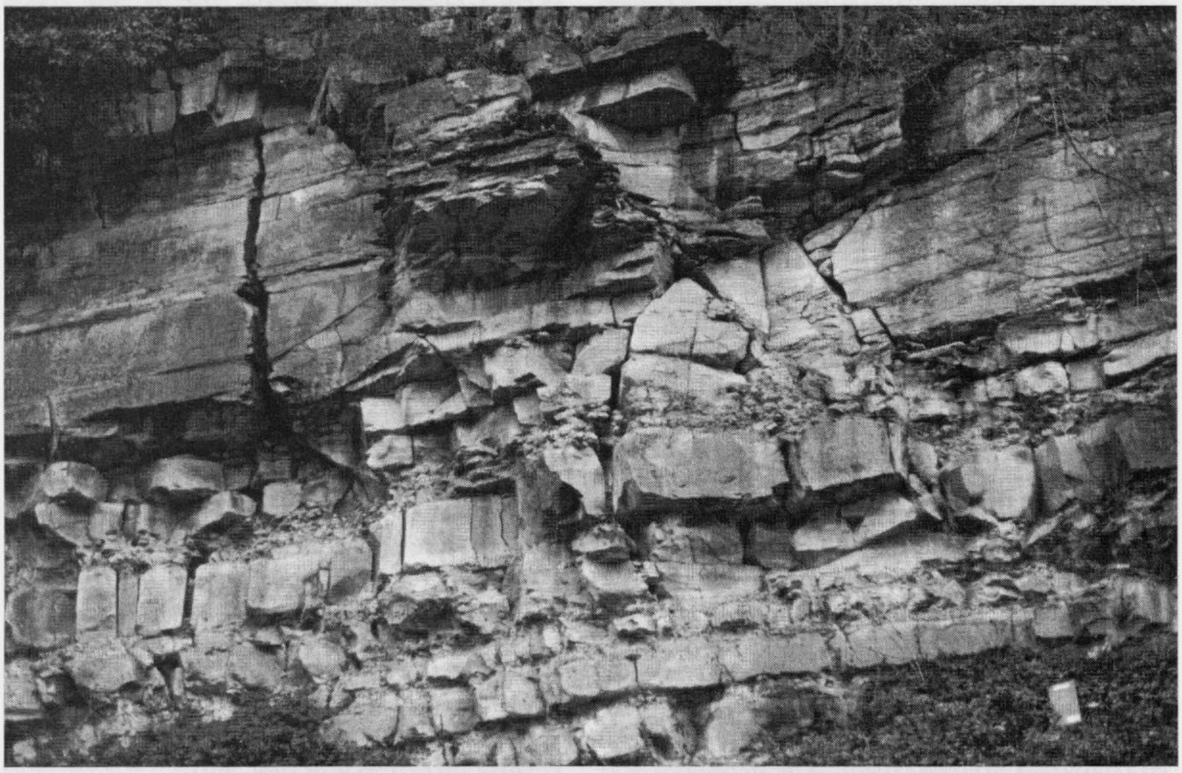

Figure 4.32 North Grimston Cementstone (Bed 1) at Snape Hill Quarry. Alternations of limestone and calcareous mudstone are overlain by massive, flaggy weathering limestone. Mapcase 35 cm. (Photo: J.K. Wright.)

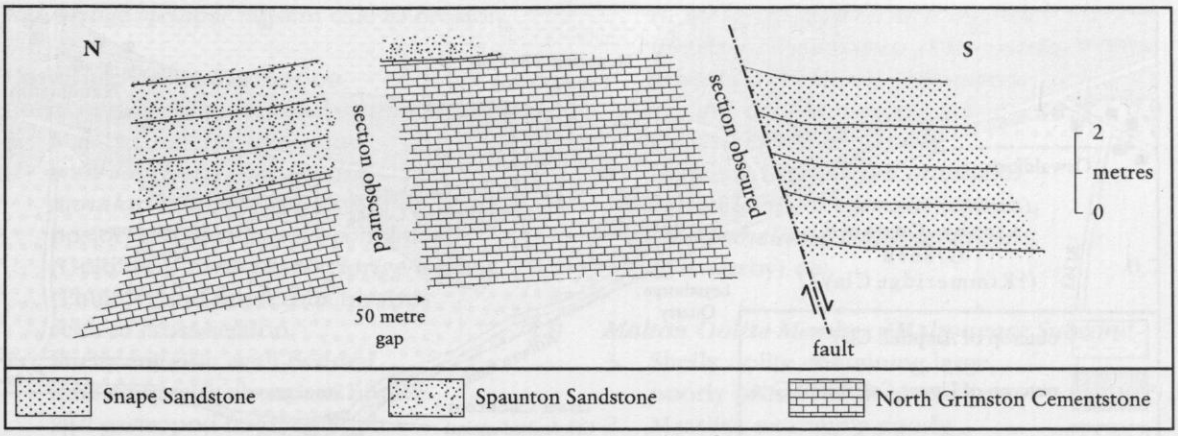

Figure 4.33 Sketch of the main north–south face at Snape Hill Quarry showing the two separate successions, as seen by J.K. Wright in 1997.

quarry to yield ammonites. Sykes and Callomon (1979) record *Amoeboceras transitorium* Spath, *A. newbridgense* Sykes and Callomon and *A. glosense* (Bigot and Brasil) and Arkell (1935–1948) recorded *Perisphinctes (Ampthillia)* aff. *ampthillensis* Arkell and *P. (Arisphinctes)* aff. *kirkdalensis* Arkell. Comparison with the succession at Leysthorpe Quarry (see site report for Nunnington, this volume) suggests the middle Glosense Subzone. These beds mark the progradation of shallower shelf conditions with the prolific growth of siliceous sponges. Intense *Thalassinoides* bioturbation has destroyed much of the bedding structure.

The Snape Sandstone, with its distinctive calcareous lithology, fine lamination, moderate bioturbation and belemnites, marks a return to slightly deeper-water shelf conditions. It was easily recognizable as a distinct unit in the West Newton Grange borehole (Wright, 1996a), and appears to occur over the whole of the western end of the Vale of Pickering and south to North Grimston (Wright, 1972). Fragmentary *Amoeboceras* were found by V. Wilson in a small quarry (SE 511 788) adjacent to Snape Hill Quarry (Arkell, 1935–1948). Powell *et al.* (1992) recorded Serratum Zone *Amoeboceras* from slightly younger beds exposed to the north-west (SE 5114 7877).

Conclusions

This is an important site for understanding the facies variations that existed in the Cleveland Basin during Oxfordian times and their relationship to biostratigraphy. Snape Hill Quarry displays excellently the North Grimston Cementstone, an atypical shaly limestone facies of the otherwise shallow-water, carbonate- or clastic-dominated successions in the Yorkshire Corallian. The Spaunton Sandstone has yielded numerous Glosense Zone ammonites. It is succeeded by the stratotype section of the Snape Sandstone *sensu stricto*, the highest, markedly calcareous member of the Upper Calcareous Grit Formation, with its prolific belemnite fauna.

NUNNINGTON (SE 646 785, SE 648 787 AND SE 649 787)

J.K. Wright

Introduction

An abandoned railway cutting, Nunnington Railway Cutting, an adjacent overgrown quarry, Nunnington Railway Cutting Quarry, and Leysthorpe Quarry, a large quarry formerly worked by E.W. Creaser (Quarries) Limited of Pocklington, York, constitute a composite site west of Nunnington village and north-west of Stonegrave village (Figure 4.34). Leysthorpe Quarry lies beside the B1257 between Stonegrave and Leysthorpe. The Ordnance Survey spelling of the latter changed from 'Laysthorpe' to 'Leysthorpe' in the 1970s.

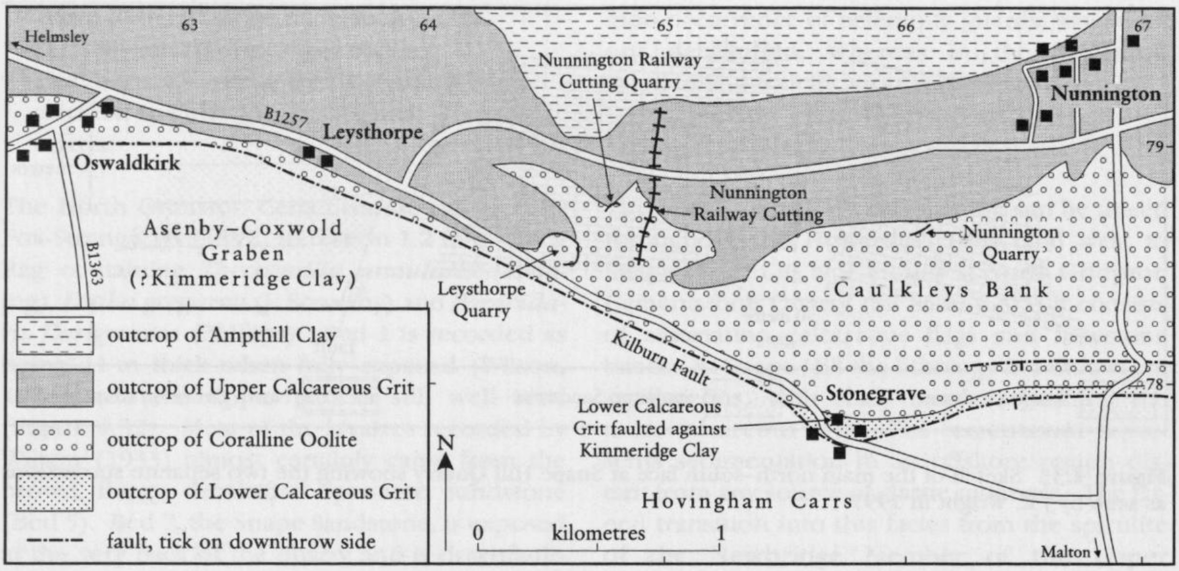

Figure 4.34 Map showing the locations of the principal exposures WSW of Nunnington. Geological information from BGS Sheet 53 (Pickering) (1973).

These exposures occur on the southern side of the Vale of Pickering adjacent to the E–W-trending Asenby–Coxwold Graben. The low ground occupied by this structure (Hovingham Carrs, Figure 4.34) separates the Corallian rocks of Caulkleys Bank, upon which the Nunnington site occurs, from the Howardian Hills to the south.

The railway cutting and adjacent quarry have been known to geologists for some time. The cutting was first described by Blake and Hudleston (1877), and by Fox-Strangways (1892). It was mentioned briefly by Arkell (1933, 1935–1948), and was visited by the Geologists' Association in 1933 and 1950 (Wilson, 1934, 1954). Wright (*in litt,* 1960) mapped the area and prepared detailed descriptions of the exposures. Wright (1972) described the Coral Rag in the cutting and adjacent quarry, and figured several ammonites collected from the Upper Calcareous Grit of Leysthorpe Quarry. The latter acquired importance as the stratotype locality of the Nunningtonense Subzone of the Upper Oxfordian Pumilus Zone (Sub-Boreal zonal scheme). Leysthorpe Quarry was referred to by Kent (1980b) as 'a quarry at Nunnington'. Wright (1996a, b) figured numerous ammonites from the two quarries, and gave a detailed measured section of the Upper Calcareous Grit at Leysthorpe Quarry.

Description

Measured sections at the three exposures: Nunnington Railway Cutting, Nunnington Railway Cutting Quarry and Leysthorpe Quarry are given below. These are updated versions of measured sections originally prepared by the present author in 1960.

Nunnington Railway Cutting section

	Thickness (m)
Upper Calcareous Grit Formation	
Spaunton Sandstone Member, Glosense Subzone	
10. Tough, massive, fine-grained sandstone	seen to 2.35
9. Poorly cemented sandstone	0.3
8. Extremely tough, calcareous sandstone, a *Rhaxella* spiculite with large calcareous concretions	0.50
7. Tough, massive sandstone with *Perisphinctes* sp.	2.1
6. Poorly cemented sandstone	0.45
5. Irregularly cemented, fine-grained sandstone, heavily bioturbated towards the top	1.25
4. Very fine-grained sandstone with bivalve fragments	0.35

Newbridge Member ?absent due to erosion

Coralline Oolite Formation
Coral Rag Member, ?Tenuiserratum Subzone

3. Massive, micritic limestone with abundant *Thecosmilia annularis* (Fleming) in living position, *Thamnasteria concinna* (Goldfuss), *Paracidaris florigemma* (Phillips) and numerous bivalves seen in cross-section — 1.9
2. Shelly, micritic, well-bedded limestone with abundant bivalve and gastropod fragments, plus occasional rolled *Thecosmilia* and *Cidaris* spines — 1.5

Malton Oolite Member, ?Maltonense Subzone

1. Fine-grained oolite — seen to 0.55

Blake and Hudleston (1877) record *Hemicidaris* sp., *Natica clio, Nerinea* sp., *Chemnitzia* sp. and *Nanogyra nana* (J. Sowerby) from Bed 2.

Nunnington Railway Cutting Quarry section

Thickness (m)

Upper Calcareous Grit Formation
Newbridge Member, Ilovaiskii Subzone

7. Fine-grained, flaggy sandstone containing *Amoeboceras transitorium* Spath, *A. newtonense* Wright *A.* sp., *Perisphinctes (Pseudarisphinctes)* sp. and *P.* sp. — seen to 2.1

Coralline Oolite Formation
Coral Rag Member, ?Tenuiserratum Subzone

6. Impure, rubbly limestone, heavily recrystallized, containing *Isastraea explanata* (Goldfuss), *Thecosmilia annularis, Paracidaris florigemma* spines and bivalve fragments — 1.35
5. Massive, micritic limestone containing *Thecosmilia annularis, Rhabdophyllia phillipsi* Edwards and Haime, *Thamnasteria concinna, Montlivaltia dispar* (Phillips), *Paracidaris florigemma, Cidaris smithi* (Wright), *Ctenostreon proboscideum* (J. Sowerby), *Lithophaga inclusa* (Phillips), *Chlamys* sp., *Ditremaria tornatilis* (Phillips), *?Solenopora* sp. and crinoid ossicles — 0.9
4. Pisoidal oolite containing frequent *Thecosmilia annularis, Paracidaris florigemma* (spines), *Pseudomelania heddingtonensis* (J.Sowerby) etc. — 0.7

Malton Oolite Member, ?Maltonense Subzone

3. Shelly oolite containing large, poorly preserved bivalves — 1.15
2. Massive, extremely poorly sorted oolite — 4.20
1. Tough, shelly oomicrite — seen to 1.80

Blake and Hudleston (1877) record *Gervillella aviculoides* (J. Sowerby), *Cerithium muricatum* (J. Sowerby) and '*Trigonia*' sp. from Bed 4.

Leysthorpe Quarry section

Thickness (m)

Upper Calcareous Grit Formation
Spaunton Sandstone Member, Glosense Subzone

13. Fine-grained, spicular sandy limestone containing septarian cracks. The fauna includes *Amoeboceras nunningtonense* Wright, *A. glosense* (Bigot and Brasil), *A. ilovaiskii* (M. Sokolov), *A. transitorium* and *Perisphinctes* sp. — seen to 0.05
12. Flaggy, spicular sandstone with occasional *Amoeboceras newtonense* and *Perisphinctes (Pseudarisphinctes) pachachii* Arkell — approx. 2.0
11. Massive, pale-coloured, spicular sandstone full of infilled *Thalassinoides* burrows, and weathering brown. Contains *Amoeboceras glosense, A. ilovaiskii, A. newtonense, Perisphinctes (Dichotomosphinctes)* sp. and numerous bivalve fragments including *Chlamys* sp. — 1.0

Newbridge Member, Ilovaiskii Subzone

10. Massive, white, blocky, homogeneous spiculite containing

Amoeboceras nunningtonense, A. glosense, A. transitorium, A. ilovaiskii, A. newtonense, Perisphinctes (Perisphinctes) aff. *parandieri* de Loriol, *P. (P.) uptonensis* Arkell, *P. (Arisphinctes) kirkdalensis* Arkell, *P. (A.)* sp., *P. (Dichotomosphinctes)* aff. *elizabethae* de Riaz, *P. (D.)* spp. and *Nanogyra nana* 0.6

9. White, laminated, sandstone with frequent flattened, distorted ammonites: *Amoeboceras* aff. *transitorium, A. ilovaiskii, A. newtonense, Perisphinctes (P.)* aff. *parandieri, P.(A.) kirkdalensis, P. (D.)* sp., and *Decipia ravenswykensis* Wright 0.3
8. Soft, flaggy, decalcified, laminated sandstone approx. 0.6

Coralline Oolite Formation

Coral Rag Member, ?Tenuiserratum Subzone

7. Shelly, coralliferous micrite with *Thamnasteria concinna* and *Rhabdophyllia phillipsi* 1.1
6. Shelly oobiosparite with *Thecosmilia annularis*, numerous fragments of *Fungiastraea* and *Thamnasteria*, and *Chlamys* sp., *Lima aciculata* Münster, *Nerinaea* sp. and *Perisphinctes sp.* 1.3

Malton Oolite Member, ?Maltonense Subzone

5. Monotonous series of poorly bedded, ill-sorted, fine-grained oosparites containing *Dentalium* sp. and *Macromesodon* cf. *bucklandi* (Agassiz) 8.3
4. Shelly pelmicrite with only very sporadic ooids. Contains *Nanogyra nana, Pseudomelania beddingtonensis,* and thin-shelled bivalves and gastropods 2.6
3. Shelly, very poorly sorted oosparite, numerous shell fragments having micrite envelopes. Contains *Chlamys fibrosus* (J. Sowerby) and '*Cerithium*' sp. 1.6
2. Well-bedded to massive, shelly oomicrite with *N. nana* and thin-shelled bivalves and gastropods. Some quartz silt present 2.2
1. Well-bedded, sandy oomicrite passing up into oosparite. The quartz sand content is appreciable below, with pyrite skins to the ooids so that these weather an orange colour seen to 1.9

A log of the Coralline Oolite Formation in Leysthorpe Quarry is given in Figure 4.35.

The shelly oomicrites and oosparites of Beds 1–4 in the quarry mark a distinctive series of limestone beds that can be traced along Caulkleys Bank and pass into a coral bed and a shell bed at Ness (Wright, 1972). The upper Malton Oolite in the quarry is a very poorly sorted, pasty oolite (bed 5), with very few fossils preserved. The sequence of limestone beds at Leysthorpe Quarry is illustrated in Figure 4.36.

The Coral Rag has an extremely prolific fauna. In all three exposures it divides into a coralliferous shell bed below, overlain by a fossilized coral reef with corals in growth position. The shell bed has yielded bivalves, gastropods and echinoids, spines of *Paracidaris florigemma* being abundant. The upper massive, micritic limestone is well exposed both at the Railway Cutting Quarry and in the railway cutting. It is noteworthy for the variety of corals present. *Isastraea explanata* occurs sparingly, and only one specimen of *Montlivaltia dispar* has been recorded. The tiny branching coral *Rhabdophyllia phillipsi* is more common, but the most abundant phaceloid coral is *Thecosmilia annularis*, with several arborescent colonies weathering out in Nunnington Railway Cutting and the Railway Cutting Quarry. *Thamnasteria concinna* is ubiquitous, layer upon layer of this massive coral encrusting bivalves and gastropods into one solid mass. Of the bivalves, *Chlamys* is notably rare, its place being taken by abundant *Ctenostreon proboscideum*. The massive corals are riddled with *Gastrochaenolites* borings containing *Lithophaga inclusa*, and many specimens can be found with the bivalve nestling in its hole. Gastropods and echinoid spines abound in the micritic matrix in between the corals, spines of *Paracidaris florigemma* being much more numerous than those of *Cidaris smithi*. The thickness of the Coral Rag varies considerably, increasing from 2.5 to 3.5 m when traced southwards in a 50 m length of the railway cutting.

The chief interest of the Upper Calcareous Grit is its remarkable ammonite fauna (Figure 4.5A–C, G), the most diverse, abundant and best-preserved in this formation in Yorkshire.

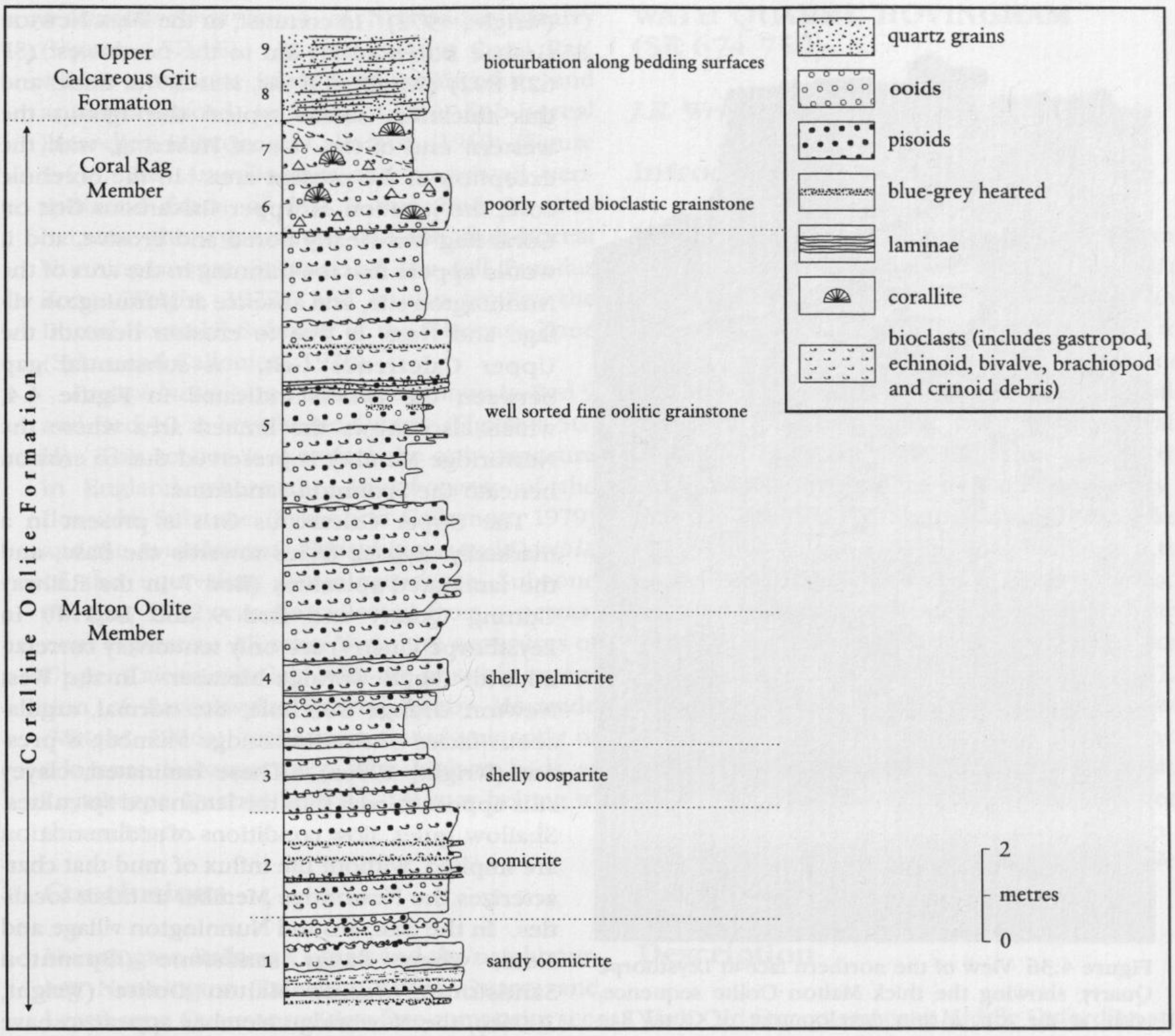

Figure 4.35 Log of the Coralline Oolite Formation in Leysthorpe Quarry, as measured by Mr D. Sharp and J.K. Wright, 1991–1992.

Though often compressed, particularly in the Newbridge Member, the ammonites, both macroconchs and microconchs, are usually fully preserved complete with body chamber. Wright (1996a, b) has figured 35 specimens collected in the two quarries.

Interpretation

During deposition of the Malton Oolite, Leysthorpe Quarry seems to have been situated in a slightly sheltered or depressed area, possibly lagoonal, accumulating sediments deposited in lower energy conditions. The sandy oolites of Bed 1, with their appreciable pyrite content, thus seem to have been laid down in a poorly circulated, stagnant area separating clastic sedimentation to the west from pure carbonate sedimentation to the east. They mark the lateral transition from the Middle Calcareous Grit into Malton Oolite (Figure 4.4). These sandy carbonates are overlain by micrites laid down under quiet, fully marine conditions, and yielding a thin-shelled bivalve and gastropod fauna (Bed 2 and Bed 4), separated by a higher-energy incursion containing much broken shell debris (Bed 3). The higher ooidal beds (Bed 5) are remarkably ill-sorted at Leysthorpe Quarry, without cross-bedding, and thus show no sign of winnowing by currents. They were presumably dumped into deeper water immediately after being formed in tidal channels. These channels,

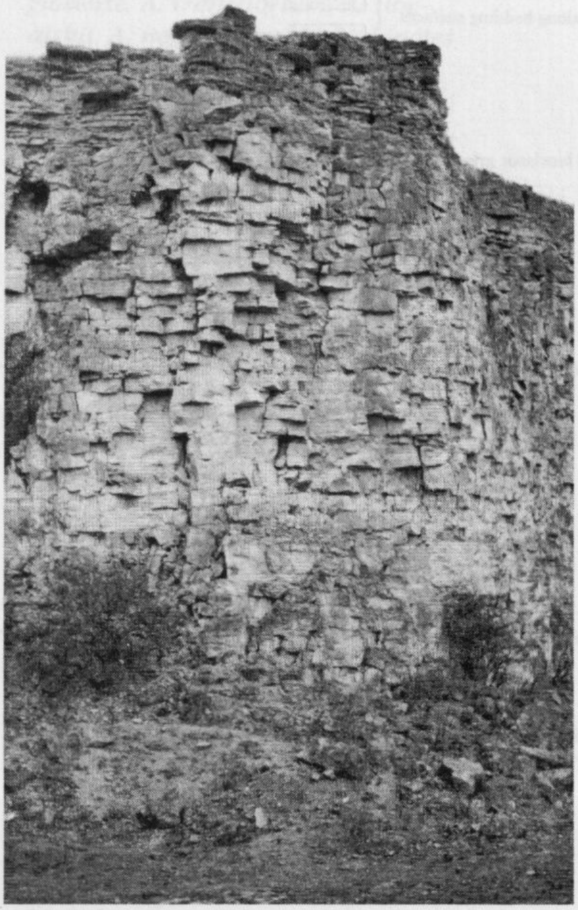

Figure 4.36 View of the northern face at Leysthorpe Quarry, showing the thick Malton Oolite sequence, with, at the top, a thin development of Coral Rag overlain by thin-bedded, flaggy Upper Calcareous Grit. (Photo: J.K. Wright.)

with their cross-bedded oolite, can be seen only 1.5 km away to the east in Nunnington Quarry (SE 661 787) (Figure 4.34).

The Coral Rag has a profusion of *Paracidaris florigemma* and a large variety of corals preserved in shelly micrite. This is clearly the true Coral Rag, and not simply a coralliferous facies of the Malton Oolite as was the case at Betton Farm Quarry (this volume). Many of the corals, particularly the 1 m high arboresques of *Thecosmilia,* indicate slightly more sheltered conditions away from the reef-front, which was probably situated to the south (see site report for Wath Quarry, this volume). The development of the Coral Rag at this site is much thinner than is usual and it is absent altogether east of Leysthorpe, at Nunnington village and Ness (Wright, 1972). In contrast, in the West Newton Grange Borehole 1.5 km to the north-west (SE 628 802) (Wright, 1996a), it is 8.7 m thick, and this thickness seems typical throughout the western end of the Vale of Pickering, with the exception of the present area. In the borehole core, the junction of Upper Calcareous Grit on Coral Rag was clearly bored and erosive, and it would appear that the thinning in the area of the Nunnington site, and absence at Nunnington village and Ness, is due to erosion beneath the Upper Calcareous Grit. A substantial gap between the two is indicated in Figure 4.4, which also shows the limited area where the Newbridge Member is preserved due to erosion beneath the Spaunton Sandstone.

The Upper Calcareous Grit is present in a markedly atypical facies towards the base, and the laminated spiculites (Bed 7 in the Railway Cutting Quarry and Bed 9 and Bed 10 in Leysthorpe Quarry) are only tentatively correlated with the Newbridge Member. In the West Newton Grange Borehole, the normal, argillaceous facies of the Newbridge Member is present (Wright, 1996a). These laminated, clayey silts appear to pass into the laminated spiculites. Shallow, quiet, slow conditions of sedimentation are implied, without the influx of mud that characterizes the Newbridge Member at other localities. In the east, around Nunnington village and Ness, where flaggy sandstone (?Spaunton Sandstone) overlies Malton Oolite (Wright, 1996b), the Newbridge Member appear to have been overstepped (Figure 4.4). This is probably the case also in the railway cutting section. The upper members of the Upper Calcareous Grit, the Spaunton and Snape sandstones, were instantly recognizable in the borehole core, and comparison of these thicknesses with those measured in the Nunnington Railway Cutting suggests that the Snape Sandstone comes above the highest beds seen in the cutting.

The Upper Calcareous Grit at Leysthorpe Quarry, and to a lesser extent at Nunnington Railway Cutting Quarry, has yielded an *Amoeboceras* fauna that fills a significant gap in British Oxfordian stratigraphy (Wright, 1972). With its coarsely ribbed *A. transitorium* and *A. glosense* (Figure 4.5B, C), and its finer-ribbed *A. ilovaiskii, A. newtonense* and *A. nunningtonense* (Figure 4.5A) this fauna is older than the Glosense Subzone *Amoeboceras* fauna of the Clavellata Formation of Dorset (Figure 2.11B, E). It is therefore also older than the equivalent Bed

4 *Amoeboceras* fauna of Newbridge Quarry (Figure 4.5D, E). It rests on the Coral Rag, whose ammonite fauna both in Yorkshire and around Oxford is that of the Sub-Boreal Parandieri Subzone of Callomon (1960) (Figure 1.4). The *Amoeboceras* and associated perisphinctid fauna of Bed 9 and Bed 10 thus became the type fauna of the Sub-Boreal Nunningtonense Subzone of the full Pumilus Zone (Wright, 1972), and it also typifies the Boreal Ilovaiskii Subzone of the Glosense Zone (Sykes and Callomon, 1979).

Perisphinctes is remarkably common in Bed 9 and Bed 10 at Leysthorpe Quarry (Figure 4.5G, H). This section is therefore the only exposure in England where the *Amoeboceras* of the Ilovaiskii Subzone (Sykes and Callomon, 1979) and the *Amoeboceras*, *Perisphinctes* and *Decipia* of the equivalent Nunningtonense Subzone (Wright, 1972) can be collected from a permanent exposure. All other Yorkshire exposures of Upper Calcareous Grit, with the possible exception of Ravenswyke Quarry, Kirkby Moorside (Wright, 1996a), yield faunas predominantly of Glosense Subzone age. The highest beds at Leysthorpe Quarry (beds 11–13) may belong to this subzone.

Conclusions

Nunnington Railway Cutting and the neighbouring Nunnington Railway Cutting Quarry and Leysthorpe Quarry provide a fine composite section through the Malton Oolite and Coral Rag Members of the Coralline Oolite Formation. The shelly facies of the Malton Oolite forms a significant marker band that can be traced throughout the Caulkleys Bank area. The Coral Rag shows lateral thickness and facies changes together with a rich and diverse reef-forming and reef-dwelling invertebrate assemblage.

The Upper Calcareous Grit has yielded important holotype ammonites defining a new Sub-Boreal subzone (Nunningtonense Subzone). This allows correlation with areas containing similar ammonites in the Sub-Mediterranean Province in southern Europe and Poland. The presence in addition of ammonites typifying the Boreal Ilovaiskii Subzone allows correlation with areas in the Boreal Realm such as Skye and Greenland. Nunnington is thus a key stratigraphical locality for both the wide variety of lithologies and fossil groups present here, and its bearing on intercontinental correlations.

WATH QUARRY, HOVINGHAM (SE 674 750)

J.K. Wright

Introduction

Wath Old Quarry comprises a large quarry 0.7 km east of Hovingham in the Howardian Hills, and is one of several large working and non-working quarries that extend eastwards for 1.5 km along the south side of the B1257 from Hovingham to Slingsby (Figure 4.37). Whilst these various exposures were first generally described by Blake and Hudleston (1877), the earliest specific reference to Wath Old Quarry is that provided by Fox-Strangways (1892). Arkell (1933) and Wilson (1933, 1936) mentioned the quarry only briefly. Twombley (1965) undertook detailed palaeoenvironmental studies of the Oxfordian strata exposed in this area. The locality figures prominently in Wright's (1972) stratigraphy of the Yorkshire Corallian. Wath Old Quarry is now disused, and a large new quarry, showing a more expanded succession than than seen in the old quarry, has been opened up half a kilometre to the ESE (Figure 4.40). This will be referred to as 'Wath New Quarry'.

Description

Wath Old Quarry exposes Middle Oxfordian strata of Maltonense Subzone and ?Tenuiserratum Subzone ages, with both the higher part of the Malton Oolite and the Coral Rag members of the

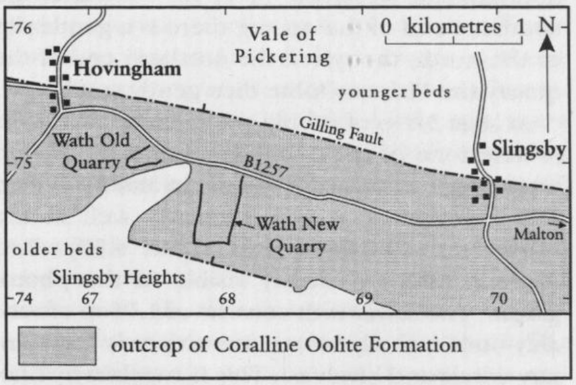

Figure 4.37 Locality map of the Wath Quarries. Outcrop of the Coralline Oolite from BGS Sheet 53 (Pickering) (1973).

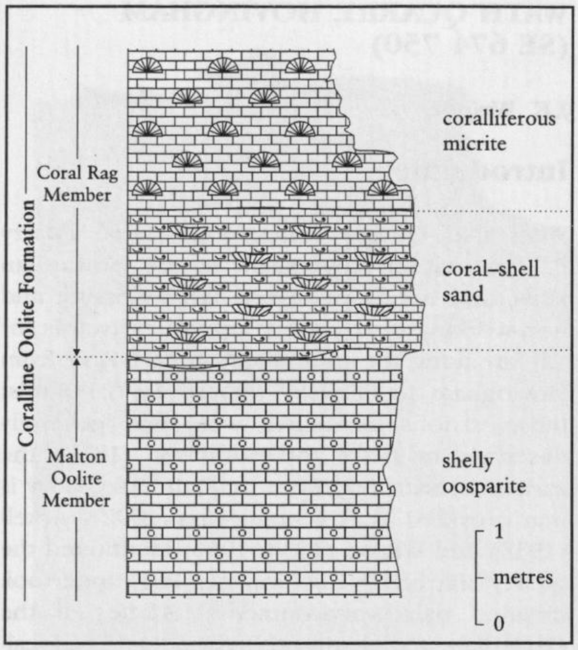

Figure 4.38 Weathering profile of the upper Malton Oolite and Coral Rag at Wath Old Quarry, as measured by J.K. Wright in 1997.

Coralline Oolite Formation being present. A weathering profile of the quarry is given in Figure 4.38.

The Malton Oolite is characteristically a thick-bedded bioclastic oolite. Occasional specimens of *Pseudomelania heddingtonensis* (J. Sowerby), *Chlamys fibrosus* (J. Sowerby), *Nanogyra nana* (J. Sowerby), *Gervillella aviculoides* (J. Sowerby), *Chlamys* sp., *Lima* sp., *Perisphinctes* sp. and *Nucleolites scutatus* Lamarck have been found (Wilson, 1933). The member is seen to an approximate thickness of 10 m. Towards the southern end of the quarry, there is a gentle dip to the north, though at the northern end of the quarry the Malton Oolite dips gently south.

At least 3.4 m of rubbly, poorly bedded, micritic limestone of the Coral Rag Member rests on an irregular erosion surface cut in Malton Oolite. The junction is seen particularly well at the southern end of the quarry (Figure 4.39). Two distinct units are clearly visible in the photograph. The lower unit consists of 1.75 m of variably oolitic, shelly biomicrite with only fragmentary corals and bivalves. This is overlain by fine-grained, micritic limestone that is very fossiliferous, containing *Montlivaltia* sp., *Thecosmilia* sp., abundant *Thamnasteria concinna* (Goldfuss) and other corals. Wilson (1933) noted in addition *Isastraea explanata* (Goldfuss), *Fungiastraea arachnoides* (Parkinson) and *Stylina tubulifera* (Phillips). The branching coral *Thecosmilia* is present as rolled fragments infilling the spaces between the massive corals along with bivalves and echinoids. A rich reef-dwelling fauna is present, with 17 species of bivalve including *Chlamys nattheimensis* (de Loriol), seven species of gastropod and three species of echinoid, including *Paracidaris florigemma* (Phillips). Wilson (1933) gives an extensive list of bivalves, gastropods and echinoids recorded from the Coral Rag in the quarries between Hovingham and Slingsby.

Interpretation

The lower Malton Oolite, as seen in Wath New Quarry (SE 680 745) (Figure 4.40), consists of shelly, sparsely ooidal micrite laid down rapidly in deeper water. Delicate bivalve shells are unbroken, and there are silty and argillaceous laminae. Conditions were thus similar, though somewhat deeper, to those at Leysthorpe Quarry. The micrites pass up into oomicrites and shelly oosparites laid down in much shallower water, and exposed in the old quarry (Figure 4.39). There, the highest Malton Oolite comprises a shelly oosparite full of abraded, micrite-coated shell fragments and occasional coral fragments.

There is a distinct difference in dip between the Malton Oolite and the Coral Rag as seen at the north end of Wath Old Quarry. Twombley (1965) attributed this to uplift, tilting and erosion of the Malton Oolite prior to deposition of the Coral Rag, and this view was repeated by Wright (1972). However, the extension of Wath New Quarry in the 1990s, with the production of a huge, 300 m long north–south section through the Corallian beds (Figure 4.40), has revealed that the southerly dip of the Malton Oolite is due to the presence of giant, southward-dipping foresets. During deposition of the Malton Oolite, the Wath area must have been subject to sudden localized subsidence of the order of 20 m. Fine-grained, shelly carbonate sediment poured into this basin from the north, infilling it with southerly prograding foresets of amplitude as much as 10 m. When carbonate sediment was not available, dark-grey silty clay-drapes up to 0.2 m thick were laid down over the oolite, emphasizing the cross-bedding.

Wath Quarry, Hovingham

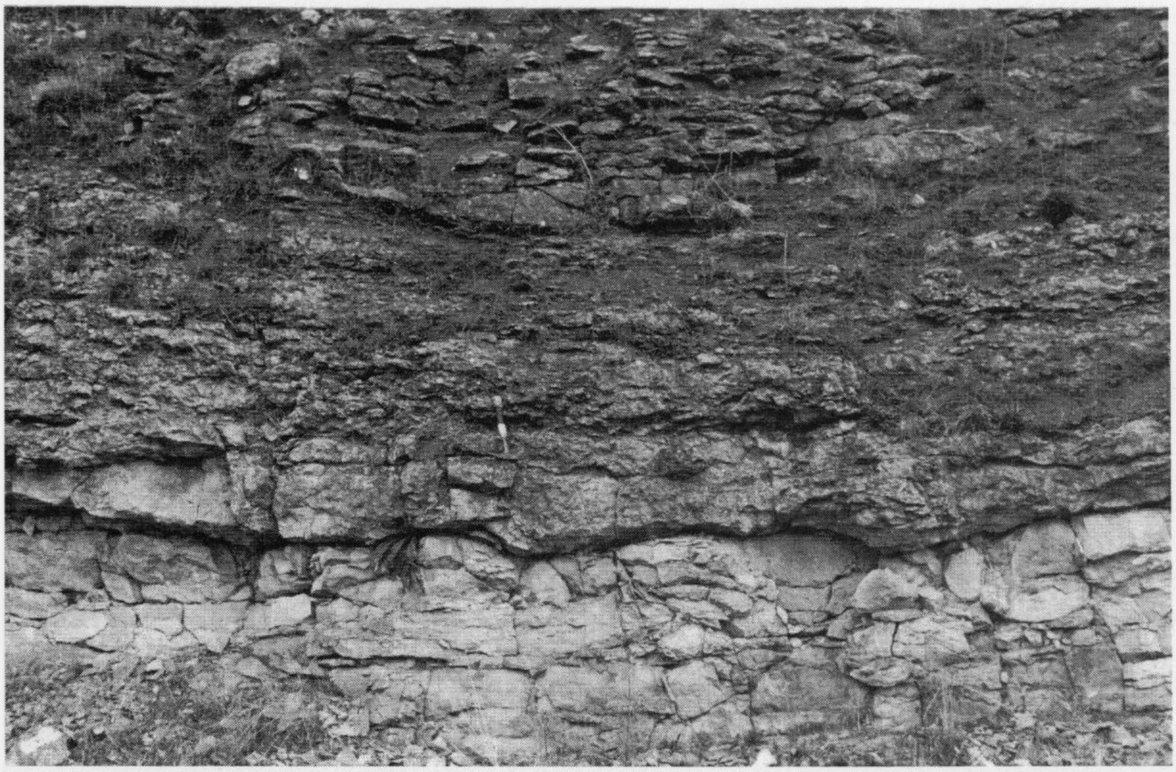

Figure 4.39 Wath Old Quarry, showing the irregular, erosive junction of Coral Rag resting on Malton Oolite. The lower rubbly coral–shell bed of the Coral Rag and the upper coralliferous micritic limestone are easily distinguished. Hammer shaft is 32 cm long. (Photo: J.K. Wright.)

The Coral Rag at Wath excellently displays its characters as a transgressive sequence (Wright, in press, fig. 1). An initial deposit of shelly, ooidal biomicrite was laid down under quite high-energy conditions upon an undulating hardground surface in Malton Oolite (Figure 4.39). As the sea transgressed over the hardground surface, corals colonized the sea floor as soon as they could, but the high energy of the shallow sea, which resulted in the precipitation of ooids, also broke up the corals and shells, producing an ooidal coral–shell sand. Such a bed is also present at Leysthorpe Quarry (see Figure 4.36), but unfortunately access is very difficult.

As the transgression progressed, deeper marine conditions led to the proliferation of coral growth in the areas that were reached by nutrient-supplying currents. Shelly micrite was deposited around the coral colonies. The coral fauna consists predominantly of lamellar and fungioid forms, the common occurrence of *T. concinna* with its small, densely spaced corallites suggesting limpid water and gentle sedimentation (Negus and Beauvais, 1979). However, other features suggest more active sedimentation. *Stylina* is a plocoid form adapted to active conditions, and dendroid corals are only present as broken fragments, suggesting moderate-energy conditions.

Conditions became slightly deeper and more sheltered northwards, encouraging the growth and preservation of dendroid corals (*Thecosmilia* at Nunnington Railway Cutting Quarry, see site report for Nunnington, this volume). On the north side of the Vale of Pickering, there are much more delicate *Rhabdophyllia* forming arboresques at Highfields House Quarry (SE 7115 8736) (Wright, 1972). Eastwards, conditions in the centre of this lagoonal area were too stagnant for prolific coral growth, with the occurrence of almost unfossiliferous, argillaceous limestone with scattered *Rhabdophyllia* at Newbridge Quarry (see site report, this volume). In contrast, the Wath area is characterized by a shallow-water reef-top environment with a wide variety of colonial and encrusting corals.

Figure 4.40 View of the eastern face of Wath New Quarry showing, near the base, Malton Oolite dipping gently north (to the left), overlain by giant cross-sets of Malton Oolite dipping south, and at the top of the quarry, Coral Rag dipping gently north. (Photo: J.K. Wright.)

Some, e.g. *Stylina tubifera*, are found only in this Howardian area in Yorkshire. This reef-top facies of the Coral Rag extends as far as Malton on the NNE flank of the Howardian Hills, separating areas to the north (Pickering) and to the south (Hildenly), which were predominantly back-reef and micritic (Wilson, 1933).

Conclusions

Wath Old Quarry is of great importance in studies of the stratigraphy and palaeontology of the Upper Jurassic of the Cleveland Basin. The locality shows the best, most accessible section anywhere in Yorkshire of the widespread discontinuity that occurs between the massive-bedded Malton Oolite and the overlying reef carbonates of the Coral Rag. The latter contains a prolific fauna of corals and their associated bivalve and echinoid faunas, including species that are not present in any other preserved site in Yorkshire.