British Middle Jurassic Stratigraphy

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Chapter 4

The Middle Jurassic stratigraphy of the East Midlands

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INTRODUCTION

B.M. Cox and M.G. Sumbler

The region covered in this chapter extends from Oxfordshire northwards to the East Riding of Yorkshire (Figure 4.1), and broadly coincides with the Mid Jurassic depositional area and structural feature known as the 'East Midlands Shelf' (see Figure 1.6d, Chapter 1). The northern limit is defined by the Market Weighton High, which, in Jurassic times, acted as a hinge between the rapidly subsiding Cleveland Basin to the north (see Chapter 5) and the more gently subsiding East Midlands Shelf to the south. Major uplift, centred on this structure during the Early Cretaceous Epoch, led to the erosion of much of the Jurassic succession that had been deposited over and adjacent to it. For this reason, Middle Jurassic strata are discontinuous and largely absent in the Market Weighton area (Kent, 1980a). The southern limit of the region covered in this chapter is marked by the so-called 'Oxfordshire Shallows', which, in Aalenian–Bajocian times, were an area of shoals at the western end of the island, of subdued relief, which occupied much of the London and Thames Valley areas as well as East Anglia (the 'London Landmass' – the western part of the Anglo-Brabant Landmass). Deposition was greatly reduced there and only a small part of the Cotswold Aalenian–Bajocian succession (see Chapter 3) is represented; most is missing owing to non-sequence (Figure 4.2). Northwards, the Aalenian–Bajocian succession thickens but there are still significant non-sequences. The Aalenian sediments show a major change to less carbonate facies, including paralic, brackish-water and freshwater, associated with the low-lying coastal plain that fringed the London Landmass. In Bajocian times, these were replaced by marine limestone facies, more reminiscent of the Cotswold succession, as the coastal plains receded. In Late Bajocian and Bathonian times, although the 'Oxfordshire Shallows' did not per-

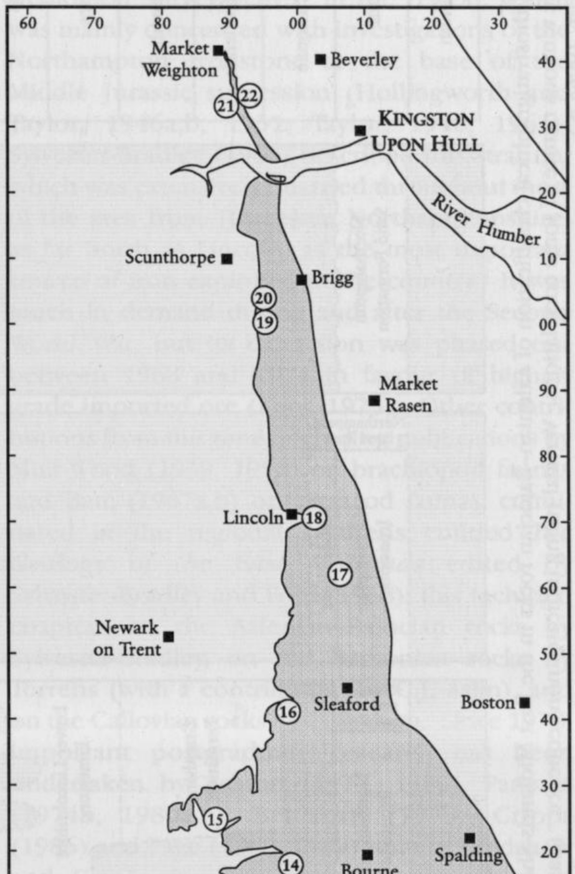

Figure 4.1 Geological sketch map showing the location of the GCR sites described in Chapter 4. (1) Woodeaton; (2) Ardley Cuttings and Quarries; (3) Stratton Audley; (4) Blisworth Rectory Farm; (5) Roade Railway Cutting; (6) Irchester Old Lodge Pit; (7) Finedon Gullet; (8) Cranford St John; (9) Thrapston; (10) Peterborough Brickpits; (11) Collyweston; (12) Ketton Quarry; (13) Clipsham Quarry; (14) Castle Bytham; (15) Sproxton Quarry; (16) Copper Hill; (17) Metheringham; (18) Greetwell Quarry; (19) Cliff Farm Pit; (20) Manton Stone Quarry; (21) Eastfield Quarry; (22) Drewton Lane Pits.

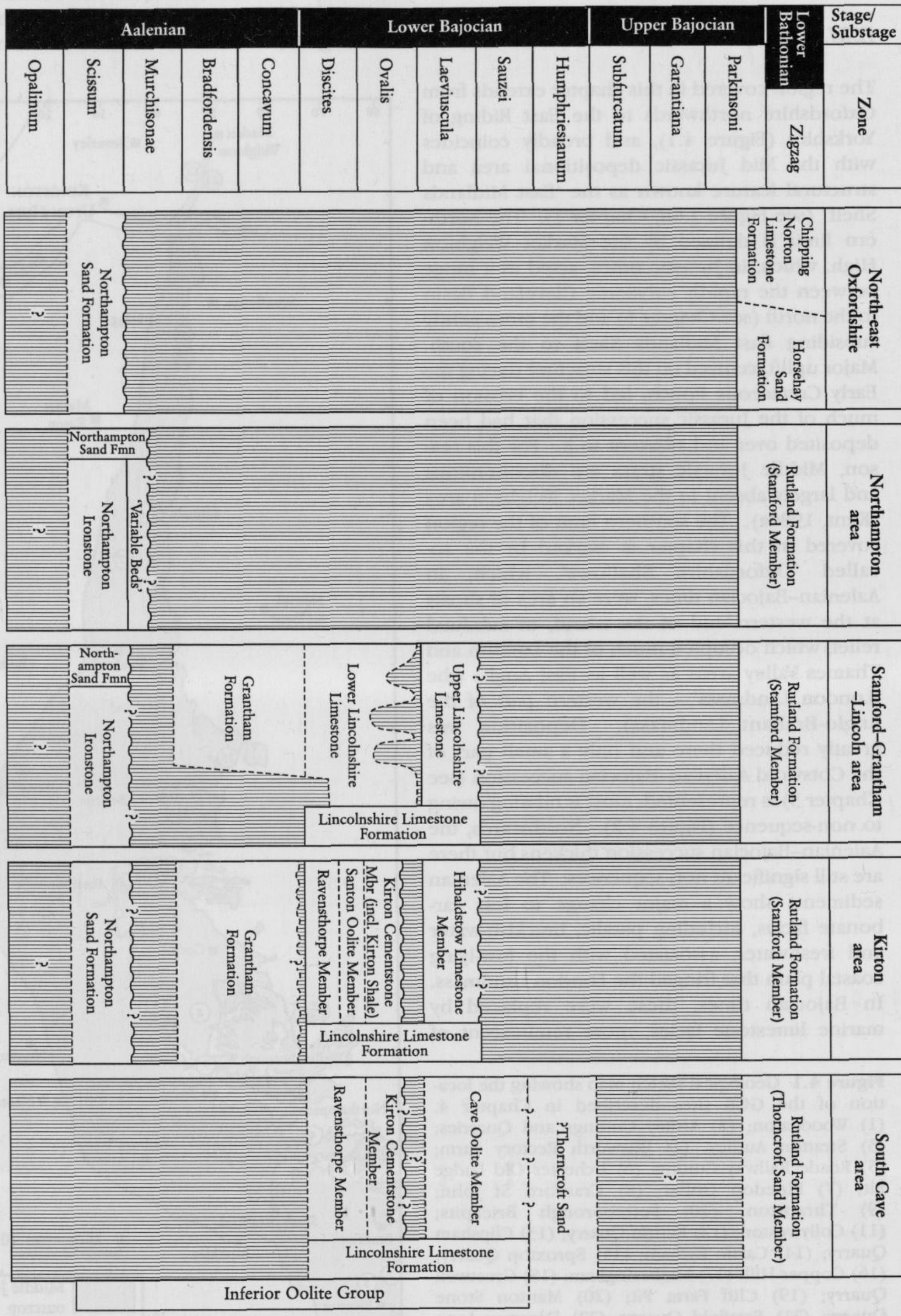

Figure 4.2 Lithostratigraphical classification of Aalenian–Bajocian rocks in the East Midlands Shelf area. Columns are deliberately separated one from the other because of the tenuous nature of some correlations. Vertical ruling indicates non-sequence. (Based on data in Ashton, 1977, 1980; Horton *et al.*, 1987; Gaunt *et al.*, 1992; Wyatt, 1996a,b.)

sist, the Oxfordshire area was nonetheless one of transition, separating the Cotswold region (see Chapter 3) of mainly continuous marine sedimentation from one of discontinuous, generally non-marine sedimentation to the north; the Bathonian succession in the transitional area is complicated by rapid variations in lithology and thickness associated with the changing environments of deposition. The eustatic rise in sea level that heralded the start of the Callovian Age brought with it a return to marine clastic deposition throughout the whole area.

The main stratal divisions of the East Midlands Shelf area are shown on the first edition of William Smith's geological map of England published in 1815, and he is known to have visited here on a number of occasions to investigate the geology (e.g. see Swinnerton and Kent, 1981). However, significant contributions to an understanding of the detail and complexities of the Middle Jurassic stratigraphy largely stem from the latter part of the 19th century when individual investigators, such as Brodie (1853), Morris (1853, 1869), Sharp (1873) and Cross (1875), produced early accounts of local sections and successions, including Sharp's demonstration of the 'Inferior Oolite age' of the Lincolnshire Limestone. Both Samuel Sharp (1814–1882) and the Rev. John Edward Cross (1821–1897) subsequently had biostratigraphically important Middle Jurassic brachiopod species (*Kallirhynchia sharpi* Muir-Wood and *Acanthothiris crossi* (Walker)), named after them. The [British] Geological Survey was also mapping in the region at this time and produced district memoirs by Judd (1875), Jukes-Browne (1885), Ussher *et al.* (1888) and Ussher (1890), as well as Woodward's (1894) stratigraphical memoir. The next major spate of publications on the Middle Jurassic succession did not come until the 1930s when Thompson's (1930) paper on the 'Upper Estuarine Series' of Northamptonshire and north Oxfordshire, and Douglas and Arkell's (1932) review of the Cornbrash Formation were published. During this decade, Linsdall Richardson (1881–1967), who had already published extensively on the Middle Jurassic rocks of the Cotswolds (see Chapter 3), turned his attention to the succession in Lincolnshire (Richardson, 1939a,b, 1940) where he was joined by Percy (later Sir Peter) Kent (1913–1986) who became the most prolific author on the Middle Jurassic rocks of this region in recent times (Richardson and Kent, 1938; Kent, 1938, 1941, 1948, 1953, 1966, 1967, 1970, 1972, 1975; Kent and Baker, 1938; Swinnerton and Kent, 1949, 1981). His work coincided with a second phase of [British] Geological Survey activity in the region, which was mainly concerned with investigations of the Northampton Ironstone at the base of the Middle Jurassic succession (Hollingworth and Taylor, 1946a,b, 1951; Taylor, 1946, 1963). Sylvester-Bradley (1968) described this stratum, which was extensively quarried throughout most of the area from Towcester, Northamptonshire, as far north as Lincoln, as the most important source of iron exploited in the country. It was much in demand during and after the Second World War, but its extraction was phased out between 1968 and 1974 in favour of higher-grade imported ore (Kent, 1975). Other contributions from this time, including publications by Muir-Wood (1939, 1952) on brachiopod faunas and Bate (1967a,b) on ostracod faunas, culminated in the regional synthesis entitled *The Geology of the East Midlands* edited by Sylvester-Bradley and Ford (1968); this included chapters on the Aalenian–Bajocian rocks by Sylvester-Bradley, on the Bathonian rocks by Torrens (with a contribution by C.J. Aslin), and on the Callovian rocks by Callomon. Since 1970, important postgraduate research has been undertaken by Ashton (1977, 1980), Parsons (1974b, 1980a,b), Bradshaw (1978), Cripps (1986) and Page (1988, 1989); that of Bradshaw and Cripps remains essentially unpublished (except in Bradshaw and Cripps, 1983, 1992) but both have allowed data from their theses to be quoted. Other recent work is referred to below and in the individual GCR site reports that follow.

The current lithostratigraphical scheme for the Middle Jurassic rocks of the East Midlands divides the succession into the Inferior and Great Oolite groups; the latter is succeeded by the Kellaways and Oxford Clay formations, which, in this region, are assigned to the Ancholme Group. The term 'Redbourne Group', which Gaunt *et al.* (1992) introduced for the combined Inferior and Great Oolite groups in the north of the region, is not used in the present volume. The current lithostratigraphical classification of the Aalenian–Bajocian rocks covered by this chapter is shown in Figure 4.2. The term 'Grantham Formation' was first used by Kent (1975) in place of the earlier term 'Lower Estuarine Series'. As shown by Bradshaw

(1978), this unit is absent in the south of the region, and any 'Lower Estuarine Series' that has been described there actually belongs to the Stamford Member of the Rutland Formation or, in the south-west, to the newly defined Horsehay Sand Formation. The classification of the Lincolnshire Limestone Formation follows Ashton (1977, 1980) except that a two-fold subdivision into Lower and Upper is preferred to his three-fold subdivision (Figure 4.3). The distinction between the Lower and Upper divisions, as used herein, is fundamental. The Lower Lincolnshire Limestone is dominated by low-energy micritic packstones and wackestones, whereas the Upper Lincolnshire Limestone largely comprises high-energy ooidal grainstones; there is often an undulating erosive contact between the two. The sedimentology and diagenesis of the Lincolnshire Limestone Formation have been investigated by Emery *et al.* (1987, 1988), Emery (1991) and Emery and Dickson (1991). Although not mappable entities, Ashton's (1977, 1980) 'members' (Figure 4.3) can be used for descriptive purposes in

This account	Ashton (1980)	
Upper Lincolnshire Limestone	Upper Lincolnshire Limestone	Clipsham Member
Upper Lincolnshire Limestone	Upper Lincolnshire Limestone	Sleaford Member
Lower Lincolnshire Limestone	Middle Lincolnshire Limestone	Blankney Member
Lower Lincolnshire Limestone	Middle Lincolnshire Limestone	Metheringham Member
Lower Lincolnshire Limestone	Middle Lincolnshire Limestone	Kirton Shale Member
Lower Lincolnshire Limestone	Middle Lincolnshire Limestone	Lincoln Member
Lower Lincolnshire Limestone	Lower Lincolnshire Limestone	Leadenham Member
Lower Lincolnshire Limestone	Lower Lincolnshire Limestone	Greetwell Member
Lower Lincolnshire Limestone	Lower Lincolnshire Limestone	Sproxton Member

Figure 4.3 Main subdivisions of the Lincolnshire Limestone Formation in the Stamford–Grantham–Lincoln area.

individual sections although they are mostly only of local correlative value. The lithostratigraphical classification of the Bathonian rocks covered by this chapter is shown in Figure 4.4. The term 'Rutland Formation', and the named rhythms within it, were introduced by Bradshaw (1978) in his unpublished D. Phil. thesis in place of the earlier term 'Upper Estuarine Series'. Bradshaw's nomenclature has since been used, with his consent, by the British Geological Survey in various maps and memoirs. Gaunt *et al.*'s (1992) term 'Glentham Formation', which includes the strata of the Rutland Formation, is now redundant. Higher in the succession, the White Limestone and Forest Marble formations of the Cotswolds (see Chapter 3) are replaced by the Blisworth Limestone and Blisworth Clay formations in the greater part of the region. The diagenesis of the limestone formations has been investigated by Hendry (1990, 1993).

Ammonites are common only in the Callovian part of the Middle Jurassic succession in this region (see **Peterborough Brickpits** GCR site report, this volume), although there is some limited ammonite control in the Inferior Oolite Group where the Scissum, ?Murchisonae, Discites, Ovalis and Laeviuscula zones are proved (Ashton, 1977, 1980; Parsons, 1980a). For the Great Oolite Group, dating and correlation has to be inferred on the basis of sedimentary rhythms recognized in the Rutland Formation, and by apparently quasi-isochronous event horizons (Excavata, Ardleyensis, Bladonensis, Sharpi and Digonoides beds) in the White Limestone and Blisworth Limestone formations. It should be noted that the brachiopods *Kallirhynchia sharpi* and *Digonella digonoides* (S.S. Buckman), on which the Sharpi and Digonides beds are based, are facies faunas that also occur at several other levels; the other event horizons listed, although named after particular gastropods, are associated with hardgrounds and are thus sedimentological events. Ostracod faunas and palynomorphs have also been used to provide some age control. For example, placement of the Bajocian–Bathonian boundary within the 'White Sands' of the south-west of the region (Horsehay Sand Formation herein; see **Horsehay Quarry** GCR site report, this volume) is based on a palynostratigraphical investigation by Fenton *et al.* (1994, 1995), and the Thorncroft Sand of the Humber area has been assigned to the Lower Bajocian

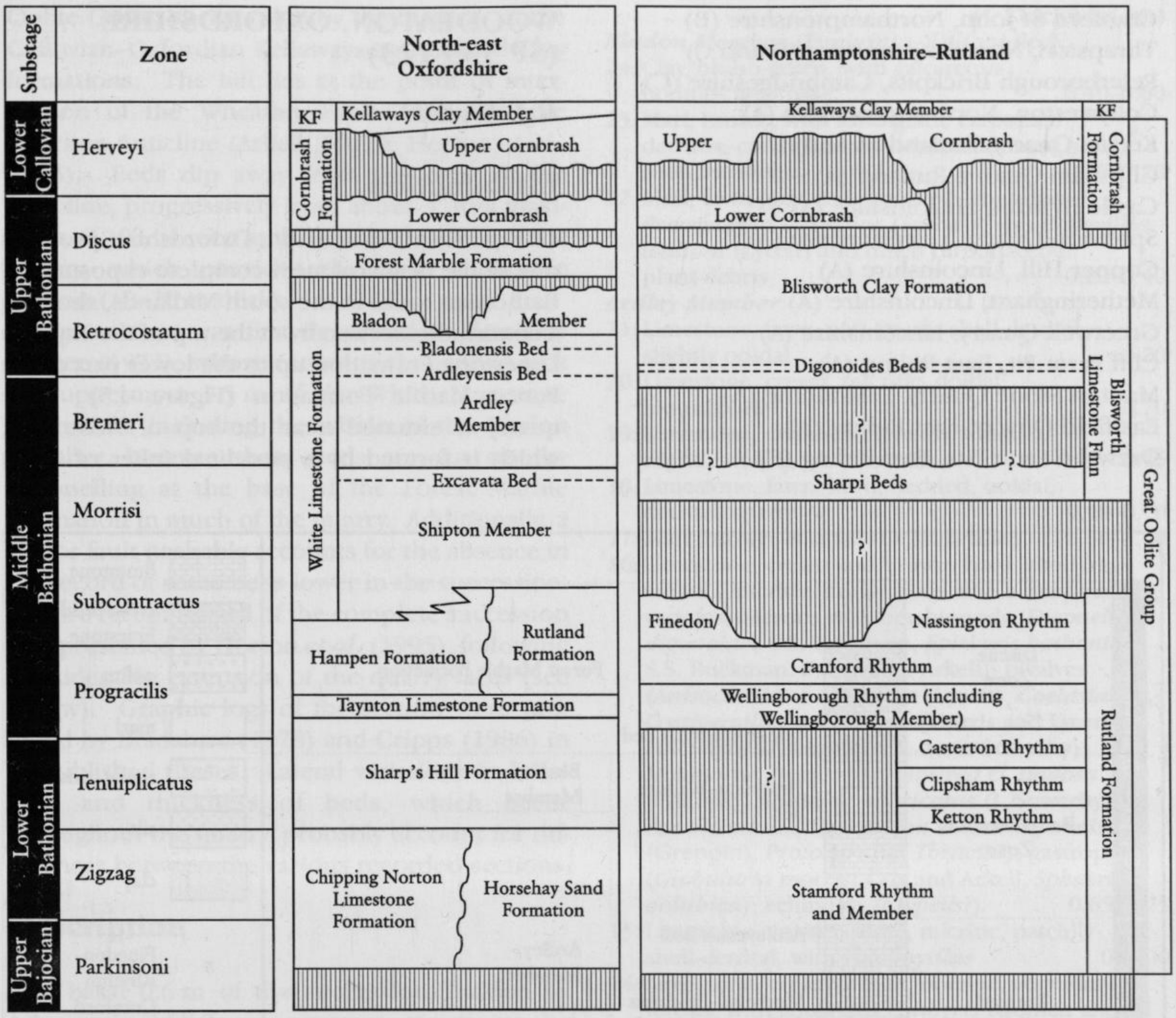

Figure 4.4 Lithostratigraphical classification of the Bathonian and overlying Callovian rocks in the southern part of the East Midlands Shelf area. Columns are deliberately separated one from the other because of the tenuous nature of some correlations. Vertical ruling indicates non-sequence. (Based on data in Bradshaw, 1978; Cripps, 1986; Horton *et al.*, 1987; Page, 1989; and Wyatt, 1996a.) (KF = Kellaways Formation.)

Humphriesianum Zone (and possibly the underlying Sauzei Zone) on the basis of dinoflagellate cysts (Riding, 1987; Gaunt *et al.*, 1992). However, the beds from which the latter floras were recovered belong to a transitional facies that may be better placed with the Lincolnshire Limestone Formation (see for example, Bradshaw and Penney, 1982). The overlying Thorncroft Sand 'proper' is almost certainly the equivalent of the Stamford Member of the Rutland Formation as shown in Figure 4.2.

Details of the main lithologies and depositional environments are included in the site descriptions that follow. In the following list of sites (arranged south to north), (A) indicates that the site belongs to the Aalenian–Bajocian GCR Block, (B) indicates the Bathonian GCR Block and (C) the Callovian GCR Block. The location of the sites is shown in Figure 4.1.

Woodeaton, Oxfordshire (B)
Ardley Cuttings and Quarries, Oxfordshire (B)
Stratton Audley, Oxfordshire (B)
Blisworth Rectory Farm, Norhamptonshire (B)
Roade Railway Cutting, Northamptonshire (B)
Irchester Old Lodge Pit, Northamptonshire (B)
Finedon Gullet, Wellingborough, Northamptonshire (B)

Cranford St John, Northamptonshire (B)
Thrapston, Northamptonshire (B and C)
Peterborough Brickpits, Cambridgeshire (C)
Collyweston, Northamptonshire (A)
Ketton Quarry, Rutland (A and B)
Clipsham Quarry, Rutland (A)
Castle Bytham, Lincolnshire (A)
Sproxton Quarry, Leicestershire (A)
Copper Hill, Lincolnshire (A)
Metheringham, Lincolnshire (A)
Greetwell Quarry, Lincolnshire (A)
Cliff Farm Pit, East Riding (A)
Manton Stone Quarry, East Riding (A)
Eastfield Quarry, East Riding (A)
Drewton Lane Pits, East Riding (C)

WOODEATON, OXFORDSHIRE (SP 533 123)

R.J. Wyatt

Introduction

The quarry at Woodeaton, Oxfordshire, provides one of the best and most complete exposures of Bathonian rocks in the south Midlands, showing a continuous section from the top of the Taynton Limestone Formation up to the lower part of the Forest Marble Formation (Figure 4.5). The quarry is situated near the top of Noke Hill, which is formed by a periclinal inlier of Great

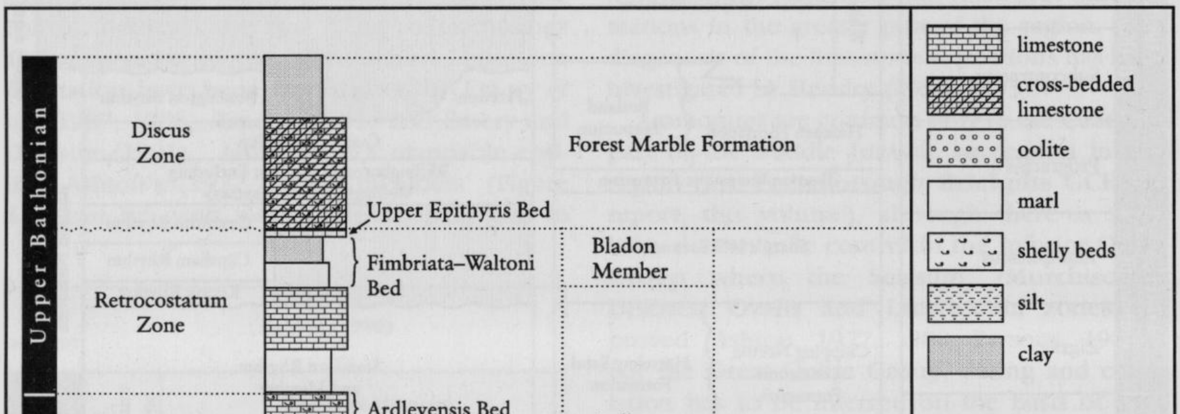

Figure 4.5 Graphic section of the Bathonian succession in the quarry at Woodeaton. (After Horton *et al.*, 1995, fig. 9.)

Oolite Group surrounded by the outcrop of the Callovian–Oxfordian Kellaways and Oxford Clay formations. The hill lies at the point of intersection of the Wheatley Fault Zone and the Charlton Anticline (Arkell, 1947b; Horton *et al.*, 1995). Beds dip away from the crest of the pericline, progressively from about 3° to a maximum of 10°, as seen in the south-west face of the quarry, which provides the most complete section (18–20 m thick).

The section was first described in detail by Palmer (1973), whose record is thought to lack the uppermost 3.5 m of the White Limestone Formation, including the whole of the Bladon Member, because these beds are cut out by channelling at the base of the Forest Marble Formation in much of the quarry. Additionally, a minor fault probably accounts for the absence in his record of some beds lower in the succession. A more recent record of the complete succession was presented by Horton *et al.* (1995), following considerable extension of the quarry faces (see below). Graphic logs of the section were provided by Bradshaw (1978) and Cripps (1986) in unpublished theses. Lateral variations in lithology and thickness of beds, which occur throughout the quarry, probably account for differences between the various recorded sections.

Description

The basal 0.6 m of the succession, hidden by talus or backfill for many years, represents the topmost beds of the Taynton Limestone Formation. It consists of shell-fragmental, sparry, ooidal limestone. Complete fossils are uncommon but *Kallirhynchia*? has been recorded (Palmer, 1973). The following section through the overlying beds is taken, with minor amendments, from Horton *et al.* (1995); Bed 3 and Bed 5 of the Rutland Formation were not recorded by Palmer (1973), and Bed 4 is much thicker than his 'Monster Bed' with which it equates.

	Thickness (m)
White Limestone Formation	
Bladon Member **(*Upper Epithyris Bed*)**	
25: Limestone, cream and buff, finely detrital or micritic, with greenish-grey clay-filled burrows, brown wood-fragments; poorly preserved bivalves including *Anisocardia*?, *Eomiodon* cf. *fimbriatus* (Lycett), *Lucina*?, *Modiolus*, *Protocardia*, *Quenstedtia*?, *Vaugonia* cf. *angulata* (J. de C. Sowerby); and gastropods including *Sphaeriola oolithica* (Rollier) and *Fibula* cf. *phasanioides* (Morris and Lycett)	0–0.12
Bladon Member **(*Fimbriata–Waltoni Bed*)**	
24: Clay, bluish-green, with calcareous nodules near base	0.40–0.60
23: Marl, brown, with sand-grade carbonate detritus; carbonaceous debris and, near base, shell fragments	0.10–0.20
22: Marl, fawn-grey, rusty mottled; abundant *Praeexogyra hebridica* (Forbes), also *Bakevillia waltoni* (Lycett) and much carbonaceous plant-debris	0.20–0.40
Ardley Member	
21: Limestone, fawn, soft, marly, shell-detrital, slightly ooidal	0.20
20: Limestone, cream, micritic, ooidal, bioturbated	0.70
19: Limestone, cream, soft, marly, micritic, slightly ooidal, bioturbated	0.45
18: Limestone, fawn, hard, bedded, ooidal, detrital, sparry	0.50–0.70
17: Marl, brown; abundant *P. hebridica*	0.50–1.00
16: Limestone, cream and brown, hard, shell-fragmental, micritic; in two beds with a marl parting; very fossiliferous with brachiopods (*Digonella digonoides* S.S. Buckman, *Epithyris bathonica* S.S. Buckman, *E. oxonica* Arkell); bivalves (*Anisocardia* cf. *islipensis* (Lycett), *Coelastarte*?, *Costigervillia crassicosta* (Morris and Lycett), *Falcimytilus sublaevis* (J. de C. Sowerby), *Homomya*, *Isocyprina*, *Liostrea* cf. *undosa* (Phillips), *Modiolus imbricatus* (J. Sowerby), *Parallelodon*, *Plagiostoma subcardiiformis* (Greppin), *Protocardia*?, *Thracia*?); gastropods (*Globularia morrisi* Cox and Arkell, *Sphaeriola oolithica*); echinoids (*Clypeus*?)	0.65–0.75
15: Limestone, creamy-white, micritic, patchily shell-detrital, with *Falcimytilus*	0–1.00
14: Limestone, creamy-white, micritic, very fossiliferous, with abundant *Epithyris oxonica* and *Modiolus*; also *Anisocardia* cf. *islipensis*, *Falcimytilus sublaevis*, *Pholadomya* cf. *ovalis* (J. Sowerby) and *Sphaeriola oolithica*; at southern end of quarry face, passing into 0.40 m of buff or fawn, finely ooidal, fine-grained, detrital limestone with laminae of creamy-white micrite; *Digonella digonoides* and various bivalves	0.20–0.50
13: Limestone, creamy-white, micritic, bioturbated in lower part; *Anisocardia*, *Bakevellia waltoni*, *Costigervillia*?, *Cuspidaria ibbetsoni* (Morris), *Lucina*, *Modiolus*, *Protocardia*, *Globularia*	0.30–0.50
12: Limestone, creamy-brown, fine- to medium-grained, detrital, cross-bedded	0.60–1.50
11: Limestone, brown, fine grained, marly, slightly sandy, with bivalve casts	0.20–0.25
10: Marl to marly limestone, rusty-brown	0.03–0.08
Shipton Member	
9: Limestone, cream, finely detrital, slightly ooidal, with poorly preserved bivalves; top locally brown, hard, recrystallized, with marl-filled burrows; thickest in north-west corner of quarry where four beds are separated by thin marly limestone bands; ?*Epithyris oxonica*, *Unicardium*?, *Cossmannea*	0.40–1.10

		Thickness (m)
8:	Marl to marly limestone, fawn and rusty-brown, soft, shell-detrital, ooidal	0.12
7:	Oolite, cream, fine grained, well sorted	0.60–0.70
6:	Limestone, creamy-white, finely detrital, rubbly weathering; bivalves including *Camptonectes laminatus* (J. Sowerby), *Ceratomya concentrica* (J. de C. Sowerby), *Coelastarte* cf. *compressiuscula* (Morris and Lycett), *Costigervillia crassicosta*, *Isognomon isognomonoides* (Stahl), *Lucina*, *Pleuromya*, *Protocardia buckmani* (Morris and Lycett); gastropods (*Trochotoma*); brachiopods (*Kallirhynchia* cf. *deliciosa* S.S. Buckman)	0.65–0.80
5:	Limestone, pale-buff, massive, finely detrital, slightly ooidal; *Thalassinoides* on top surface	0.65–0.80
4:	Silt to siltstone, fawn, shaly weathering	0.15–0.20
3:	Limestone, fawn, finely detrital; bivalves (*Ceratomya concentrica*, *Isognomon*, *Myoconcha*, *Myophorella*, *Protocardia*?); gastropods (*Ampullospira*)	1.2
2:	Limestone, creamy-white, finely detrital; bivalves (*Antiquicyprina loweana*? (Morris and Lycett), *Ceratomya concentrica*, *Isognomon* cf. *isognomonoides*, *Pholadomya lirata* (J. Sowerby), *Plagiostoma cardiiformis* (J. Sowerby), *P. subcardiiformis*); gastropods (*Ampullospira*)	0.40–0.45
1:	Marl, rusty-brown, finely shell-detrital; *Praeexogyra hebridica*	0.15
Rutland Formation		
8:	Mudstone, pale greenish-grey, silty, with dark-green burrow-mottling in top 0.14 m; passing laterally into calcareous siltstone with shell-debris filled burrows at top; scattered thin-shelled bivalves and oyster-shell debris; carbonaceous rootlets truncated at top surface	0.42–0.70
7:	Mudstone, dark-grey and brownish-grey, bioturbated with shell debris and many bivalves	0.17
6:	Marl, dark-grey, sandy with much shell-debris; passing laterally into nodular, sandy, shell-fragmental limestone with fine plant-detritus; *Ampullospira*?; and bivalves (*Mactromya*, *Placunopsis socialis*, *Praeexogyra hebridica*); sharp base	0.90
5:	Mudstone, dark brownish-grey, wispy bedded, intensely bioturbated and with distinct, green, clay-filled burrows; pockets of bivalve shells; sharp, uneven burrowed base	0–0.10
4:	Mudstone, pale greenish-grey, silty; in places at top passing laterally into marl with siltstone; rare bivalves; scattered calcareous nodules; well-defined rootlets marked by grey clay traces in upper part	0.65
3:	Mudstone, dark-grey, shell-debris rich with many oysters; sharp base	0.03–0.06
2:	Marl, pale-green, silty; rare shells and scattered rootlets	1.36
1:	Mudstone, medium-grey with silt wisps, some ripple-laminated; green clay-filled burrows	seen to 0.15

Up to 3.5 m of Forest Marble Formation are present above the White Limestone Formation in the western face of the quarry. Grey and brown mottled clay with calcareous race nodules, overlie fawn, cross-bedded, shell-fragmental oolite containing angular fragments of derived white micritic limestone at the base. Ripple marks, clay drapes and clay flakes characterize these limestones.

Within the White Limestone Formation, the Shipton, Ardley and Bladon members are readily recognizable. The limestones of the basal Shipton Member are less well-cemented, softer and more easily weathered than those of the Ardley Member, which enables the two units to be readily differentiated in the quarry face. A shelly marl at the base of the Shipton Member (Bed 1) sharply truncates the uppermost rootlet bed of the Rutland Formation. As well as the fauna listed in the above section and in Palmer (1973), colonial corals such as *Cyathophora*, *Isastrea* and *Thamnasteria*, and the red alga *Solenopora jurassica* Brown, rare in the White Limestone Formation, have been recorded in the upper half of the member (Palmer, 1979). Sporadic nerineid gastropods are also present. Rootlets have been noted at the top of Bed 2 and also beneath Bed 4 (Bradshaw, 1978). The fine-grained, well-sorted oolite of Bed 7 is a useful marker. The locally hard and recrystallized top of Bed 9 is an incipient hardground of Dagham Stone type. Bed 11, near the base of the overlying Ardley Member, may be compared with the 'Roach Bed' (see **Ardley Cuttings and Quarries** GCR site report, this volume). Two very fossiliferous beds higher up in the member are noted for an abundance of well-preserved bivalves and brachiopods. The lower of the two (Bed 14) is the *Modiolus–Epithyris* Bed of Palmer (1973), which is characterized by an abundance of well-preserved *Modiolus imbricatus* (J. Sowerby) and *Epithyris oxonica* Arkell, the latter representing all life stages of the brachiopod. A facies change occurs at the southern end of the quarry, where this shelly, creamy-white micrite passes into buff, finely ooidal, detrital limestone with micrite laminae, in which *Digonella digonoides* S.S. Buckman is common, to the exclusion of *Epithyris*. However, these brachiopods are both present in the higher fossiliferous bed (Bed 16), which is overlain by a conspicuous shelly marl containing abundant *Praeexogyra hebridica*. The overlying Bladon Member is present only in the north-west corner of the quarry; all but the top limestone bed constitutes the so-called 'Fimbriata–Waltoni Bed'. Its basal marl (beds 22 and 23) contains much carbonate sand and carbonaceous plant-debris, large lignitic logs, and, in the lowest part, abundant oyster-shells. Bed 25 occurs along only a short section of the face and is all that is preserved of the Upper Epithyris Bed beneath the Forest Marble Formation. The basal erosion surface of the latter channels up to 4.7 m into the underlying White Limestone Formation, cutting out the Bladon Member and the top of the Ardley Member.

Minor faults are seen to displace strata in the north-west part of the quarry; the one with the greatest downthrow (*c.* 5 m) is associated with well-formed terminal bending (Figures 4.6 and 4.7).

Interpretation

The Taynton Limestone Formation was deposited in the turbulent waters of a shallow shelf-sea, and constitutes the marine phase and lower part of the Wellingborough Rhythm of Bradshaw (1978).

The beds traditionally assigned to the dominantly marine Hampen Formation were referred to the Rutland Formation by Horton *et al.* (1995) because occurrences of brackish-water bivalves and ostracods, seatearth lithologies and well-developed rootlet beds resemble the characteristic facies of the latter formation. The bivalves include marine forms such as *Mactromya* and *Praeexogyra hebridica* (Forbes), and others, such as '*Corbula*', *Cuspidaria*, *Neomiodon* and *Placunopsis socialis* Morris and Lycett, which tolerated brackish-water conditions. However, the distribution of these various forms may have had as much to do with substrate as with salinity (J.D. Hudson, pers. comm., 1998). Three rootlet beds define the tops of three rhythmic, shallowing-up depositional units (Horton *et al.*, 1995; Wyatt, 1996a,b). These are, in ascending order, the Wellingborough, Cranford and Finedon rhythms of Bradshaw (1978) (Figure 4.5). The top of the Finedon

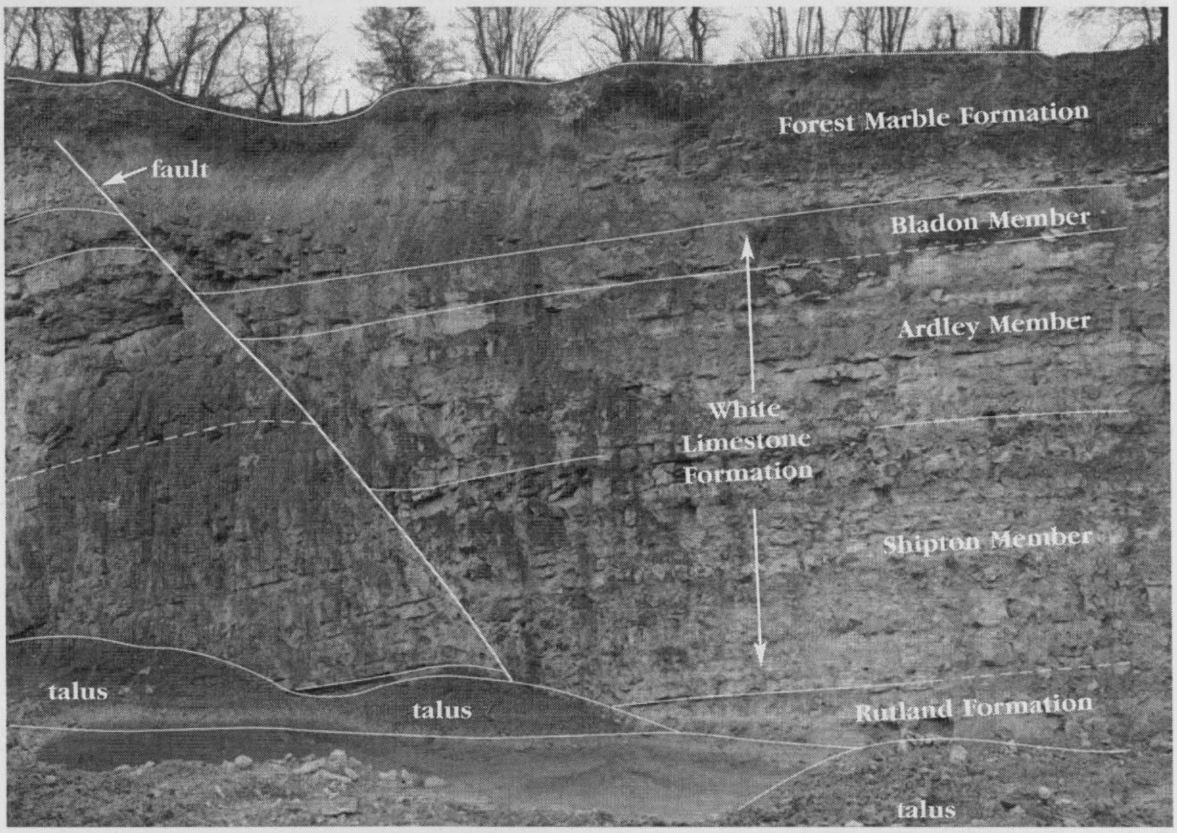

Figure 4.6 The quarry at Woodeaton; flaggy limestones of the Forest Marble Formation overlie a complete White Limestone Formation, with a fault of *c.* 3 m downthrow. (Photo: British Geological Survey, No. A15356; reproduced with the permission of the Director, British Geological Survey, © NERC, 1991.)

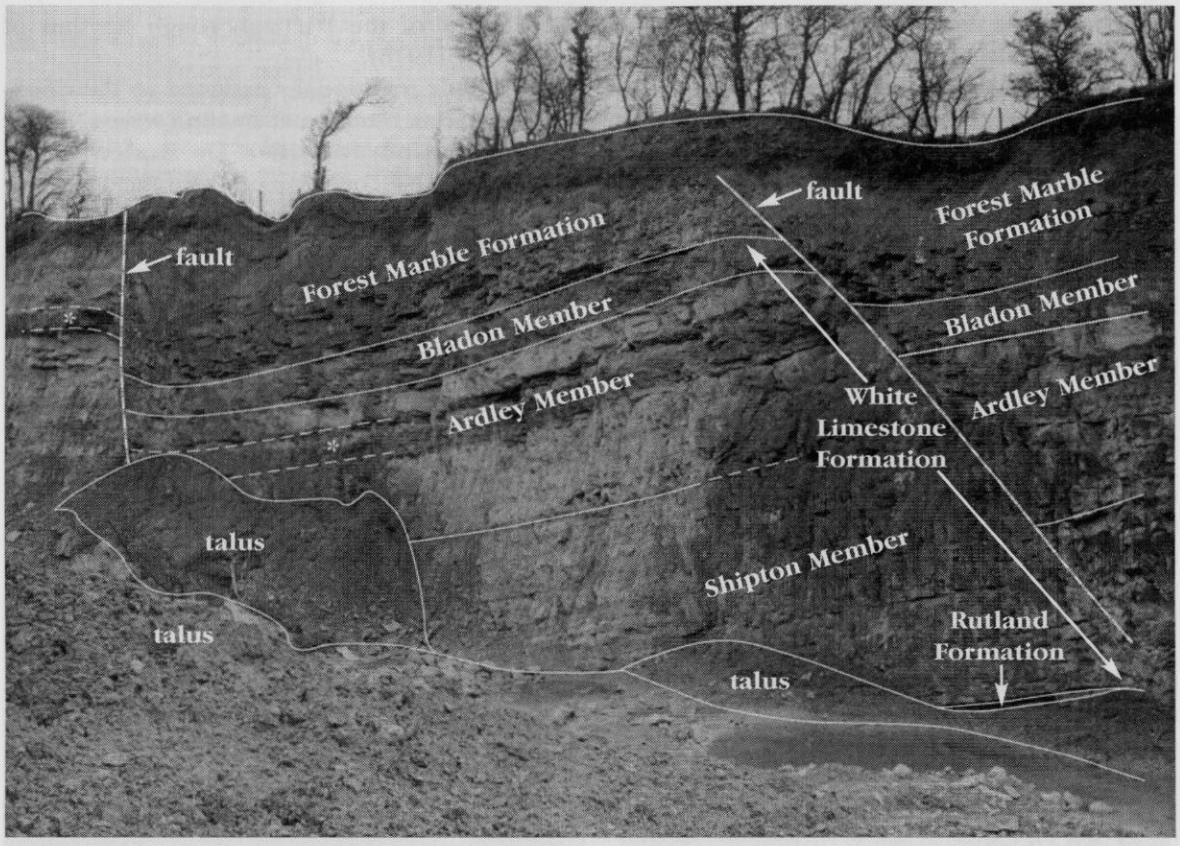

Figure 4.7 The quarry at Woodeaton; west face showing faults with terminal bending of beds. (Photo: British Geological Survey, No. A15358; reproduced with the permission of the Director, British Geological Survey, © NERC, 1991.)

Rhythm (the top of Bed 8) is marked by a particularly distinctive pale greenish-grey clay with long, vertical rootlets infilled with dark-green clay. The rootlet beds indicate the establishment of coastal saltmarshes at the termination of the regressive rhythms. Marine bivalves, notably *P. hebridica*, characterize the basal parts of the Cranford and Finedon rhythms, whilst a mixed brackish-water to marine bivalve fauna occurs in the remaining sediments. The 'Monster Bed' of Palmer (1973) (= Bed 4 above), which forms the bulk of the Cranford Rhythm in Horton *et al.* (1995), has yielded two mid-dorsal vertebrae of the dinosaur *Cetiosaurus*, numerous bone fragments and a large quartzite pebble, interpreted to be a gastrolith (stomach stone). The freshwater gastropods *Valvata* and *Viviparus* also occur in this bed, together with a dominantly brackish-water ostracod microfauna. The calcified oogonia (egg cells) of charophytes form another freshwater element. Some rootlets in this bed have been assigned to the genus *Equisetites*, colonization by which suggests emergent conditions; higher-order plants are present as fragmentary material only. This mixed brackish-water fauna, together with its freshwater elements, suggests rapidly changing salinity levels, probably caused by influxes into a nearshore brackish-water lagoon of freshwater from streams draining the London Landmass. The streams transported the freshwater gastropods and charophytes, and the terrestial plant-debris.

The dominant micritic or finely detrital, pelletal, bioturbated limestones in the Shipton and Ardley members of the White Limestone Formation are inferred to have been deposited in the marine, shallow, quiet waters of a lagoon that formed the proximal part of an extensive shelf-sea marginal to the London Landmass. The coarser, cross-bedded limestone in the lower part of the Ardley Member denotes more turbulent depositional conditions. An abundance of burrowing bivalves throughout accounts for the common occurrence of bioturbation. Beds of mudstone, marl and silt represent periodic influxes of terrigenous sediment that generally form the bases of the regressive depositional units. Only the basal oyster-rich bed of the Bladon Member is marine; the occurrence of the eponymous bivalve *Bakevellia waltoni* (Lycett) above suggests brackish-water conditions. An abundance of coarse, carbonaceous, terrestrial plant-debris throughout indicates proximity to the shoreline. The calcareous nodules in the uppermost clay unit of the Fimbriata–Waltoni Bed may represent a caliche, suggesting subaerial exposure. The strata of the White Limestone Formation can be interpreted in terms of shallowing-up, rhythmic, depositional units (Palmer, 1979; Wyatt, 1996a,b), some capped by rootlet beds, some clearly separated by depositional breaks. Thus, in the Shipton Member, there are three rhythms, the lower two capped by rootlet beds, the uppermost by a burrowed hardground (the top of Bed 9) that may be correlated with the regionally persistent Excavata Bed (Sumbler, 1984; Wyatt, 1996a,b). Three rhythms are evident in the Ardley Member, the lower two capped by the highly fossiliferous beds 14 and 16, which contain abundant epifaunal elements in addition to the ubiquitous burrowing bivalve fauna. The higher of these fossiliferous units (Bed 16), which comprises two distinct beds with a marl parting, probably corresponds to the Ardleyensis Bed hardground elsewhere, another regionally persistent marker (Sumbler, 1984); its double character suggests the presence of a fourth minor rhythm (Wyatt, 1996a,b). Unlike some other exposures in Oxfordshire, no hardground is developed at the top of the Ardley Member at Woodeaton. The Fimbriata–Waltoni Bed (the lower and greater part of the Bladon Member) represents a rhythm in the brackish-water facies.

The succeeding cross-bedded ooidal limestones of the Forest Marble Formation were laid down in conditions similar to those of the Taynton Limestone Formation. The uppermost clay represents a return to deposition of quiet-water terrigenous sediment.

No ammonites have been collected from the quarry, but a zonal interpretation (Progracilis to Discus zones) is made possible by regional correlation of the rhythmic depositional units (Figure 4.5).

Conclusions

The quarry at Woodeaton exposes the complete White Limestone Formation, and offers one of the more accessible exposures of the Rutland Formation in the south Midlands. The rocks include representatives of a brackish-water, nearshore saltmarsh (Rutland Formation); a marine, high-energy, open shelf-sea (Taynton Limestone and Forest Marble formations); and a marine, quiet-water, protected lagoon (White Limestone Formation). Of special interest are highly fossiliferous beds yielding well-preserved fossils in the White Limestone Formation, and the 'Monster Bed' with its vertebrate remains and mixed brackish-water–freshwater fauna and flora in the Rutland Formation. The succession is characterized by several shallowing-up, rhythmic, depositional units, some capped by distinctive rootlet beds. The quarry exhibits the increasingly inclined strata on the south-western flank of the Noke Hill Pericline, in part disrupted by minor faults associated with terminal bending.

ARDLEY CUTTINGS AND QUARRIES, OXFORDSHIRE (SP 514 291–SP 558 250)

M.G. Sumbler and R.J. Wyatt

Introduction

The GCR site known as 'Ardley Cuttings and Quarries', north-west of Bicester, Oxfordshire, comprises sections in the Ardley Fields Farm (SP 543 265) and Ardley Wood (SP 537 273) quarries, and a 6 km stretch of railway cutting (SP 514 291–SP 559 250) in which there are a number of discrete exposures. Together, they have displayed a succession ranging from the uppermost beds of the Lower Jurassic Lias Group to the top of the Great Oolite Group, including all of the Bathonian succession (Figure 4.8). The site is of special interest as the type locality of the Ardley Member of the White Limestone Formation. A number of authors have referred to these sections since Barrow's (1908) initial description. Odling (1913) provided the first full account of the Bathonian succession in the railway cutting and, later, a revised description was presented by Arkell *et al.* (1933). The Middle to Upper Bathonian succession in Ardley Fields Farm Quarry was recorded

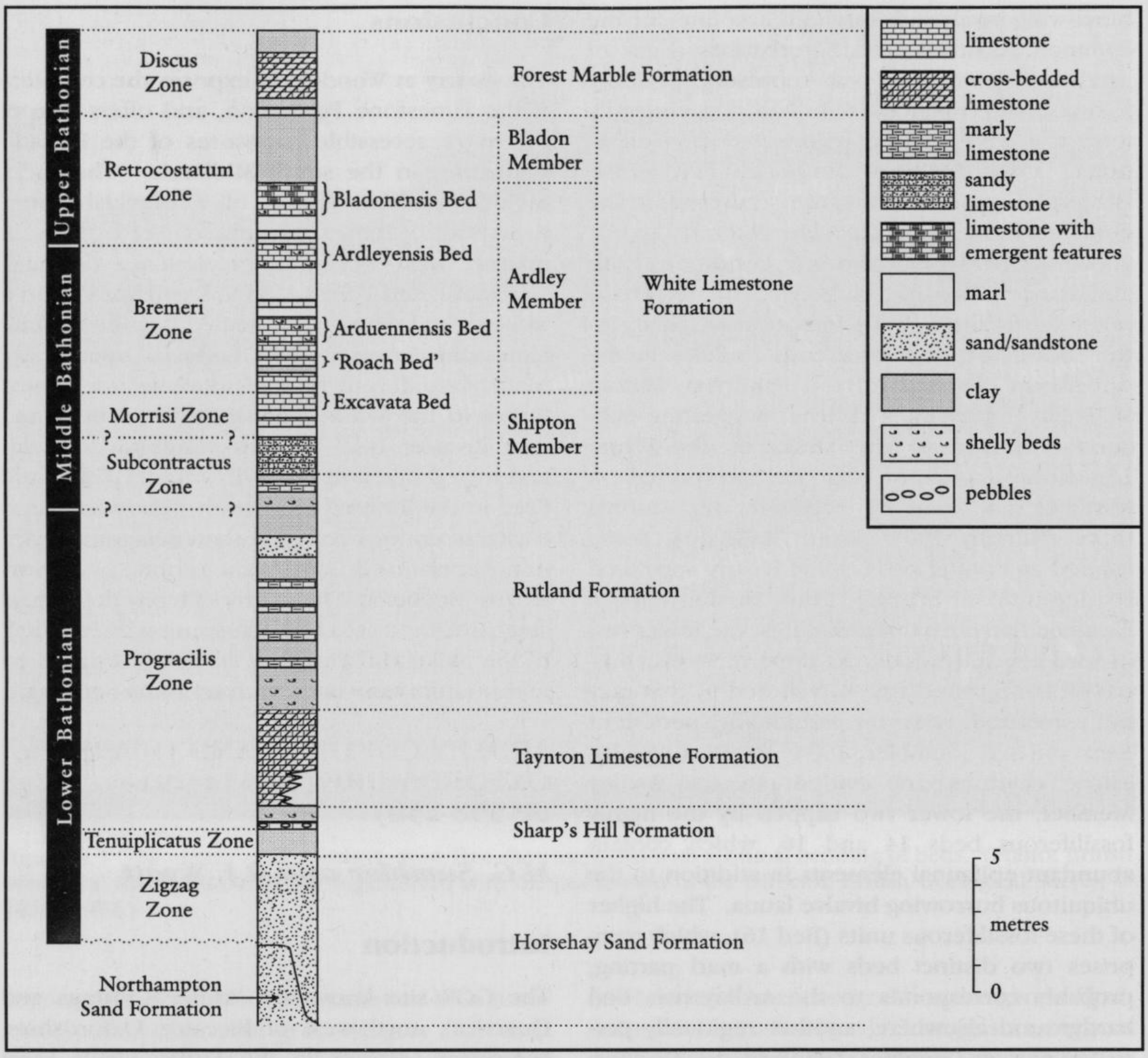

Figure 4.8 Graphic section of the Bathonian succession at the Ardley Cuttings and Quarries GCR site.

by Palmer (1973), and graphic logs of the same section were included by Barker (1976), Sumbler (1984) and Cripps (1986). Bradshaw (1978) and Cripps (1986) also provided graphic logs of the railway cutting and Ardley Wood sections (the latter referred to as 'Ardley Station Quarry'). Exposure in the railway cutting is now rather poor except for parts of the White Limestone Formation that can be seen to best advantage in the middle part of the cutting. Both Ardley Wood and Ardley Fields Farm quarries are largely backfilled, but preserved faces show up to 5 m of strata in the Ardley Member, and excellent sections of White Limestone Formation are visible in the extensive working quarry to the south of the latter site (SP 541 255).

Description

The several accounts of the succession exposed in the Ardley Cuttings and Quarries differ in detail, partly because there is much variation in lithology and thickness. The following generalized description is based mainly on the observations of Arkell *et al.* (1933), whose bed numbers are indicated where appropriate, supplemented by information from other sources, notably Palmer (1973) for the White Limestone Formation. The strata in the railway cutting dip gently south-eastwards from the mouth of the Fritwell Tunnel (SP 514 291), with minor flexuring. Much of the succession exposed in the cutting is repeated south-east of a reverse fault located close to the Ardley–Somerton road bridge (Odling, 1913).

Non-sequentially overlying the hard, massive to rubbly, bluish-grey to brown calcareous sandstone of the Northampton Sand Formation (the strata incorrectly classified by Arkell *et al.* (1933) as 'Hook Norton Beds'), the Bathonian succession starts with the Horsehay Sand Formation (Bed 6), the 'White Sands' of previous authors (see **Horsehay Quarry** GCR site report, this volume). These strata comprise up to 6.1 m of sand, the lower part of which is black, with a high carbonaceous content, and the upper 1.5 m of which is yellow, weathering white. At one point at least, this sand infills a channel perhaps 30 m wide and 3 m deep, cut down into the Northampton Sand Formation (Arkell *et al.*, 1933, pl. 34a).

Resting on the Horsehay Sand Formation, the Sharp's Hill Formation (beds 7 to 11) is about 1.4 m thick. The lower part (beds 7 to 9) consists of 0.30 m of grey and brown mottled sandy clay with paper-thin, white shell-fragments and many gastropods (cf. *Cerithium*) at the base, overlain by a 0.05–0.45 m-thick, black, carbonaceous seam with rootlets, and capped by a 0.10 m-thick, greyish-blue clay (the 'Peat Bed'). The overlying 0.9 m of the Sharp's Hill Formation (beds 10 and 11) probably correspond with the Charlbury Formation of Boneham and Wyatt (1993). These beds comprise a prominent unit of hard, pebbly limestone, overlain by grey clay and marl packed with the oyster *Praeexogyra hebridica* (Forbes).

The succeeding Taynton Limestone Formation (beds 12 and 13), perhaps up to 5 m in thickness, consists mainly of cross-bedded, flaggy, coarsely shell-fragmental limestones. Locally, however, the lower beds pass laterally into grey and greenish, muddy, shaly limestone and indurated marl.

The succeeding Rutland Formation, about 8.4 m thick, is close to its western limit where it passes into the more fully marine Hampen Formation (Horton *et al.*, 1987, fig. 8). The lowest 5.6 m comprise green and dark-grey sandy clays, with some beds of sandy, muddy limestone. The fossiliferous basal bed (Bed 14) has yielded the bivalves *Modiolus imbricatus* J. Sowerby, *Pinna* and *Praeexogyra hebridica*, and the brachiopod *Burmirhynchia concinna* (J. Sowerby). The holotype of the ammonite *Procerites imitator* (S.S. Buckman) was collected from a little higher (Bed 15). There is much lignite at the top of these beds, which are succeeded by a conspicuous 0.7 m-thick bed of greenish, patchily cemented sandstone with rootlets attributed to *Equisetites*; this unit (Bed 17) is one of the few parts of the succession below the White Limestone Formation that is still well exposed (SP 516 289). There follow 1.6 m of green sandy clay containing lignite, with abundant *P. hebridica* at the top (beds 18 and 19) succeeded by a 0.3 m-thick bed of grey, muddy limestone, which is shelly and ooidal at the base (Bed 20); it contains the oyster *Lopha costata* (J. de C. Sowerby), the brachiopod *Stiphrothyris* and echinoid debris. The Rutland Formation is completed by 0.25 m of grey clay and sandy clay with *Isognomon*, *Lopha costata*, *P. hebridica* and *Stiphrothyris* (Bed 21).

Within the succeeding White Limestone Formation, three regionally persistent units, in ascending order the Shipton, Ardley and Bladon members, are recognized (Palmer, 1979; Sumbler, 1984). The whole succession at Ardley (Figure 4.9) comprises mainly whitish-weathering micritic limestones, many of them pelletal and shell-detrital, with subordinate beds of clay or marl. There are several very fossiliferous beds.

The Shipton Member (beds 22 to 30) is about 3.5 m thick. The lower part is characterized by sandy limestones and sandstones, which may be laminated. These beds contain a wide variety of bivalves, including species of *Ceratomya*, *Gresslya*, *Lucina*, *Modiolus*, *Pholadomya*, *Pleuromya* and *Pseudotrapezium* (Odling, 1913); also the brachiopods *Burmirhynchia concinna* and '*Terebratula*' *globata* J. de C. Sowerby, the echinoid *Clypeus muelleri* Wright, and corals such as *Isastrea*. The ammonites *Tulites glabretus* S.S. Buckman and *T. subcontractus* (Morris and Lycett) have been collected from near the base. Palmer (1973) noted that the topmost limestone of the member, a 1 m-thick bed capped by a hardground with *Lithophaga* borings (the Excavata Bed), yielded *Homomya*, *Pholadomya* and *Pleuromya* in life position, as well as many *C. muelleri*. From the same bed, Barker (1976) collected the gastropods *Aphanoptyxis excavata* Barker (the index species) (see Barker, pp. 244–5, this volume), *Endlepolocus munieri* (Rigaux and Savage) and *Eunerinea arduennensis* (Buvignier). The full Shipton Member succession was formerly seen in the railway cutting and Ardley Wood Quarry, but only the topmost 1.9 m in Ardley Fields Farm Quarry.

Figure 4.9 Ardley–Fritwell railway cutting (Ardley Cuttings and Quarries GCR site) showing the White Limestone Formation. (Photo: British Geological Survey, No. A9865; reproduced with the permission of the Director, British Geological Survey, © NERC, 1960.)

The succeeding Ardley Member is about 7 m thick, based on the record of Odling (1913). It comprises beds 31 to 42 of Arkell *et al.* (1933) plus additional beds (1 and 2 of Odling, 1913) not seen by them. The basal 0.75 m comprises soft, argillaceous, shelly, bioturbated, micritic limestone passing down into clay. The fauna includes the bivalves *Eonavicula minuta* (J. de C. Sowerby), *Plagiostoma subcardiiformis* (Greppin) and *Praeexogyra hebridica*, the coral *Isastrea*, and the brachiopod *Kallirhynchia*; a small unnamed or indeterminate terebratulid is also common. This bed is succeeded by a thin clay with *P. hebridica*, which is very conspicuous in the quarry faces. The overlying 'Roach Bed', 0.15–0.30 m thick, is a sandy limestone in which an abundant fauna of bivalves and gastropods is preserved as moulds, giving the rock a distinctive cavernous character. About 0.60 m above this bed, there is the '*Nerinea eudesii* bed' of Arkell (1931) and Arkell *et al.* (1933), a shelly, ooidal limestone with an abundance of the gastropod *E. arduennensis* (Arduennensis Bed herein). '*Nautilus*' *subcontractus* Morris and Lycett has been collected from near the base of the overlying 1.8 m of dominantly marl beds, which are succeeded by a whitish, shelly, pelletal, micritic limestone, up to 0.8 m thick. This latter bed is capped by a hardground encrusted with oyster shells ('*Exogyra*') and penetrated by burrow-fills. This, the Ardleyensis Bed, is divided into upper and lower parts by a softer, marly limestone layer (Barker, 1976). The bed is packed with the diagnostic gastropod *Aphanoptyxis ardleyensis* Arkell. A massive, bioturbated, shelly, micritic limestone follows (Bed 42 of the cutting), locally (in Ardley Fields Farm Quarry) with a marl containing *P. hebridica* at the base, and a similar marl above it. The coral *Isastrea* in life position is present in this limestone, as well as the brachiopod *Epithyris oxonica* Arkell and the bivalves *Modiolus imbricatus* and *Plagiostoma subcardiiformis* (Greppin). The Ardley Member is capped by the Bladonensis Bed, the highest stratum ever exposed in Ardley Fields Farm Quarry. It is a massive micritic limestone, the top of which is a hardground featuring shrinkage cracks, algal laminae and 'birdseye' vugs. This is the 'Cream Cheese Bed' of early authors. The barren upper part passes down into shelly limestone yielding bivalves such as *Astarte*, *Corbula* and *Perna* (Palmer, 1973).

Recent mapping (Sumbler, in press) shows that the succeeding Bladon Member is present in the railway cutting to the south-east of Ardley Fields Farm Quarry, around the point where the M40 motorway crosses the cutting (SP 550 259). Hereabouts, Barrow (1908, beds 7 and 8) recorded 1.52 m of 'grey shaly clay' representing the Fimbriata–Waltoni Bed (Sumbler, 1984); this is probably the 'clay with rootlets' recorded by Palmer (1973). It was succeeded by 0.76 m of 'grey, bedded limestone' comprising the Upper Epithyris Bed. Farther north-west, on the downthrow side of the fault, the Bladon Member may be absent having been cut out beneath the basal erosion surface of the Forest Marble Formation, although it seems likely that part at least of a 2.4 m-thick bed of 'dark blue and green clay' recorded here by Odling (1913), represents the Fimbriata–Waltoni Bed. The succeeding 3.1 m of blue clays with flaggy, cross-bedded limestone, belong to the Forest Marble Formation.

The Bathonian succession is completed by the Cornbrash Formation, up to about 3 m thick in total, which is present at the top of the cutting for 700 m at the south-eastern end of the GCR site, but has never been recorded.

Interpretation

A non-sequence separates the Aalenian Northampton Sand Formation from the Horsehay Sand Formation; it is prominently marked by channelling at the base of the latter. The controversy surrounding the age of the latter (the 'White Sands') is discussed elsewhere (see **Horsehay Quarry** GCR site report, this volume); it appears that they are largely Bathonian in age, being transitional between the non-marine Stamford Member (Rutland Formation) to the north-east and the fully marine Chipping Norton Limestone Formation to the south-west.

The Sharp's Hill Formation is known to have been deposited in mainly brackish-water to marine conditions, with intermittent episodes characterized by a marginal saltmarsh environment, attested to by rootlet beds, including that in the Ardley sequence. The abundance of carbonaceous plant-debris in this rootlet bed, and also in the Horsehay Sand Formation, signifies the proximity of the London Landmass. The pebbly bed corresponding with the base of the Charlbury Formation has the character of a transgressive lag deposit, whilst the overlying shell-packed clay and marl suggest the establishment of an oyster reef (cf. Palmer, 1979). The succeeding Taynton Limestone Formation indicates the onset of high-energy, shallow-water, current-dominated, carbonate shelf-sea conditions; less turbulent waters, perhaps located between carbonate sand-banks, are represented by the localized passage of the cross-bedded limestones into muddy limestones and marls. The clay, sandy clay and sand, which dominate the Rutland Formation in the Ardley district, were deposited in a nearshore region of shallow, brackish-water lagoons (Palmer, 1979); rootlet beds indicate the occasional development of saltmarsh conditions.

The pelletal, shell-detrital, micritic limestones that characterize much of the White Limestone Formation, were deposited in the shallow, restricted, low-energy waters of an extensive lagoon, which formed the proximal part of an extensive shelf-sea marginal to the London Landmass. The common occurrence of bioturbation in these limestones reflects the activity of a variety of burrowing bivalves, which are sometimes preserved in life position. The greater proportion of marly limestone and marl beds than is typical of the Shipton Member, together with the presence of sandy limestones at the base, indicates greater proximity to the source of terrigenous sediment. These features appear to be the first indication of a passage eastwards into a corresponding sequence dominated by clay and marl, as seen at **Stratton Audley** (see GCR site report, this volume). The three hardgrounds in the succession (Excavata, Ardleyensis and Bladonensis beds) indicate distinct pauses in sedimentation, associated with lithification of the substrate; they formed at the tops of shallowing-upwards, regressive units, at times when sea level fell to its lowest levels, as demonstrated by 'dinosaur trackways' recently uncovered in the working quarry to the south of the GCR site. The shrinkage cracks, 'birdseye' vugs and lamination of the Bladonensis Bed are interpreted as being indicative of deposition on a temporarily emergent algal mat (Palmer and Jenkyns, 1975).

The Bladon Member represents a transition between the carbonate regime of the underlying Ardley Member and the clays of the Forest Marble Formation; this reflects a change to dominantly terrigenous mud sedimentation in relatively quiet waters. The basal erosion surface of the Forest Marble Formation and its cross-bedded limestones indicate an episode of high-energy, shallow-water deposition, influenced by current activity.

The stratigraphically diagnostic ammonites *Tulites glabretus* (S.S. Buckman) and *T. subcontractus* (Morris and Lycett), collected from the basal bed of the White Limestone Formation (Shipton Member), indicate that the lower part of the member belongs to the Subcontractus Zone. The Excavata Bed that caps the member is thought to mark the top of the overlying Morrisi Zone throughout the Cotswolds (Torrens, 1980b); thus, the Shipton Member is inferred to span both the Subcontractus and Morrisi zones. The Ardley Member can, in turn, be referred to the Bremeri and Retrocostatum zones. *Procerites glabretus* and *P. imitator*, from close to the base of the Hampen Formation, are not sufficiently diagnostic for use as zonal indicators. However, correlation of rhythmic, depositional units (Wyatt, 1996a,b) suggests that the uppermost part of the Hampen Formation belongs to the Subcontractus Zone and the remainder to the Progracilis Zone and also suggests that the Arduennensis Bed (formerly the '*Nerinea eudesii* bed') at Ardley corresponds to the *Modiolus–Epithyris* Bed at **Woodeaton** (see GCR site report, this volume); according to Barker (1976), the gastropods of the former are *Eunerinea arduennensis* (Buvigner). The eponymous gastropods found at Ardley Cuttings and Quarries in the Excavata and Ardleyensis beds identify the latter as regionally persistent and correlatable horizons; the Bladonensis Bed is also a useful marker (see Barker, pp. 244–5, this volume). Using these and other indicators, satisfactory correlation can be made with the succession near Oxford (Wyatt, 1996a,b; see **Woodeaton** GCR site report, this volume) and beyond.

Conclusions

At the Ardley Cuttings and Quarries GCR site, a complete Bathonian succession, from the basal Horsehay Sand Formation up to the Cornbrash Formation, is present. It is therefore one of the key sites for this stage in southern England. The site is also the type locality of the Ardley Member of the White Limestone Formation. The succession is transitional between those of the Cotswolds (open marine environment) and the East Midlands (nearshore, brackish-water–freshwater environment); it thus has particular significance for regional correlation. The succession exhibits sedimentological features, such as hardgrounds, an emergent surface, rootlet beds and channel-fills, as well as regionally persistent, fossiliferous marker beds.

Aphanoptyxis excavata sp. nov. – eponymous gastropod of the Excavata Bed (White Limestone Formation)

Michael J. Barker

The index species of the Excavata Bed has never been formally published, but has been described and figured in an unpublished PhD thesis (Barker, 1976). The opportunity is taken here to remedy this situation, and also to illustrate the other gastropod indices of marker beds in the White Limestone – *Aphanoptyxis langrunensis* (d'Orbigny, 1850b), *A. ardleyensis* Arkell, 1931 and *A. bladonensis* Arkell, 1931, as well as *Eunerinea arduennensis* (Buvignier, 1852) (see Figure 4.10).

Derivation of name: Latin *ex* = out of, *cavus* = hollow; pertaining to the conspicuously concave ('hollowed out') whorls.

Type material: Holotype (Oxford University Museum (OUM) J29500) and paratypes (OUM J29501–J29523) from the Excavata Bed (Bed 5 of Barker, 1976; or Bed 4 of Sumbler, 1985) at the top of the Shipton Member, White Limestone Formation, Great Oolite Group (Middle Bathonian, uppermost Morrisi Zone) of Sturt Farm (or Whitehill North) Quarry (SP 271 109) (Barker, 1976; Sumbler, 1984, 1985).

Diagnosis: A small (maximum observed height 38 mm) nerineid gastropod with neither internal folds nor umbilicus. Whorls are wide and low (whorl width/height ratio 2.29), conspicuously concave and usually without ornament. Growth lirae commonly visible. The base is convex and ornamented with 6–8 prominent spiral cords, beaded when crossed by growth lirae. The junction of the shell side and base is angular and carinate. Suture on raised carinae of which the adapical carina (i.e. juxtasutural selenizone) is more prominent, wider and bears crescentic lunulae. Where preserved, the juxtasutural slit is deep (up to one sixth of whorl). The aperture is quadrate with columellar-parietal junction rounded; small amounts of inductura on columellar lip. The siphonal canal is short.

Biometric data (*based on specimens from the type locality*): Apical angle: mean = 24.8°, SD = 3.3°, n = 27; whorl width/height ratios: mean = 2.29, SD = 0.22, n = 80; reduced major axis: height = 0.456, width = 0.01, CC = 0.881.

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Remarks: *A. excavata* has the largest mean apical angle of all known species of *Aphanoptyxis*. The presence of spiral ornament on the base, smaller size and angulated periphery readily serve to distinguish it from *A. bladonensis* with which there is otherwise some morphological overlap. *A. excavata* is somewhat variable depending upon the development of the sutural carinae, spiral ornament and growth lines that affect the degree of whorl concavity and ornament. It is the oldest species of a short evolutionary lineage (*A. excavata–A. langrunensis–A. ardleyensis*) that exhibits systematic changes in morphology through the White Limestone Formation and which provides reliable local biostratigraphical indices (Barker, 1976; Torrens, 1980c; Barker, 1994).

Distribution: *A. excavata* is the most geographically widespread of the *Aphanoptyxis* species in the White Limestone Formation. It gives its name to and is noticeably concentrated in considerable abundance in the Excavata Bed at the top of the Shipton Member.

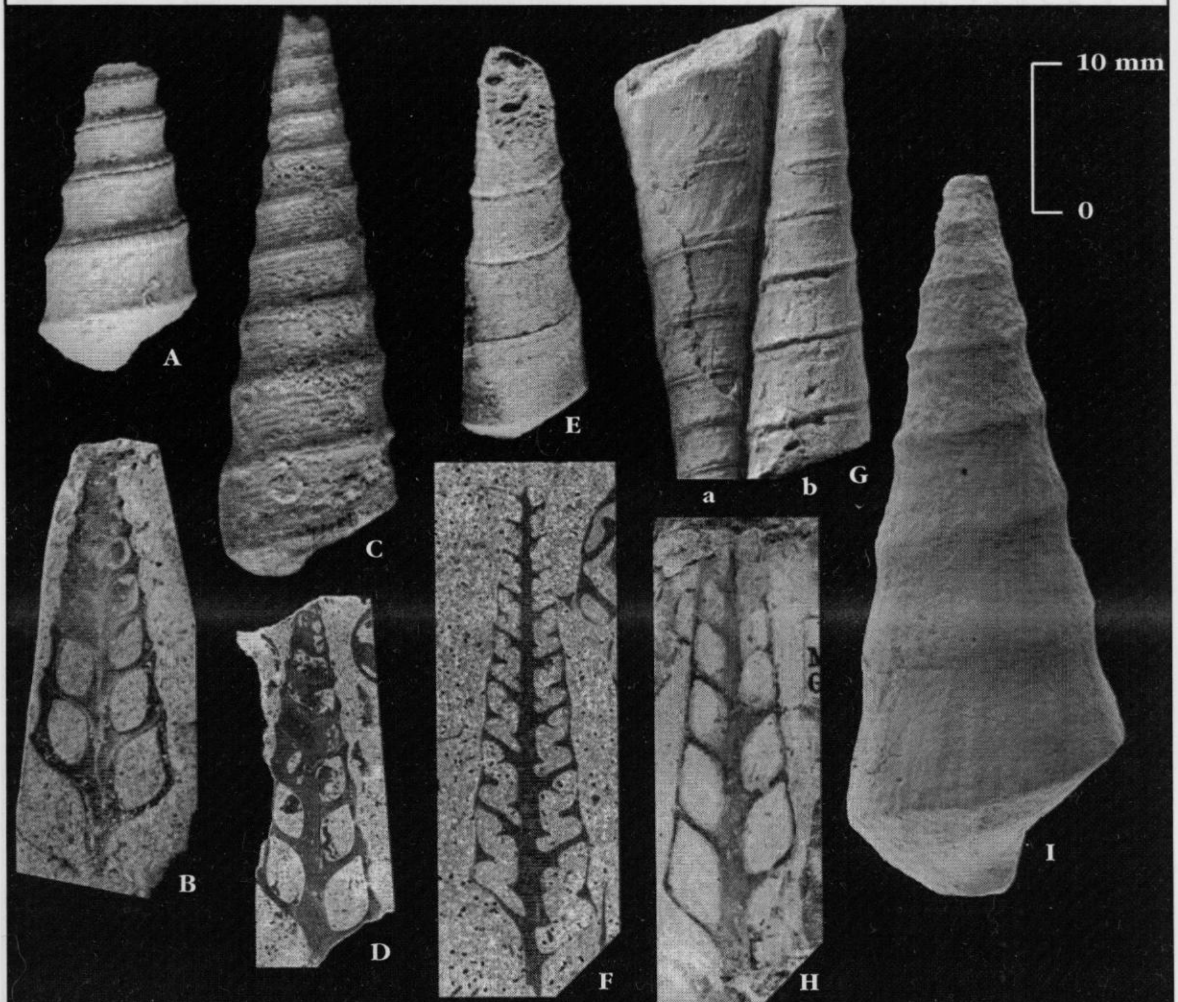


Figure 4.10 Stratigraphically useful nerineid gastropod species. (A,B) *Aphanoptyxis excavata* sp. nov.; (A) OUM J29500 holotype; (B) OUM J29501 paratype; White Limestone Formation, Shipton Member, Excavata Bed; Sturt Farm (or Whitehill North) Quarry, Burford, Oxfordshire. (C,D) *Aphanoptyxis langrunensis* (d'Orbigny); (C) UP 77/50, Hydrequent, Pas de Calais, France; (D) UP EC/43; White Limestone Formation, Ardley Member, Bed 14 of Barker (1976); Eton College Quarry, Asthall, Oxfordshire. (E,F) *Eunerinea arduennensis* (Buvignier); (E) UP Sl.H.Ox./5/296; (F) UP Sl.H.Ox/5/23; White Limestone Formation, Ardley Member, Bed 5 of Barker (1976); Slape Hill, Wooton, Oxfordshire. (G,H) *Aphanoptyxis ardleyensis* Arkell; (Ga) OUM J829 lectotype; (Gb) OUM J828 paratype; (H) OUM J830 paratype; White Limestone Formation, Ardley Member, Ardleyensis Bed; Ardley-Fritwell railway cutting, Ardley, Oxfordshire. (I) *Aphanoptyxis bladonensis* Arkell; OUM J840 holotype; White Limestone Formation, Ardley Member, Bladonensis Bed; Orchard Quarry, Bladon, Oxfordshire. (OUM = Oxford University Museum UP = University of Portsmouth.)

STRATTON AUDLEY, OXFORDSHIRE (SP 601 254, SP 602 251)

R.J. Wyatt and M.G. Sumbler

Introduction

The quarry that constitutes the GCR site known as 'Stratton Audley', is located about 1 km south-west of the village of Stratton Audley, near Bicester, in Oxfordshire (Figure 4.11). Though partly flooded and largely infilled by tipping, it still exposes an Upper Bathonian succession comprising, in ascending order, the White Limestone and Forest Marble formations, and the lower part of the Cornbrash Formation. Middle Bathonian beds, assigned to the Rutland Formation, have also been proved in boreholes drilled from the floor of one of the quarries (Figure 4.12). The main significance of the section recorded here is the evidence of transition between open marine depositional environments to the south-west and restricted, nearshore, brackish-water, lagoonal and salt-marsh environments adjacent to the London Landmass to the east. Of special interest also are hardground beds that display sedimentary structures indicative of emergent, supratidal depositional conditions. Descriptions of the section have been recorded by Palmer (1973, 1979) and Barker (1976). The following account is based mainly on Palmer (1973), although the stratigraphical nomenclature has been modified.

Description

Only the upper two major units (Ardley and Bladon members) of the White Limestone Formation are present in the section described by Palmer (1973). However, two beds of black sand proved in borings below Palmer's (1973) basal limestone bed (numbered 14) are here considered to be decalcified sandy limestone equivalent to the 'Roach Bed' at the base of the Ardley Member and to overlie the Excavata Bed (cf. Sumbler, 1984; see **Ardley Cuttings and Quarries** GCR site report, this volume). The latter is thus the sole representative of the Shipton Member here. Barker (1976) also identified this limestone as the Excavata Bed; the *c.* 3 m of marl and clay proved in the borings below it are herein assigned to the Rutland Formation (cf. Palmer, 1979).

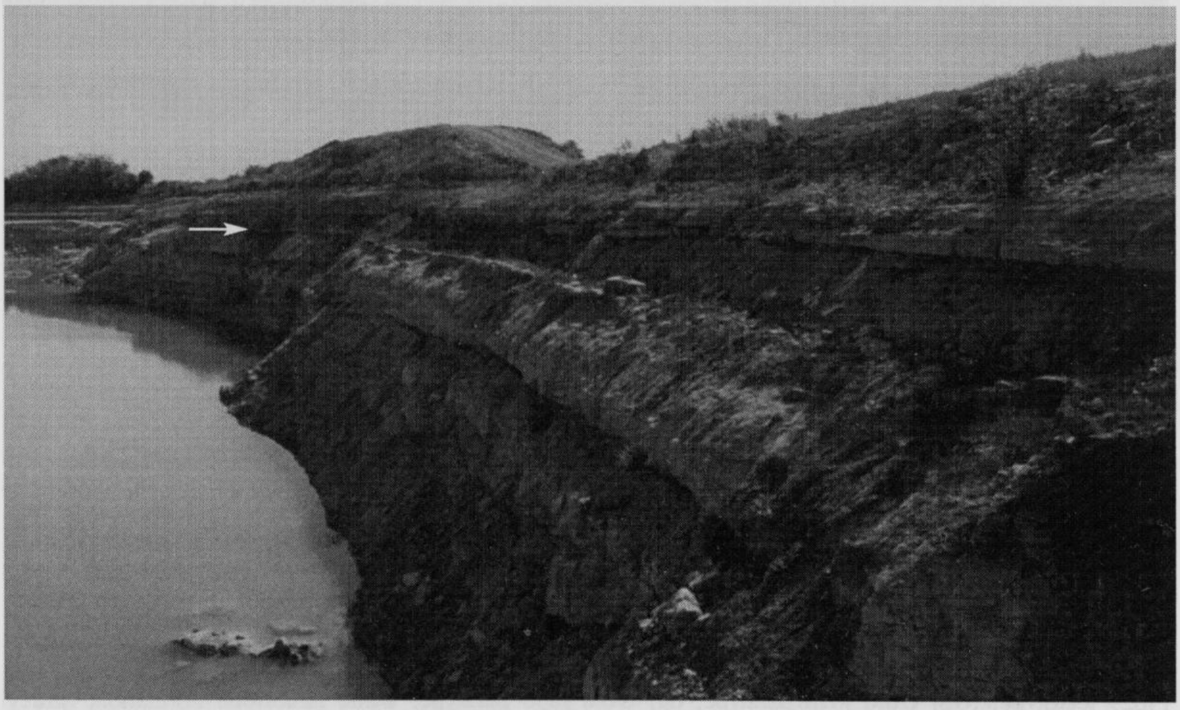


Figure 4.11 The southern face of the partly flooded quarry at Stratton Audley showing the White Limestone Formation overlain by the Forest Marble Formation. The formational boundary is marked by the white arrow. (Photo: M.G. Sumbler.)

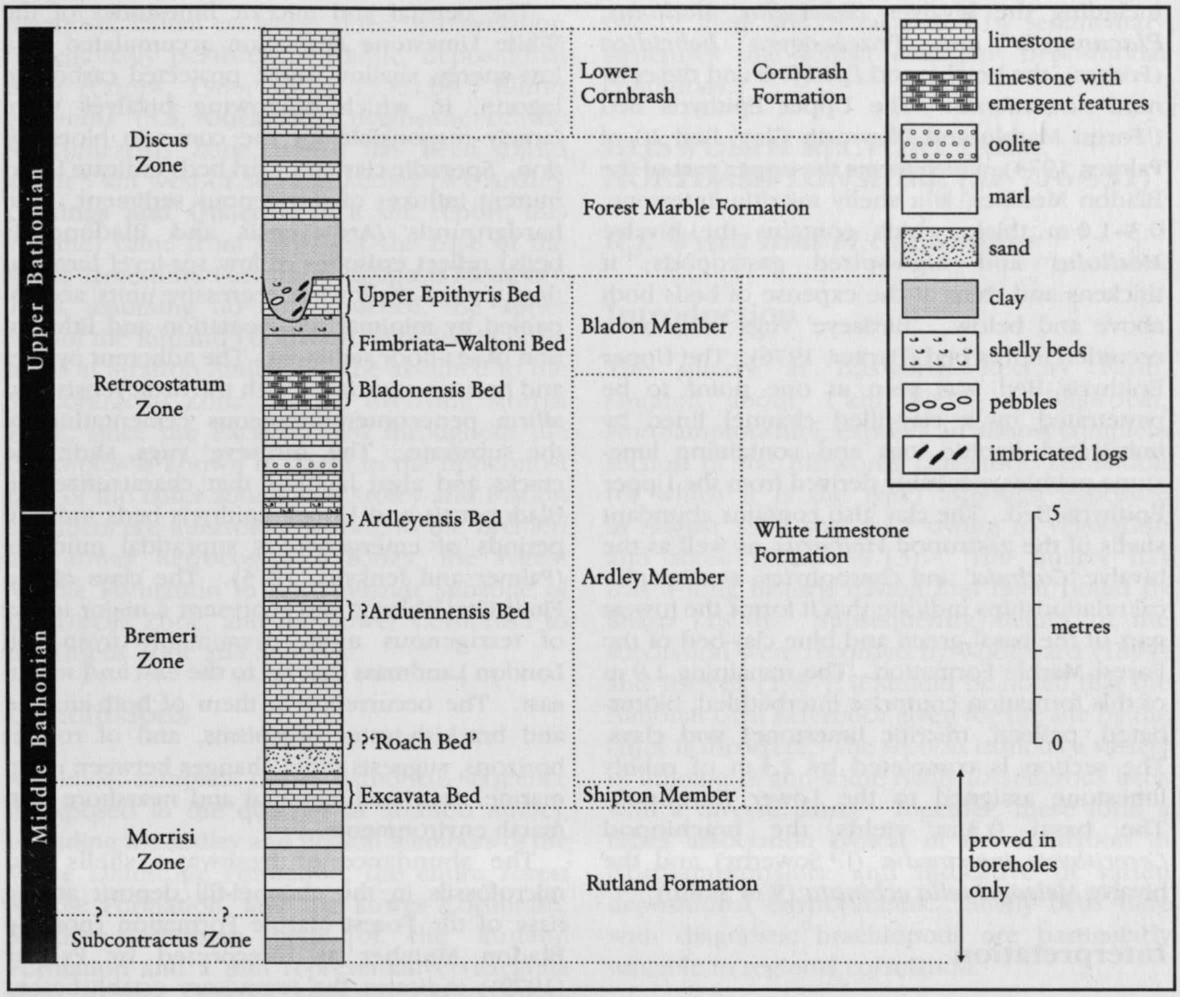


Figure 4.12 Graphic section of the Bathonian succession at the Stratton Audley GCR site.

The *c.* 4.6 m of beds above the 'Roach Bed' comprise finely detrital and pelletal, micritic, commonly bioturbated limestones, which contain the gastropods *Cossmannea bathonica* (Rigaux and Sauvage) and *Eunerinea arduennensis* (Buvignier), the bivalve *Isognomon* and the echinoid *Clypeus*. These limestones are capped by a bed of burrowed limestone (White Limestone Formation Bed 6 of Palmer, 1973; the Ardleyensis Bed) that contains the diagnostic gastropod *Aphanoptyxis ardleyensis* Arkell. In places, the upper surface of this bed is developed as a bored hardground with adherent oysters (*Nanogyra*). The overlying limestones include a clayey oolite yielding *Anisocardia*, *Astarte* and high-spired gastropods, and a thin marl with current-sorted bivalves at its top, and rootlets. Above a *c.* 1 m-thick shelly, pelletal limestone, the top of the Ardley Member is marked by the Bladonensis Bed (White Limestone Formation Bed 1 of Palmer, 1973), a micritic limestone the lower part of which is clayey and the top of which is capped by a hardground. The shelly bed yields the diagnostic gastropod *Aphanoptyxis bladonensis* Arkell, the bivalves *Bakevellia* and *Protocardia*?, fragments of the coral *Isastrea*, and lignite. The Bladonensis Bed displays shrinkage cracks and algal laminae, and is penetrated by rootlets. The total thickness of the Ardley Member is about 8 m.

The lower sediments of the succeeding Bladon Member ('Forest Marble and Blisworth Clay' beds 11 and 12 of Palmer, 1973), together known as the 'Fimbriata–Waltoni Bed', comprise 0.9 m of brown clay, overlain by even-bedded green and grey clay, 0.10–0.45 m thick, with rootlets in the lower part and shells above, including the bivalves *Bakevellia*, *Modiolus*, *Placunopsis* and *Praeexogyra hebridica* (Forbes), the brachiopod *Epithyris* and the echinoid *Acrosalenia*. The Upper Epithyris Bed ('Forest Marble and Blisworth Clay' Bed 10 of Palmer, 1973), which forms the upper part of the Bladon Member, is a shelly micritic limestone, 0.3–1.0 m thick, which contains the bivalve *Modiolus* and high-spired gastropods; it thickens and thins at the expense of beds both above and below. 'Birdseye' vugs have been recorded in this bed (Barker, 1976). The Upper Epithyris Bed was seen at one point to be penetrated by a clay-filled channel lined by imbricated lignitic logs and containing limestone pebbles, probably derived from the Upper Epithyris Bed. The clay also contains abundant shells of the gastropod *Viviparus*, as well as the bivalve '*Corbula*' and charophytes; stratigraphical relationships indicate that it forms the lowest part of the basal green and blue clay-bed of the Forest Marble Formation. The remaining 1.9 m of this formation comprise interbedded, bioturbated, pelletal, micritic limestones and clays. The section is completed by 2.3 m of rubbly limestone assigned to the Lower Cornbrash. The basal 0.3 m yields the brachiopod *Cererithyris intermedia* (J. Sowerby) and the bivalve *Meleagrinella echinata* (Wm Smith).

Interpretation

Marls and clays beneath the White Limestone Formation, proved in boreholes at Stratton Audley, were formerly assigned to the Hampen Formation but are now more appropriately classified as Rutland Formation (Horton *et al.*, 1995). They were probably deposited in a nearshore, brackish-water, lagoonal environment (Palmer, 1979). They correspond to the lower and greater part of the Shipton Member of the White Limestone Formation as exposed at **Ardley Cuttings and Quarries** (see GCR site report, this volume), about 6 km to the WNW, i.e. the lower part of the Shipton Member passes laterally (shorewards) in this area into the upper part of the Rutland Formation. An implication of this is the likely equivalence of the Excavata Bed (uppermost Shipton Member) in Oxfordshire and the Sharpi Beds (lowermost White Limestone Formation) in Northamptonshire, both of which are considered to form part of the same regionally correlatable rhythmic, depositional unit (Cripps, 1986).

The detrital and micritic limestones of the White Limestone Formation accumulated in a low-energy, shallow-water, protected carbonate lagoon, in which burrowing bivalves were largely responsible for the common bioturbation. Sporadic clay and marl beds indicate intermittent influxes of terrigenous sediment. The hardgrounds (Ardleyensis and Bladonensis beds) reflect episodes of low sea-level terminating upward-shallowing, regressive units, accompanied by minimal sedimentation and lithification of sea-floor sediment. The adherent oysters and borings associated with the Ardleyensis Bed affirm penecontemporaneous cementation of the substrate. The 'birdseye' vugs, shrinkage cracks and algal laminae that characterize the Bladonensis and Upper Epithyris beds indicate periods of emergence as supratidal mudflats (Palmer and Jenkyns, 1975). The clays of the Fimbriata–Waltoni Bed represent a major influx of terrigenous mud, presumably from the London Landmass that lay to the east and south-east. The occurrence in them of both marine and brackish-water organisms, and of rootlet horizons, suggests rapid changes between open marine, restricted lagoonal and nearshore salt-marsh environments.

The abundance of freshwater shells and microfossils in the channel-fill deposit at the base of the Forest Marble Formation (not the Bladon Member as interpreted by Palmer (1979)) indicates the temporary establishment of a freshwater shoreline lagoon fed by streams draining the London Landmass. Such streams would have transported the abundance of plant debris found in the channel-fill. The limestone pebbles in the channel suggest the occasional influence of stronger currents, perhaps induced by storms. The interbedded micritic limestones and clays that form the bulk of the Forest Marble Formation serve as witness to changing patterns of quiet-water lagoonal environments, which were at times characterized by terrigenous mud deposition, and at other times by carbonate mud sedimentation. This low-energy, lagoonal region marginal to the London Landmass was transitional to the higher-energy, open marine area to the south-west, where shell-fragmental, ooidal limestones form a substantial part of the formation.

No fossil of biostratigraphical significance has been found in the quarries at Stratton Audley and so dating of the succession must rely on comparison with other sections yielding diagnostic faunal evidence, aided by correlation of regionally persistent rhythmic, depositional units (Cripps, 1986; Wyatt, 1996a,b). *Tulites glabretus* (S.S. Buckman), diagnostic of the Subcontractus Zone, which has been found about 5 km west of Stratton Audley (see **Ardley Cuttings and Quarries** GCR site report, this volume) came from very near the base of the White Limestone Formation (Shipton Member). Thus, assuming no non-sequence, the upper part of the Rutland Formation recorded in boreholes at Stratton Audley may be assigned to the Subcontractus Zone and the overlying Morrisi Zone, since the Excavata Bed throughout the Cotswolds is known to occur in the uppermost part of the latter zone. The Ardley and Bladon members are inferred to belong to the Bremeri and lower Retrocostatum zones, the Forest Marble Formation to the Hollandi Subzone of the Discus Zone, and the Lower Cornbrash to the Discus Zone and Subzone.

Conclusions

An almost complete Upper Bathonian sequence is exposed in the quarries at Stratton Audley, including the Ardley and Bladon members of the White Limestone Formation, the entire Forest Marble Formation, and the Lower Cornbrash. Middle Bathonian beds of the Rutland Formation and a thin representative (Excavata Bed) of the Shipton Member (basal White Limestone Formation) have also been proved in boreholes to lie beneath the exposed section. The section is of special significance in the study of lithological and faunal facies changes that occur between open marine depositional environments to the south-west, and restricted brackish-water and intermittent freshwater environments to the east, marginal to the London Landmass. Thus, the fine-grained micritic limestones of the Forest Marble Formation, deposited in quiet-water lagoons here, contrast with the more typical coarse-grained ooidal and shell-fragmental limestones of open marine environments to the west. Also, beds equivalent to the micritic limestones of the White Limestone Formation (Shipton Member) to the west are here mainly represented in a clay–marl facies transitional to the freshwater deposits of the Rutland Formation to the east. Hardground beds in the White Limestone Formation indicate temporary breaks in sedimentation, accompanied by lithification of the substrate; two of them are characterized by sedimentary structures that reflect emergent depositional conditions.

BLISWORTH RECTORY FARM, NORTHAMPTONSHIRE (SP 716 531)

R.J. Wyatt and M.G. Sumbler

Introduction

The quarry at Blisworth Rectory Farm, situated about 1 km WSW of Blisworth, Northamptonshire, exposes an almost complete section of the Blisworth Limestone Formation (of which it is the type) although exposure in August 1997 was poor owing to vegetation and scree (Figure 4.13). The quarry has had a long history, having first been noted by Sharp (1870). Subsequently, details of the succession were recorded by Woodward (1894) and Torrens (1967); it should be noted that the National Grid Reference given for the site by the latter is incorrect. The section exhibits a variety of lithologies and some richly fossiliferous beds with a diverse fauna. Together, these form a facies association typical of the formation in Northamptonshire and indicative of varied depositional environments. Shelly beds here with diagnostic brachiopods are particularly valuable in regional correlation.

Description

The following description of the section is based on Torrens (1967).

	Thickness (m)
Blisworth Limestone Formation	
19: Shelly, platy limestone	0.15
18: Soft marl with *Praeexogyra hebridica* (Forbes) lumachelle near top	0.53
17: Shelly, platy limestone	0.15
16: Ooidal marl	0.08–0.15
15: Shelly, platy limestone	0.10
14: Limestone	0.08
13: Brown marl with *P. hebridica*	0.05
12: Prominent, white to cream, rubbly limestone packed with fossils including common, large epithyrid brachiopods, *Stiphrothyris*, *Isastrea limitata* (Lamouroux), common *Calamophyllia radiata* (Lamouroux), *Plagiostoma cardiiformis* (J. Sowerby), *Modiolus imbricatus* J. Sowerby, pectinids, nautiloids (*Procymatoceras*)	0.76

Figure 4.13 Poorly exposed Blisworth Limestone Formation at the Blisworth Rectory Farm GCR site. (Photo: M.G. Sumbler.)

		Thickness (m)
11:	Marl	0.10–0.13
10:	Limestone with abundant nerineid gastropods (*Cossmannea*), *Pinna*	0.30
9:	Marl	0.10–0.13
8:	*Digonoides Beds*: Detrital, ooidal, graded platy limestones showing small-scale cross-bedding and marl pellets, grading down through softer and more marly limestone to cream marls at base; *Digonella digonoides* (S.S. Buckman) common but sporadic; *Trigonia*, and *Strophodus* tooth at base	1.52
7:	Prominent limestone with uneven base; *P. hebridica*	0.18–0.23
6:	Soft, sandy-weathering limestone with occasional *Praeexogyra* and abundant bivalve casts; *Anisocardia*, *Pholadomya*, *Pleuromya*	0.46
5:	Thin, impersistent, ferruginous marl-seam	0–0.05
4:	Massive limestone forming ledge in western part of face but wedging out into softer limestone to east; *Clypeus muelleri* Wright	up to 0.71
3:	Soft, sandy-weathering, yellow limestone	0.30
2:	Gap (strata obscured)	1.22
1:	*Sharpi Beds*: Limestone, clayey, with much detritus; abundant *Kallirhynchia sharpi* Muir-Wood	0.15

Interpretation

The Blisworth Limestone Formation at Blisworth Rectory Farm (Figure 4.14) and areas to the north-east is less pure than the coeval White Limestone Formation of Oxfordshire and Gloucestershire, for it contains a greater proportion of fine terrigenous sediment. This reflects greater proximity to the London Landmass, the probable source of this sediment, in Bathonian times. The mainly micritic and finely shell-detrital limestones of the formation were deposited in a shallow, protected, low-energy, carbonate lagoon into which intermittent pulses of dominantly muddy sediment were introduced to form the sporadic beds of marl. The very fossiliferous beds in the succession, characterized by a variety of both epifaunal and infaunal organisms, indicate relatively quiet waters and a stable substrate. The same conditions probably applied when reefs of *Praeexogyra hebridica* became established; they are typically associated with marls and muddy limestones. The ooidal, cross-bedded limestone in the Digonoides Beds

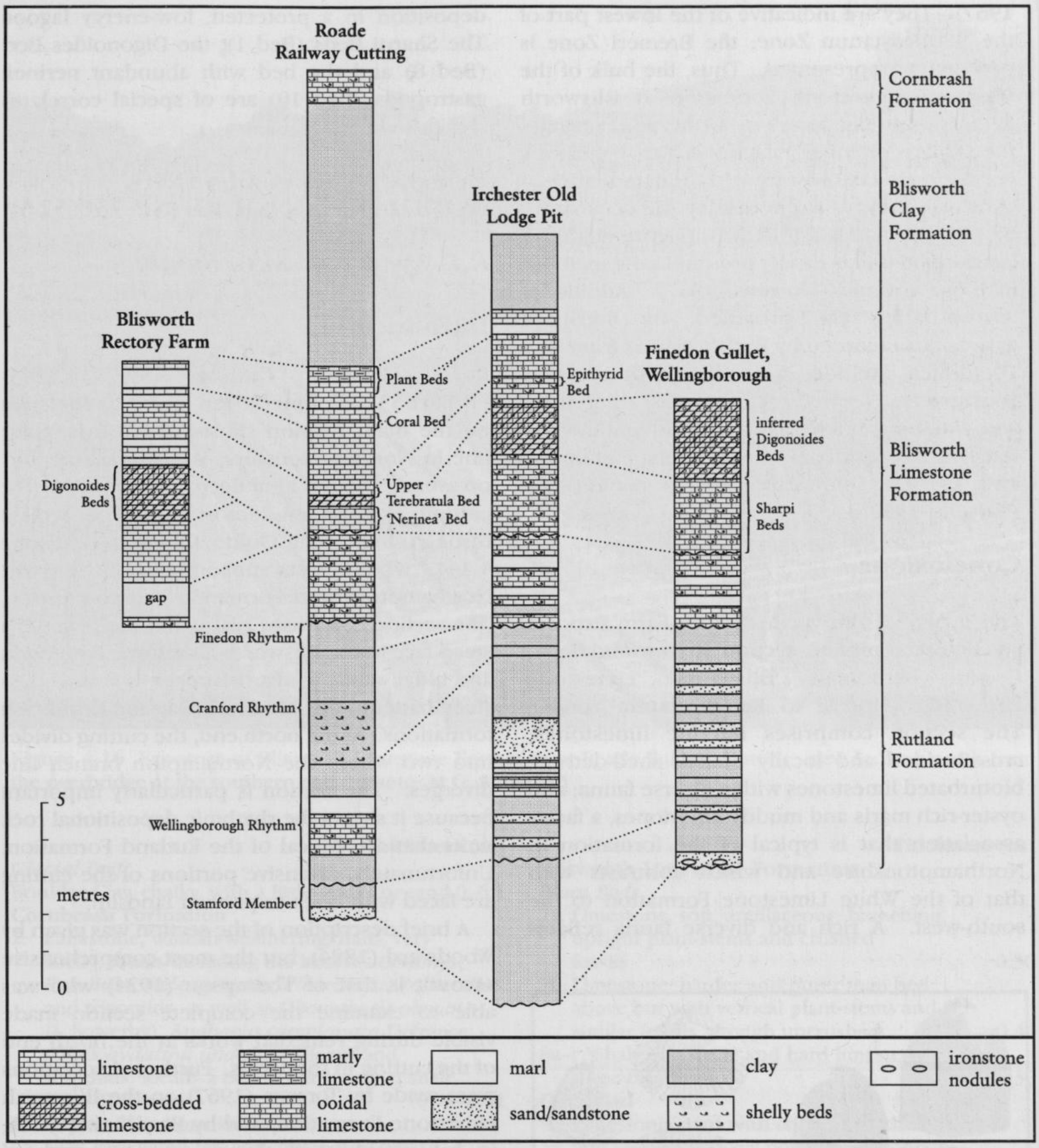


Figure 4.14 Correlation of GCR sites between Blisworth and Wellingborough (Blisworth Rectory Farm, **Roade Railway Cutting**, **Irchester Old Lodge Pit** and **Finedon Gullet**).

suggests a transient phase of more turbulent current-dominated waters.

There are few well-authenticated and localized ammonites from the Blisworth Limestone Formation of the East Midlands and refined dating is difficult. None are known from the Sharpi Beds at the base of the formation, but these beds are believed to correspond to the Excavata Bed of the Oxford–Bicester area, which belongs to the Morrisi Zone (see **Ardley Cuttings and Quarries** GCR site report, this volume). From sections a little to the east of Blisworth Rectory Farm and at Kingsthorpe in Northampton, specimens of *Procerites quercinus* (Terquem and Jourdy) have been collected from a level close above the top of the Sharpi Beds (Torrens, 1967). They are indicative of the lowest part of the Retrocostatum Zone; the Bremeri Zone is probably unrepresented. Thus, the bulk of the Blisworth Limestone Formation at Blisworth Rectory Farm is equivalent to the upper part of the Ardley Member of the White Limestone Formation in Oxfordshire and Gloucestershire, a conclusion that is supported by the occurrence of *D. digonoides* in Bed 8 (Figure 4.15), a brachiopod that is locally present in the member in those counties (Torrens, 1967). Additional corroboration is provided by nerineid gastropods recorded by Barker (1976) from Bed 10, which include *Eunerinea arduennensis* (Buvignier), *Nerinella* cf. *acicula* (d'Archaic) and *Bactroptyxis implicata* (d'Orbigny). The last two are restricted to the Upper Bathonian, and are also indicative of this zonal level (Torrens, 1980b).

Conclusions

The quarry at Blisworth Rectory Farm exposes an almost complete section in the Middle to Upper Bathonian Blisworth Limestone Formation (Morrisi to Retrocostatum zones). The section comprises micritic limestones; cross-bedded and locally ooidal, shell-detrital, bioturbated limestones with a diverse fauna; and oyster-rich marls and muddy limestones, a facies association that is typical of the formation in Northamptonshire and which contrasts with that of the White Limestone Formation to the south-west. A rich and diverse fauna reflects deposition in a protected, low-energy lagoon. The Sharpi Beds (Bed 1), the Digonoides Beds (Bed 8) and the bed with abundant nerineid gastropods (Bed 10) are of special correlative significance.

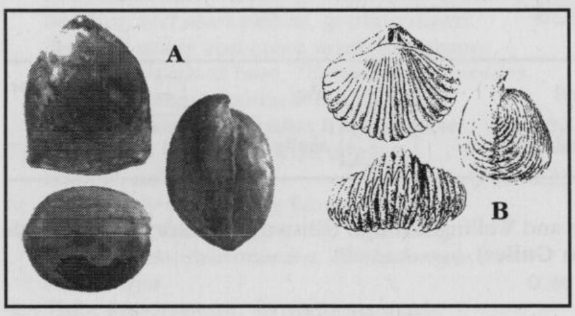


Figure 4.15 The brachiopods (A) *Digonella digonoides* (S.S. Buckman), and (B) *Kallirhynchia sharpi* Muir-Wood which give their names to marker horizons in the Blisworth Limestone Formation. ((B) is reproduced from Muir-Wood (1938, fig. 15, 2A–C) courtesy of The Geologists' Association.) All natural size.

ROADE RAILWAY CUTTING, NORTHAMPTONSHIRE (SP 750 525)

R.J. Wyatt and M.G. Sumbler

Introduction

Roade Railway Cutting (SP 7534 5145–SP 7451 5327), some 20 km north of Bletchley on the main London (Euston) to Birmingham line in Northamptonshire, is 1700 m long and, on average, about 20 m deep (Figure 4.16). The cutting exposes an almost complete section through the Great Oolite Group (see Figure 4.14), which rests unconformably on the Northampton Sand Formation and Lias Group. The section comprises two parts: the lower is a steep face in the Blisworth Limestone Formation and older units, whilst the upper is a much less steep batter in the Blisworth Clay and Cornbrash formations. At the north end, the cutting divides into two where the Northampton branch line diverges. The section is particularly important because it shows the rhythmic depositional rock units that are typical of the Rutland Formation. Unfortunately, extensive portions of the cutting are faced with brick to prevent landslip.

A brief description of the section was given by Woodward (1894), but the most comprehensive account is that of Thompson (1924) who was able to examine the complete section made visible during remedial works at the north end of the cutting in the 1890s. Further observations were made by Torrens (1967) on the Blisworth Limestone Formation, and by Bradshaw (1978), in his unpublished thesis, on such parts of the Rutland Formation as were visible, enabling him to demonstrate and identify rhythmic units.

Description

The following description is a composite, abbreviated version of Thompson's (1924) detailed log, and includes observations by Bradshaw (1978) and Torrens (1967); bed numbers are those of Thompson.

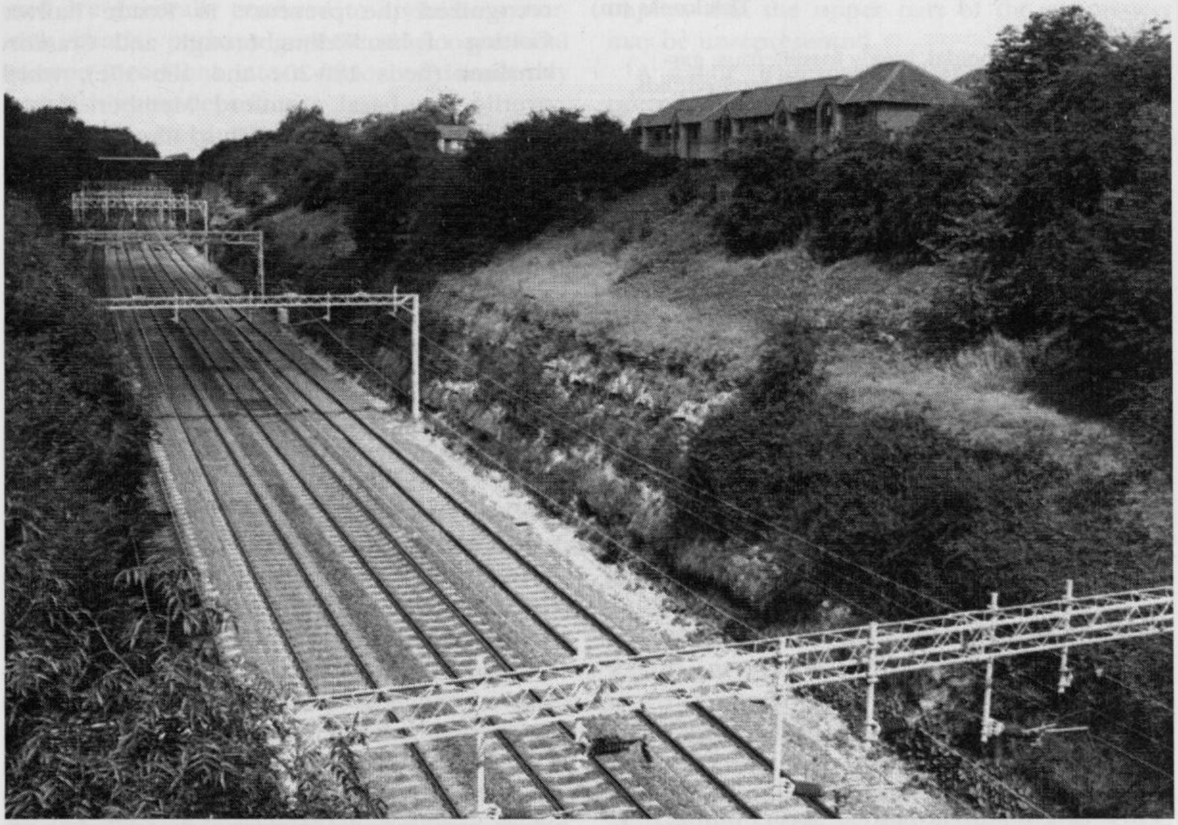


Figure 4.16 Exposure of Blisworth Limestone Formation at Roade Railway Cutting; view looking north from the overbridge at the southern end. (Photo: M.G. Sumbler.)

	Thickness (m)
Glacial Drift	
Boulder Clay, chalky, with a little gravel or sand	0–6.1
Cornbrash Formation	
2: Limestone, whitish-weathering, hard, very shelly; fossils including the bivalves *Chlamys*, *Entolium*, *Meleagrinella*, *Pleuromya*, *Rollierella* and trigoniids, as well as *Obovothyris obovata* (J. Sowerby), *Anabacia complanata* Defrance; *Palaeohydatina undulata* (Bean) and serpulids; locally a bed of hard, brown shale (Bed 3) at base	0.74–0.91
Blisworth Clay Formation	
4a: Clay, variegated red and green; thin bed of hard shale *c.* 0.15 m below top; much selenite; *Placunopsis socialis* Morris and Lycett, *Praeexogyra hebridica* (Forbes); purple, oyster-rich clay layer at base (4b)	0.61
4c: Clay, green with shelly layers	0.86
5a: Clay, purple-mottled, with carbonaceous wood-fragments and selenite crystals; layer of red ironstone nodules about middle	2.44
5b: Clay, red, yellow and green variegated, with rootlets; irregular layer of ironstone at base	3.05
6a: Clay, bluish and ferruginous, with carbonaceous debris; 0.15 m oyster-shell debris bed (6b) at base	0.30–0.46

	Thickness (m)
Blisworth Limestone Formation	
Plant Beds	
7a: Limestone, soft, argillaceous; branching, upright plant-stems and crushed fossils	0.30
7b: Limestone, harder and purer than bed above but with vertical plant-stems and similar fossils, though uncrushed	0.46
8a–c: Shaly limestone and hard limestone; three thin beds	0.30
Coral Bed	
9a: Limestone, hard with coral in patches and very extensively bored by *Lithophaga*; *Thamnasteria* probably dominant coral; passing down into a 0.23 m-thick basal marl bed (9b)	0.61
10: Limestone, hard, flaggy, ooidal, unfossiliferous	1.47
Upper Terebratula Bed	
11: Limestone, ooidal, fossiliferous, with common bivalves; also *Clypeus* and common ?epithyrid brachiopods identified by S.S. Buckman as *Kutchithyris* aff. *circumdata* Deslongchamps	0.30
12: Limestone, cross-bedded, shell-detrital; variable thickness	0.23

	Thickness (m)
'Nerinea' Bed	
13: Limestone, ooidal, highly fossiliferous; gastropods, mainly in middle; large terebratulids, *Epithyris*? and *Burmirhynchia*?; also corals (*Chomatoseris*)	0.56
14: Limestone, darker, bluish, more argillaceous than bed above	0.15
Sharpi Beds	
15a–b: Limestone, hard, blue-hearted, with *Kallirhynchia sharpi* Muir-Wood and terebratulids, *Pholadomya* and other bivalves	0.53
15c: Limestone, argillaceous, with abundant *K. sharpi*, terebratulids and *Pholadomya*; nautiloid and *Acrosalenia* also recorded	1.98
Rutland Formation	
16a: Mudstone, blue, shaly, sandy, with abundant rootlets	0.46–0.91
16b–c: Clay, dark-green, with abundant rootlets; darker green in lower 0.61 m with *Corbulomima*	1.47
16d: Clay, pale-green, calcareous, very fossilferous; *Corbulomima*, *Eomiodon angulatus* (Morris and Lycett), *Modiolus imbricatus* J. Sowerby, *Cuspidaria ibbetsoni* (Morris), *Placunopsis socialis* Morris and Lycett	1.60
17e: Clay, dark-green, laminated, very fossiliferous; *P. socialis* dominant	0.15
18f: Clay, dark-blue, with rootlets, ferruginous near base; passing down into	0.91
19a: Marl, shelly, rich in oysters	0.53
19b-c: Limestone, blue-hearted, shelly; *Astarte*, *Protocardia*, *Pholadomya*, *P. socialis*	1.07
20d: Limestone, blue, very hard, poorly fossiliferous	0.46
20e: Limestone, argillaceous, ferruginous in part; becoming shelly mudstone towards base; layer of oysters at base	0.41
Stamford Member	
21: Clay, purple; rootlets and plant debris	0.15–1.04
22: Sand, white; rootlets; irregular base	0.30
Northampton Sand Formation below	

Interpretation

The Rutland Formation, which unconformably overlies the uppermost sands ('Variable Beds') of the Northampton Sand Formation, is characterized by a succession of rhythmic depositional units, each of which is ideally capped by a rootlet bed (Bradshaw, 1978). They are regarded as shallowing-upwards, regressive units deposited in a shallow lagoon, marginal to the London Landmass, in which deposition of muddy sediment was dominant. The clays of each unit become increasingly organic and increasingly charged with carbonaceous plant-debris upwards; the final rootlet bed denotes exposure of the substrate as a nearshore saltmarsh environment became established. Bradshaw (1978) recognized the presence in Roade Railway Cutting of his Wellingborough and Cranford rhythms (beds 18f–20e and 16b–17e), which overlie the basal Stamford Member rhythm (beds 21–22). An upper 'Third Rhythm' may be regarded as his Finedon Rhythm (Bed 16a). The basal sands of the Stamford Member are the local representative of an extensive deposit, known as the 'White Sands' (now Horsehay Sand Formation; see **Horsehay Quarry** GCR site report, this volume), which extends westwards to near Banbury and, in the subcrop, perhaps as far south as Wallingford (Fenton *et al.*, 1994). The fauna of the Rutland Formation, dominated by bivalves, indicates largely brackish-water depositional conditions.

The general character of the Blisworth Limestone Formation in Roade Railway Cutting is comparable to that of the quarry at **Blisworth Rectory Farm** (see GCR site report, this volume), about 3 km to the west (see Figure 4.14). The lithology and fauna of the formation represent a change to mainly carbonate mud–sand sedimentation in a fully marine environment. A number of very fossiliferous beds reflect flourishing, mainly epifaunal associations in which brachiopods, bivalves and corals abound, suggesting a relatively stable substrate. The Sharpi Beds at the base of the formation, with their diagnostic brachiopod, constitute a regionally correlatable unit (Torrens, 1967).

The Digonoides Beds, present at **Blisworth Rectory Farm** (see GCR site report, this volume) are absent in Roade Railway Cutting; the occurrence of a '*Nerinea* Bed' (cf. **Blisworth Rectory Farm**, Bed 10) close above the Sharpi Beds suggests an erosional interval between the two, accounting for the absence of the Digonoides Beds. Other stratigraphical breaks in the succession are indicated by the bored hardground at the top of the 'Coral Bed' and by the rootleted 'Plant Beds' that cap the formation.

The Blisworth Clay Formation represents a return to dominantly mud deposition in the low-energy, protected waters of a nearshore lagoon. The occurrence of carbonaceous plant-debris suggests proximity to the London Landmass. The bright, variegated colours of the clays result from varying states of oxidation of iron compounds; ferruginous layers and bands of ironstone nodules indicate a considerable input of iron-rich compounds. Rootlet beds in the lower part of the formation indicate the establishment of saltmarsh conditions. Fossils are uncommon and are generally confined to sporadic oyster-rich bands, perhaps representing occasional marine incursions into a region of dominantly brackish-water deposition.

Only the basal 1 m or so of the Cornbrash Formation is preserved beneath glacial boulder clay; it was deposited in an extensive shallow, carbonate shelf-sea, probably subject to only gentle currents.

Although the Rutland Formation of the East Midlands yields no diagnostic fossils, correlation with corresponding strata of the carbonate shelf succession farther west in Oxfordshire indicates that it ranges in age from the Lower Bathonian Zigzag Zone to the Middle Bathonian Subcontractus Zone (Wyatt, 1996a,b). However, the absence of the Ketton, Clipsham and Casterton rhythms (see **Ketton Quarry** GCR site report, this volume) means that the Tenuicostatum Zone is unrepresented. The Sharpi Beds at the base of the Blisworth Limestone Formation in Northamptonshire are considered to be the lateral equivalent of the Excavata Bed, which caps the Shipton Member of the White Limestone Formation in Oxfordshire and which belongs to the Morrisi Zone. Cripps' (1986) record of the gastropod ?*Aphanoptyxis excavata* Barker near the top of the Sharpi Beds in the cutting supports this correlation. Since, at Roade Railway Cutting, the Sharpi Beds rest directly on beds of the Rutland Formation, which are assigned to the Finedon Rhythm, there must be a non-sequence between the two.

The occurrence of the ammonite *Procerites quercinus* (Terquem and Jourdy) in beds close above the Sharpi Beds in the Northampton–Blisworth area (see **Blisworth Rectory Farm** GCR site report, this volume) indicates the lowest part of the Retrocostatum Zone but, as noted above, the equivalent beds, as well as the Digonoides Beds, are absent in Roade Railway Cutting (Figure 4.14).

In the absence of an age-diagnostic fauna, correlation of the Blisworth Clay Formation is debatable. It has traditionally been equated with the Forest Marble Formation of Oxfordshire (Hollandi Subzone), but Cripps (1986) and Wyatt (1996a,b) have suggested its equivalence to the Bladon Member of the White Limestone Formation in Oxfordshire (Retrocostatum Zone); recent work suggests that both these units may be represented (Sumbler, in press) but a considerable non-sequence between the Blisworth Clay and the Cornbrash formations implies that the upper part of the succession may be unrepresented.

A major, widespread, marine transgression preceded deposition of the Cornbrash Formation. The occurrence of *Obovothyris obovata* in Bed 2 identifies it as the Lower Cornbrash.

Conclusions

Roade Railway Cutting exhibits one of the most complete Bathonian sections in the region, potentially displaying sections in the Rutland, Blisworth Limestone, Blisworth Clay and Cornbrash formations, together ranging from the basal Lower Bathonian Zigzag Zone to the Upper Bathonian Discus Zone. The rhythmic depositional units of the Rutland Formation, capped by distinctive rootlet beds, are of considerable importance for regional correlation. The Blisworth Limestone Formation in the cutting is representative of the East Midlands generally and, together with that of the nearby quarry at **Blisworth Rectory Farm** (see GCR site report, this volume), provides an essential basis for correlation with the corresponding Middle to Upper Bathonian succession of Oxfordshire. The absence of the Digonoides Beds provides a key to a probable local non-sequence above the Sharpi Beds in the Northampton area. Other stratigraphical breaks in the Blisworth Limestone Formation provide the potential for recognition and extrapolation of the rhythmic units established in the White Limestone Formation of Oxfordshire. The range of lithologies and faunas in the section provides a basis for reconstruction of a variety of Bathonian depositional environments.

IRCHESTER OLD LODGE PIT AND IRCHESTER COUNTRY PARK, NORTHAMPTONSHIRE (SP 914 649, SP 915 657)

R.J. Wyatt and M.G. Sumbler

Introduction

Irchester Old Lodge Pit, near Wellingborough, Northamptonshire, exposed a Bathonian section extending from the top of the Northampton Sand Formation (worked for ironstone; Figure 4.17) up into the Blisworth Clay Formation, and was one of the few complete Blisworth Lime-

Figure 4.17 Irchester Old Lodge Pit; general view of former ironstone pit showing bared bed of ironstone (Northampton Sand Formation) and overburden of Grantham, Rutland and Blisworth Limestone formations. (Photo: British Geological Survey, No. A8194, 1945.)

stone Formation sections in Northamptonshire (see Figure 4.14). It included the Rutland Formation, displaying rhythmic depositional units, each with a capping rootlet bed; in the Wellingborough Member, laminated algal limestones are also of special interest. The Blisworth Limestone Formation at the site is characterized by a variety of carbonate limestone lithofacies, some richly fossiliferous; the Sharpi Beds at its base are of regional correlative significance. Cross-bedded calcarenites in the succession displayed interesting sedimentary structures. The quarry has been recorded by Torrens (1967), and in unpublished theses by Ferguson (1972), Pittham (1970), Bradshaw (1978) and Cripps (1986). The quarry is now entirely backfilled and restored to agriculture but comparable sections exhibiting most of the succession can be seen in Irchester Country Park, immediately to the north (SP 915 657) (Sutherland and Hudson, 1982).

Description

The following composite description of the Irchester Old Lodge Pit section is based on Torrens (1967), Bradshaw (1978) and Cripps (1986). Bed numbers in the Blisworth Limestone Formation are those of Torrens (1967).

	Thickness (m)
Blisworth Clay Formation	
Clay, dark-blue, with a basal ironstone nodule bed	2.0
Blisworth Limestone Formation	
26: Limestone, argillaceous, shell-detrital, micritic, rubbly; locally with rootlets; *Aphanoptyxis bladonensis* Arkell common in places	0.40
25: Marl, passing down into soft marly limestone; abundant *Praeexogyra hebridica* (Forbes)	0.23
19–24: Limestone, white, shell-detrital, ooidal in part, with marly bands; ripple cross-laminated in upper part	0.9–1.6
18: Limestone, white, shelly, with abundant *Epithyris* and *Stiphrothyris*	0.23
16–17: Limestone, detrital, shelly; marl parting at base; *Anisocardia*, *Modiolus*	0.53
14–15: Limestone; cross-bedded, ooidal calcarenite; *Nucleolites* and *Hemicidaris* in lower part; sharp, undulating base with overhang	1.3
10–13: Limestone, laterally very variable; comprising shelly, bioturbated, micritic and finely shell-detrital limestones with marly limestone beds; diverse fauna including brachiopods (*Epithyris*), bivalves (*Anisocardia*, *Bakevellia*, *Modiolus*, *Praeexogyra*), and echinoids (*Clypeus*, *Nucleolites*)	0.8–2.2
9: Limestone, hard, massive, forming prominent overhang; many bivalves including *Astarte*, *Pseudolimea*, *P. hebridica*, *Vaugonia*; basal erosion surface	0.6

	Thickness (m)
Sharpi Beds	
1–8: Interbedded bluish-grey-weathering, calcareous mudstone, marl and argillaceous, shell-detrital, micritic limestone; common *Kallirhynchia sharpi* Muir-Wood; also *Modiolus imbricatus* J. Sowerby and *P. hebridica*	2.4–2.8
Rutland Formation	
6b: Clay, dark-green, silty, carbonaceous, with rootlets; convoluted basal contact	0.5
6a: Clay, pale-green-weathering, silty; passing down into varicoloured, finely laminated silt and clay	0.2
5: Clay, green, with rootlet bed at top	1.6
4: Sandstone, fine grained, calcite-cemented, quartzose, bioturbated, with trace fossils (*Rhizocorallium*, *Planolites*); passing down into irregularly laminated sand and silty clay	1.2
Wellingborough Member	
3: Limestone, fine- to coarse-grained, sandy, shell-detrital, wavy and ripple cross-laminated, interbedded with contorted, very finely laminated, peloidal, micritic and finely detrital limestone (algal laminite of Bradshaw, 1978); limestones commonly channelled by coarse-grained, large-scale, trough cross-bedded, shell-fragmental limestone with foresets picked out by clasts of algal laminite	1.0
2: Mudstone, silty, with beds of current-rippled, laminated, fine-grained, shell-detrital, quartzose sandstones with groove casts	1.7
Stamford Member	
Clay, sandy, very carbonaceous, with abundant rootlets and well-preserved leaf fragments; greenish clay and sand with rootlets at top	4.0

Interpretation

The substantial non-sequence beneath the Rutland Formation indicates a period when either the area was emergent or during which erosion removed any deposits above the Northampton Sand Formation. The basal sandy clays of the Stamford Member, in which there is an abundance of plant debris and rootlets, have been interpreted as the swamp deposits associated with coastal-plain lakes, which later coalesced as a marine transgression raised the sea level (Bradshaw, 1978). However, freshwater conditions were maintained by a high input of water from the London Landmass. The remainder of the formation in the East Midlands comprises a succession of rhythmic, depositional, regressive units, each of which was initiated by a marine transgression and terminated by coastal progradation, the latter associated with a rootlet bed, indicating saltmarsh conditions. In the Irchester area, only the Wellingborough (beds 2–5) and Cranford (beds 6a–6b) rhythms are represented. The diverse marine fauna of the former indicates the increasingly open marine conditions in which, to the south-west, in Oxfordshire, the coeval Taynton Limestone Formation was formed. At Irchester Old Lodge Pit, marine limestones (Bed 3) in the Wellingborough Rhythm represent the Wellingborough Member at more-or-less its eastern limit. The clays at the top of the Cranford Rhythm have been interpreted as a widespread storm deposit.

The deposition of the Blisworth Limestone Formation represents a resumption of carbonate deposition as a more extensive marine transgression restricted the input of terrigenous sediment and introduced a more diverse, fully marine fauna. The fossils are dominantly epifaunal and restricted to the micritic and finely detrital limestones and marls, which were laid down in relatively quiet waters. The contortion of the algal, laminated micrites is thought to have been the result of the injection of bioclastic sand caused by compaction or by sudden dewatering of the sediment. The coarser, cross-bedded calcarenites (beds 14–15, 19–24) are poorly fossiliferous and represent mobile sand-banks, formed in more turbulent, current-dominated conditions. The Blisworth Clay Formation indicates a return to the deposition of wholly terrigenous fine-grained sediment in quiet, low-energy waters.

The Rutland Formation yields no age-diagnostic fossils, but correlation with the Cotswolds succession, based on regionally persistent rhythmic units (Wyatt, 1996a,b), indicates that it ranges from the Lower Bathonian Zigzag Zone up to the Middle Bathonian Progracilis Zone. However, gaps in the sequence at Irchester Old Lodge Pit are indicated by the absence of the Ketton, Clipsham, Casterton and Finedon rhythms (Bradshaw, 1978).

The Sharpi Beds at the base of the Blisworth Limestone Formation are assigned to the Morrisi Zone by correlation with the Excavata Bed of the White Limestone Formation in Oxfordshire (see **Ardley Cuttings and Quarries** GCR site report, this volume); the occurrence of *Aphanoptyxis excavata* Barker in the Sharpi Beds of **Roade Railway Cutting** (see GCR report, this volume), near Northampton, corroborates this interpretation. The remainder of the Blisworth Limestone Formation (the Irchester Member of Cripps, 1986) correlates with the Ardley Member of the

White Limestone Formation in Oxfordshire and probably belongs to the Retrocostatum Zone, with the Bremeri Zone unrepresented. The presence of *Aphanoptyxis bladonensis* Arkell in the uppermost rootleted bed of the Blisworth Limestone Formation in Irchester Old Lodge Pit supports this dating; this bed is probably coeval with the Bladonensis Bed in Oxfordshire, which caps the Ardley Member there. The overlying Blisworth Clay Formation, formerly considered to be equivalent to the Forest Marble Formation of Oxfordshire, is now known to incorporate beds coeval with the Bladon Member of the White Limestone Formation and so the lower part of the Blisworth Clay Formation probably belongs to the Retrocostatum Zone.

In the absence of the diagnostic brachiopod, the Digonoides Beds have not been recognized at this site. However, beds 14 and 15 of the recorded section are lithologically comparable to the Digonoides Beds elsewhere, including those in nearby New Lodge Pit (SP 907 650), and so may tentatively be assigned to the unit. If so, some 8 m of beds have been cut out in the latter pit, where the Digonoides Beds rest directly on the Sharpi Beds.

Conclusions

Irchester Old Lodge Pit exhibited an almost complete Bathonian succession (Zigzag to Retrocostatum zones), lacking only the upper part of the Blisworth Clay Formation and the Lower Cornbrash. It included the Rutland Formation, characterized by rhythmic depositional units capped by rootlet beds, of which the Wellingborough Rhythm contained marine limestones (Wellingborough Member) at more-or-less their easterly limit. Non-sequences are indicated by the absence of rhythmic units known elsewhere in the East Midlands. The Blisworth Limestone Formation commences with the Sharpi Beds, but no strata yielding *D. digonoides* are known at this site. However, the presence of a lithological correlative of the Digonoides Beds may be inferred. Of particular interest is the record of *Aphanoptyxis bladonensis* in the topmost rootleted limestone bed of the formation, which may be correlated with the Bladonensis Bed of Oxfordshire, where it caps the Ardley Member of the White Limestone Formation. The pit also displayed a variety of cross-bedding and associated structures in the calcarenite units.

FINEDON GULLET, WELLINGBOROUGH, NORTHAMPTONSHIRE (SP 926 698)

R.J. Wyatt

Introduction

Finedon Gullet, about 2 km north-east of Wellingborough, Northamptonshire, forms part of what was once an extensive pit from which iron ore was extracted (Figure 4.18). Although a complete Rutland Formation has been recorded here in the past, only the top *c.* 4 m were exposed in August 1997. The section (see Figure 4.14) is important in tracing laterally extensive, well-defined, rhythmic rock units in the Rutland Formation, and less readily recognizable units in the overlying Blisworth Limestone Formation. The Sharpi Beds, a valuable regional marker horizon at the base of the Blisworth Limestone Formation, are well developed and well exposed (Figure 4.19). Under its former name, Wellingborough No. 5 Pit, the section was recorded by Aslin (1965), whose description was published in Torrens (1968b). It also features in the unpublished theses of Bradshaw (1978) and Cripps (1986), whose interpretations differ considerably from that of Aslin.

Description

The basal Stamford Member of the Rutland Formation rests unconformably on the Northampton Sand Formation. It consists of 0.4 m of muddy sand with ironstone nodules, overlain by 0.9 m of sandy carbonaceous clay with rootlet traces; the latter is capped by a prominent rootlet bed. The succeeding 4.6 m comprises the Wellingborough Rhythm, which commences with a 1 m-thick bed of silty clay containing subordinate silt and sand layers. This is overlain by 3.5 m of interbedded silty clay, silt and sand, with thin layers of ooidal, finely shell-detrital limestone yielding marine fossils, which together form the Wellingborough Member of which Finedon Gullet is the type section (Bradshaw, 1978); it sharply truncates the unit below. The fauna of the member is dominated by bivalves, of which oysters are abundant in some beds; they are associated with an encrusting fauna of *Dorsoserpula* and *Berenicea*. *Modiolus imbricatus* J. Sowerby and *Placunopsis socialis* Morris and Lycett are also

Figure 4.18 The section at Finedon Gullet showing the Blisworth Limestone Formation overlying mainly grass-covered Rutland Formation. (Photo: M.G. Sumbler.)

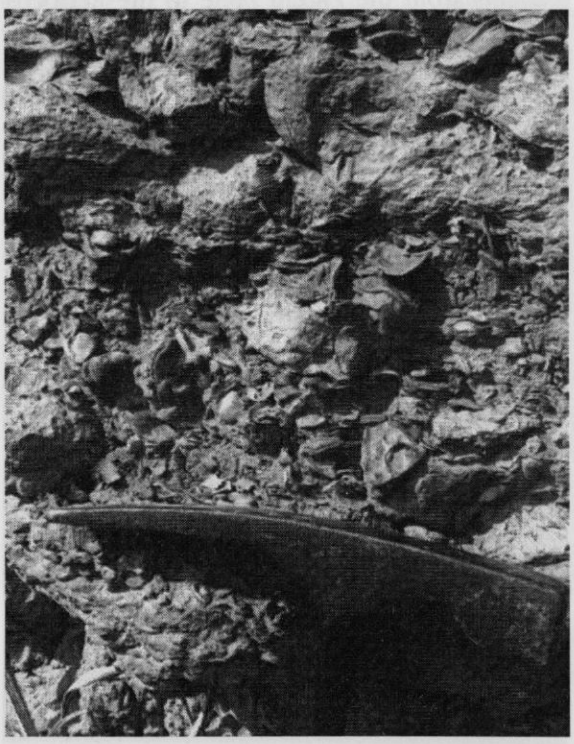


Figure 4.19 Oysters and *Kallirhynchia sharpi* Muir-Wood in the well-developed Sharpi Beds at Finedon Gullet. (Photo: M.G. Sumbler.)

prominent, as well as the echinoid *Acrosalenia* and rhynchonellid brachiopods. The member is capped by a 0.5 m-thick bed of silty clay with rootlets, which defines the top of the Wellingborough Rhythm.

The base of the overlying Cranford Rhythm comprises finely laminated, varicoloured silts and clays, which pass up into pale-green-weathering, less silty clay. The upper part consists of carbonaceous silty clay with rootlets, which rests with a convoluted contact on the beds below. The total thickness is about 0.6 m.

The overlying Blisworth Limestone Formation commences with the Sharpi Beds, which comprise 2 m of alternating bluish marl and limestone beds, containing shelly lenses with abundant oysters and other bivalves, and the brachiopod *Kallirhynchia sharpi* Muir-Wood (Figure 4.19). These beds are succeeded by 2 m of fossiliferous, bioturbated, ooidal, shell-fragmental, micritic limestones with subordinate beds of micritic limestone containing thin laminae of ooidal, sandy marl. The fauna includes the bivalves *Anisocardia*, *Eocallista*, *Pleuromya* and *Vaugonia*, and the brachiopod *Epithyris*. These shelly limestones are overlain by 2.1 m of unfossiliferous, large-scale cross-bedded calcarenites, in which individual foresets are graded and draped by micritic limestone laminae.

Interpretation

The sand and carbonaceous clay of the basal Stamford Member of the Rutland Formation are thought to have formed in a freshwater lacustrine environment, on the marginal coastal plain of the London Landmass. The succeeding deposits of the Rutland Formation throughout the East Midlands are interpreted largely as the sediments of a shallow, brackish-water lagoon, characterized by a sequence of regressive, rhythmic units that are commonly capped by a rootlet bed, signifying emergent saltmarsh conditions. At Finedon Gullet, the Wellingborough and Cranford rhythms are readily recognized; the former rests directly on the Stamford Member, indicating that the intervening Ketton, Clipsham and Casterton rhythms are missing here. The Wellingborough Rhythm includes the thin ooidal limestones of the Wellingborough Member, which reflect transient marine incursions and represent the shoreward extremity of the thicker, fully marine, dominantly ooidal Taynton Limestone Formation of Oxfordshire and Gloucestershire.

The Blisworth Limestone Formation represents a return of fully marine conditions to the East Midlands, as carbonate lagoonal deposition, accompanied by restricted input of terrigenous sediment, extended eastwards. The mixed epifaunal–infaunal fossil assemblages in the Sharpi Beds and immediately overlying strata, allied to the mainly micritic limestone lithologies, suggest relatively low-energy depositional conditions and a stable substrate. The cross-bedded calcarenites at the top of the section act as witness to turbulent, current-dominated waters that generated mobile sand-banks consisting of abraded shell-detritus. These calcarenites are similar to beds yielding *Digonella digonoides* (S.S. Buckman) at New Lodge Pit, Irchester (SP 907 650) and are inferred to be the Digonoides Beds, although the diagnostic brachiopod has not been found.

Correlation of the Rutland Formation with coeval strata in the Cotswolds indicates a vertical range at Finedon Gullet from the Lower Bathonian Zigzag Zone to the Middle Bathonian Progracilis Zone. However, the absence of certain units in the rhythmic sequence means that the intervening Tenuiplicatus Zone is probably largely unrepresented. The regionally correlatable Sharpi Beds at the base of the Blisworth Limestone Formation are considered to be coeval with the Excavata Bed of the White Limestone Formation in Oxfordshire, which there caps the Shipton Member and belongs to the Morrisi Zone. Since these beds rest directly on the clays of the Cranford Rhythm, cutting out beds of the Finedon Rhythm, the Subcontractus Zone is probably largely unrepresented. The remainder of the Blisworth Limestone Formation belongs, by comparison with nearby sections, to the Retrocostatum Zone, and the Bremeri Zone is probably unrepresented. The uppermost 2 m or so of unfossiliferous calcarenites at Finedon Gullet are lithologically similar to those of Irchester New Lodge Pit, some 6 km to the south, and so may be their lateral equivalent.

Conclusions

Finedon Gullet, Wellingborough, exposes a complete Early to Mid Bathonian Rutland Formation succession and much of the Mid to Late Bathonian Blisworth Limestone Formation, ranging from the Zigzag Zone to the Retrocostatum Zone. Rhythmic depositional units in the Rutland Formation are well displayed, but the absence of rhythms known from other localities indicates at least two non-sequences. Thin limestones in the Wellingborough Member represent more-or-less the eastern limit of a marine incursion, which in the Cotswolds is represented by the Taynton Limestone Formation. The regionally significant Sharpi Beds at the base of the Blisworth Limestone Formation are present, but the important Digonoides Beds can only be inferred in the absence of the diagnostic brachiopod.

CRANFORD ST JOHN, NORTHAMPTONSHIRE (SP 924 764)

R.J. Wyatt

Introduction

The GCR site at Cranford St John, Northamptonshire, is a 1 km-long former ironstone quarry face, up to 10 m high and extending from SP 9210 7677 in the north-west to SP 9287 7607 in the south-east (Figure 4.20). It exposes a succession that includes the whole of the Rutland Formation and most of the overlying Blisworth Limestone Formation (Figure 4.21). The section exhibits the rhythmic depositional character of the freshwater and brackish-water Rutland Formation, in which each rhythm is capped by a rootlet bed; it is the type section of the Cranford Rhythm. Along the face, the uppermost Finedon Rhythm uniquely shows a facies change into the basal unit of the Blisworth Limestone Formation (Figure 4.22). The fauna of the latter is diverse and abundant. The section is important in interpreting the lateral facies changes in the Bathonian succession in the East Midlands. The section was first described in detail by Torrens (1967) and subsequently by Bradshaw (1978) and Cripps (1986) in unpublished theses.

Description

The following description is based mainly on Torrens (1967), Bradshaw (1978) and Cripps (1986). Bed numbers are those of Torrens (1967).

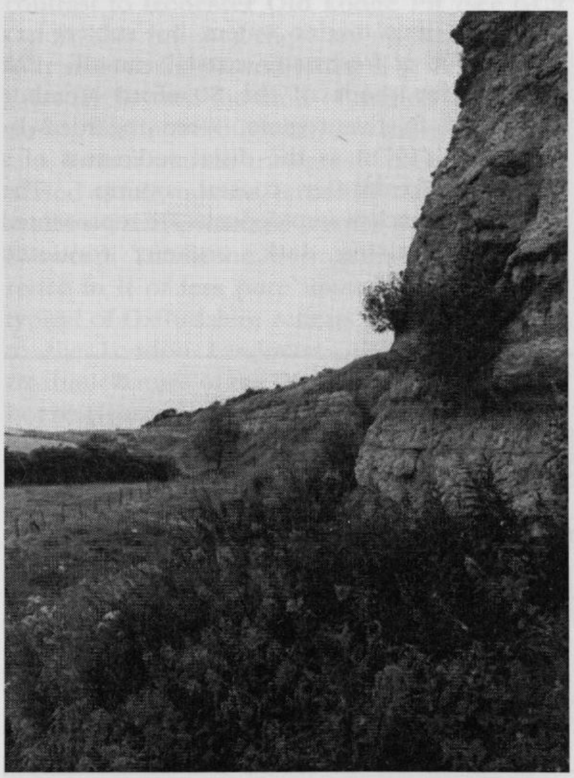


Figure 4.20 Looking south at the Cranford St John GCR site; the Blisworth Limestone Formation overlies the Rutland Formation. (Photo: M.G. Sumbler.)

	Thickness (m)
Blisworth Limestone Formation	
22: Limestone, flaggy-weathering	0.15–0.30
21: Marl, brown, shelly; abundant *Praeexogyra hebridica* (Forbes)	0.61
19–20: Limestone, ooidal; upper part flaggy, rubbly, fossiliferous below; *Homomya*, *Pholadomya* and *Praeexogyra*	0.84–0.91
18: Marl, dark-brown, ooidal; *P. hebridica subrugulosa* Morris and Lycett	0.23
16–17: Limestone, creamy-white, sparsely ooidal, shell-detrital; ripple cross-lamination near top	0.30
15: Limestone, white, soft, micritic; upper part marly	0.30
14: Limestone, similar to 15 but rubbly and shelly; many bivalves (*Anisocarodia*, *Modiolus*, *Pholadomya*, *P. hebridica* (abundant), *P. hebridica subrugulosa*, *Pseudolimea* and *Rollierella*), *Digonella digonoides* S.S. Buckman, *Epithyris*	0.23
13: Marl, brown, with abundant oysters; distinctly pocketed base	0.15–0.23
12: *Digonoides Beds*: Limestone, whitish, micritic, ooidal, rubbly, fossiliferous; bivalves (*Anisocardia*, *Limatula*, *Modiolus*, *Pholadomya*, *P. hebridica* and *Trigonia*), *Digonella digonoides*, *Epithyris*, *Acrosalenia*, *Nucleolites*, *Holectypus*	0.30
8–11: Limestone, shell-fragmental, rubbly; two thin, persistent marl-beds; sharp, planar base	1.14–1.22
7: Mudstone, dark-grey, carbonaceous, shaly (0.15 m), overlying rubbly, shelly limestone; abundant *P. hebridica* throughout (2.21 m)	2.36
6: Limestone with *Clypeus*	0.20
5: Clay, dark-grey	0.20
1–4: *Sharpi Beds*: Interbedded argillaceous, micritic, shell-detrital limestone and marl; abundant *Kallirhynchia sharpi* Muir-Wood, *Anisocardia*, *Eocallista*, *Modiolus*, *Pholadomya*, *Praeexogyra*, *Rollierella*; erosional base	1.80
Rutland Formation	
Finedon Rhythm: Clay, silty, interlayered with sand in lower part; rootlets at top; erosional base	0.60
Cranford Rhythm: Clay, dark-grey, silty, carbonaceous; convoluted contact with underlying bed	0.70
Clay, pale-green-weathering, slightly silty; '*Corbula*' locally common	0.50
Clay and silt, interlaminated, varicoloured; erosional base	0.15
Wellingborough Rhythm: Clay, silty; rootlets	0.10
Sandstone, argillaceous, quartzose, fine grained, bioturbated	0.65
Clay, silty, and sand, irregularly interlaminated	0.50
Sandstone, as above	0.95
Clay, silty, and sand, irregularly interlaminated	0.25
Sand, cross-laminated and ripple-bedded; clay-draped foresets; erosional base, channelled into underlying bed	0.15–0.60
Stamford Member	
Clay, black, slightly silty, carbonaceous; abundant rootlets	up to 1.10
Sand, fawn, fine grained, clayey, trough cross-bedded in upper part; unevenly laminated and bioturbated in lower part	*c.* 2.5
Northampton Sand Formation	

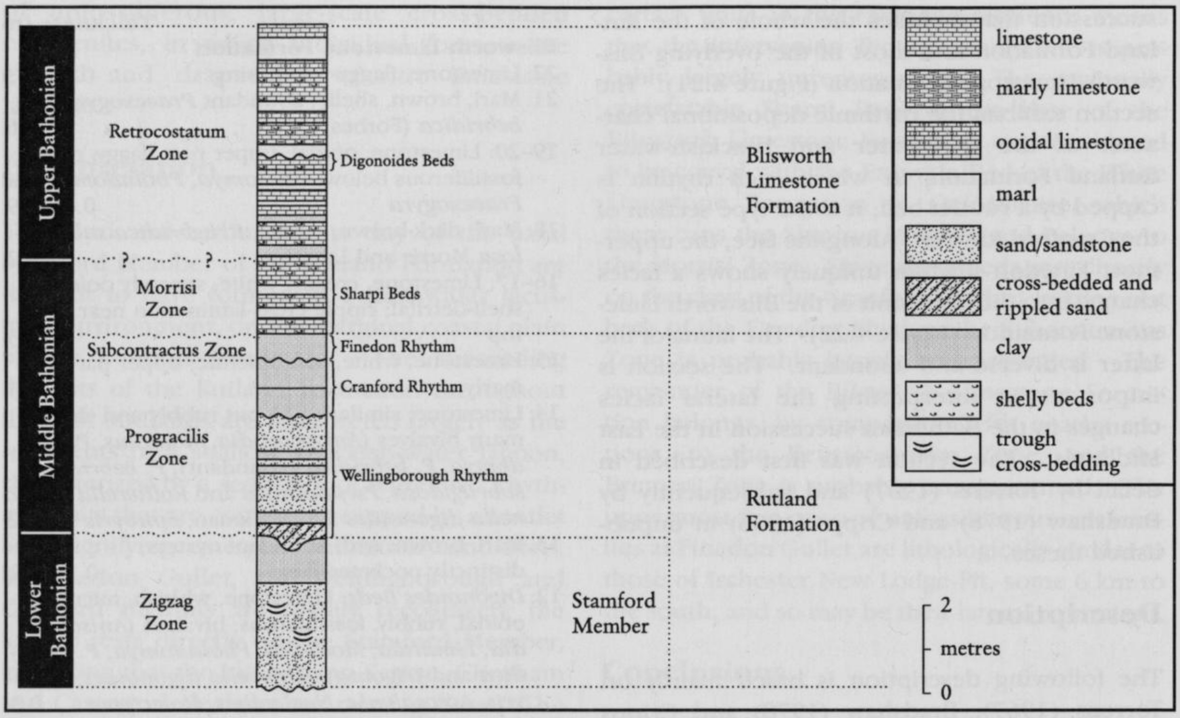


Figure 4.21 Graphic section of the Bathonian succession at Cranford St John.

Interpretation

A lengthy period of non-deposition and/or erosion occurred between deposition of the Northampton Sand and Rutland formations. Renewed sedimentation was initiated by a transgression that flooded the gently graded coastal plain of the London Landmass, producing a shallow-water, offshore shelf with restricted access to open marine waters, but subject to a high input of freshwater coastal run-off. The basal clayey sands of the Stamford Member, deposited in this regime, were regarded by Bradshaw (1978) as the distal sediments of a low-lying freshwater coastal swamp. The prograding backswamp deposits are represented by the overlying dark, organic, rootleted clays.

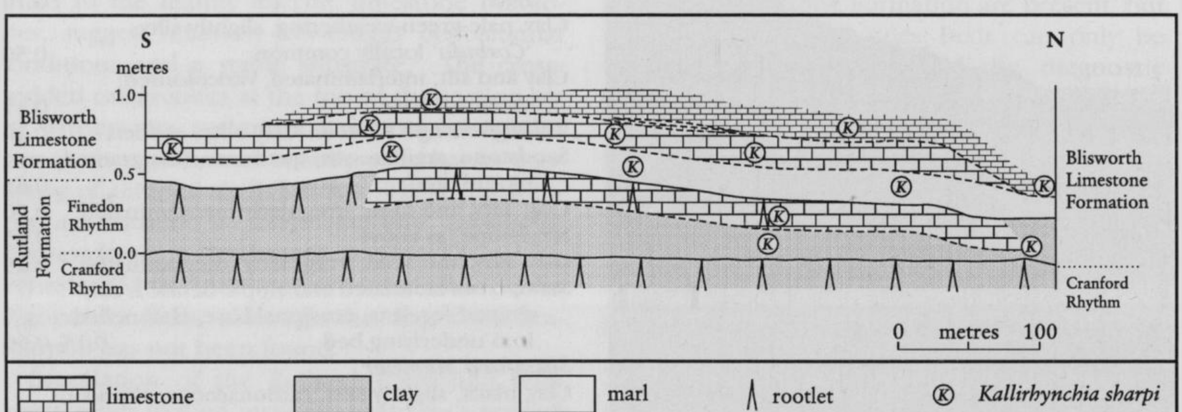


Figure 4.22 Facies changes at Cranford St John where the Finedon Rhythm of the Rutland Formation passes into the Blisworth Limestone Formation. (After Bradshaw and Cripps, 1983, fig. 11.)

The succeeding brackish-water deposits of the Rutland Formation form three regressive, rhythmic, depositional units, each initiated by a marine transgression and terminated by coastal progradation, which led to the formation of nearshore saltmarsh deposits penetrated by rootlets; these cap the units. The dark-grey clay with convoluted base at the top of the Cranford Rhythm is believed to represent a laterally extensive storm deposit. The three rhythms that, to the north-east, at **Ketton Quarry** (see GCR site report, this volume), form the base of the rhythmic sequence below the Wellingborough Rhythm, are absent at Cranford St John, having been overstepped by the latter (see Figure 4.33, see **Ketton Quarry** GCR site report). The upper part of the Finedon Rhythm, which caps the Rutland Formation, exhibits a unique facies change along the quarry face from a silty clay with interlayered sand at the south-eastern end of the section into a facies comparable to much of the overlying Blisworth Limestone Formation; a transition back into clay occurs at the north-western extremity of the face. The restricted fauna of the Rutland Formation is dominated by brackish-water bivalves; in contrast to **Irchester Old Lodge Pit** (see GCR report, this volume), there are no beds yielding fully marine fossils, indicating that Cranford St John lay beyond the limit of marine incursions during Wellingborough Rhythm times.

A further marine transgression introduced a period of fully marine, carbonate deposition in a shallow-water, protected lagoon, to produce the Blisworth Limestone Formation. The occurrence in it of less pure limestones than those typical of Oxfordshire reflects greater proximity to the London Landmass. The well-defined rhythmic nature of the Oxfordshire succession is not so clearly recognizable in the more marginal district hereabouts where, locally, only partly preserved or missing rhythmic units are characteristic. Nevertheless, erosional surfaces at the top of the Sharpi Beds (beds 1–4) and the Digonoides Beds (Bed 12), and a carbonaceous, shaly mudstone (at the top of Bed 7), probably represent the tops of rhythmic units, of which the Sharpi Beds, at least, are regionally persistent. Much of the succession yields a prolific fauna, suggesting the predominance of only moderate current activity and relatively stable substrates. Oysters are apparently more prolific than in localities to the south-west, presaging their dominance in districts farther north, where the term 'Longthorpe Member' has been used for beds above the Sharpi Beds (Cripps, 1986).

The Rutland Formation contains no age-diagnostic fossils and dating relies on long-range correlation with coeval strata in the Cotswolds, using persistent, rhythmic, depositional units (Wyatt, 1996a,b). Thus, the formation is inferred to range from the Lower Bathonian Zigzag Zone to the Middle Bathonian Morrisi Zone. The absence of the Ketton, Clipsham and Casterton rhythms suggests that the Tenuiplicatus Zone is unrepresented. The basal Sharpi Beds of the Blisworth Limestone Formation are assigned to the Morrisi Zone by comparison with other sections to the west (see particularly **Stratton Audley** GCR site report, this volume). By the same means, the remainder of the formation is inferred to belong to the Upper Bathonian Retrocostatum Zone.

Conclusions

The Bathonian section at Cranford St John includes the whole of the Rutland Formation and most of the Blisworth Limestone Formation, and ranges from the Zigzag Zone to the ?Retrocostatum Zone. It is of particular value for showing a stratigraphical succession that is transitional between that to the north (e.g. **Ketton Quarry**, see GCR site report, this volume) and that to the south-west (e.g. **Irchester Old Lodge Pit**, see GCR site report, this volume). It provides an interesting contrast with Ketton Quarry in that the lowest three units of the Rutland Formation rhythmic sequence there are cut out by the Wellingborough Rhythm, which, at Cranford St John, locally has a strikingly channelled base. The section is also significant for exposing the Wellingborough Rhythm immediately beyond the limit of marine limestone interbeds (Wellingborough Member) that are typical farther south (see **Finedon Gullet** and **Irchester Old Lodge Pit** GCR site reports, this volume). A dark, freshwater clay at the top of the Cranford Rhythm (for which this is the type section) is believed to represent a laterally extensive storm deposit. The overlying Finedon Rhythm exhibits a unique facies change into the base of the Blisworth Limestone Formation. The Sharpi Beds and the Digonoides Beds, both of correlative value, are present in this section.

THRAPSTON, NORTHAMPTONSHIRE (TL 000 776)

R.J. Wyatt, K.N. Page, M.G. Sumbler and B.M. Cox

Introduction

The quarry at Thrapston, also known as 'L.M.S. Railway Station Quarry', 'Thrapston Railway Station Quarry', 'Midland Railway Pit' and 'Excelsior Limestone Company's Pit', at Thrapston, Northamptonshire, formerly exposed a section ranging from the upper part of the Blisworth Limestone Formation to the basal part of the Kellaways Formation and thus included one of the few complete sections of the Cornbrash and Blisworth Clay formations in Northamptonshire; it is regarded as the type section of the latter (Figure 4.23). Sadly, the quarry is now largely infilled and remaining exposures (1998) are restricted to the Blisworth Clay and Cornbrash formations. Both the Blisworth Limestone and Cornbrash formations are very fossiliferous; the latter has yielded stratigraphically age-diagnostic ammonites. The Blisworth Limestone Formation is characterized by a locally rootleted horizon at the top. The Bathonian–Callovian stage boundary separates the Lower and Upper Cornbrash, and the site is therefore included in both the Bathonian and Callovian GCR blocks. The section was first described by Woodward (1894), at a time when an additional 2 m of the Blisworth Limestone Formation was visible at the base, although Vine (1893) had earlier described an important bryozoan fauna from this locality. Blake (1905), Douglas and Arkell (1932) and Page (1988) recorded the section in their researches on the Cornbrash Formation, and it was also noted by Taylor (1963), Torrens (1968b), Pittham (1970) and Cripps (1986).

Description

The following section is based on Douglas and Arkell (1932), Torrens (1968b), Cripps (1986) and Page (1988). Bed numbers are those of Douglas and Arkell.

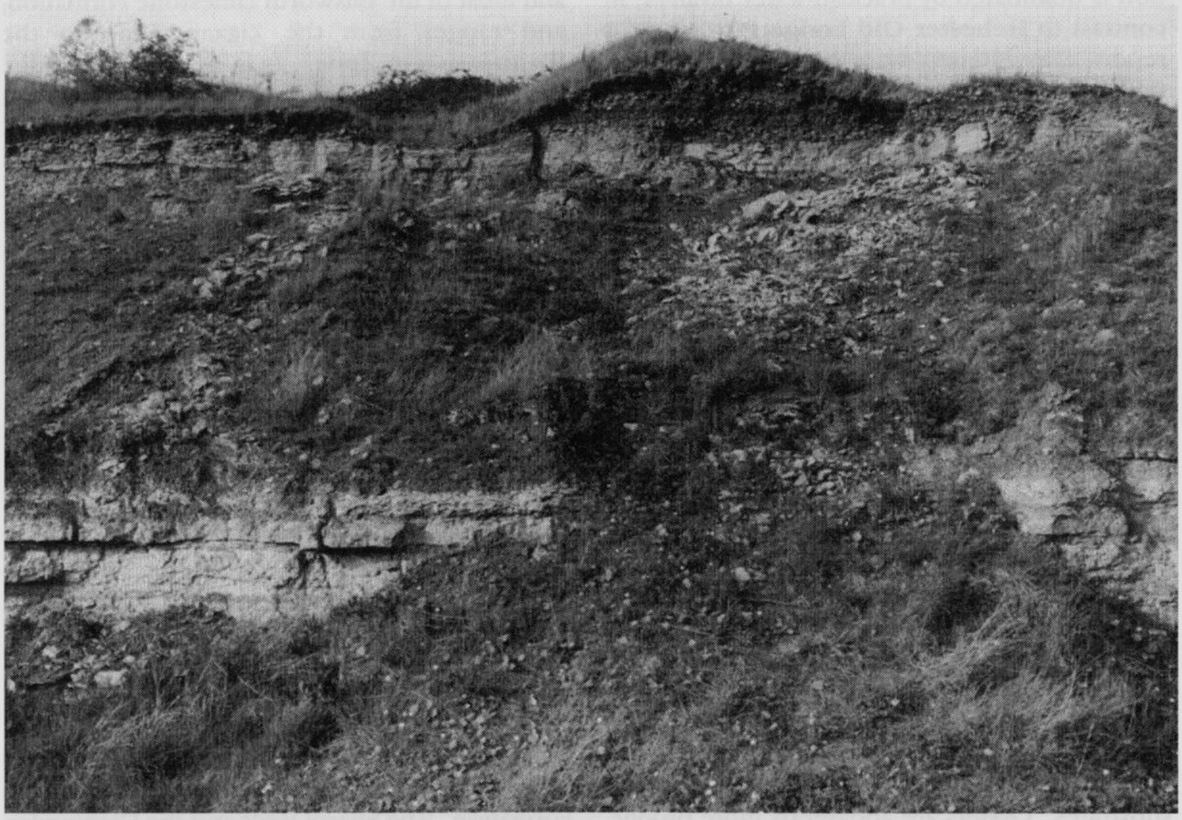


Figure 4.23 The quarry at Thrapston showing the Cornbrash Formation overlying the grass-covered Blisworth Clay Formation with Blisworth Limestone Formation below. (Photo: British Geological Survey, No. A8361, 1949.)

Thickness (m)

Kellaways Formation

Kellaways Clay Member **(Cayton Clay Formation** of Page, 1989)

7: Clay, blue — up to 1.2

Cornbrash Formation

Upper Cornbrash

5: Limestone, reddish-brown, soft, marly, fossiliferous with brachiopods, including *Microthyridina lagenalis* Douglas and Arkell *non* Schlotheim (abundant) and *Rhynchonelloidea cerealis* S.S. Buckman; bivalves (particularly myoids, pectinids and *Lopha marshii* (J. Sowerby)); echinoids (*Nucleolites*); ammonites (*Macrocephalites*); vertebrate remains; capped by layer of oysters (Bed 6) with *Lopha marshii* and *Liostrea undosa* (Phillips) — 0.55

4: Limestone, hard, flaggy, calcarenite (*Thrapston Flags* of Douglas and Arkell); less fossiliferous than overlying bed but yielding bivalves, *Microthyridina sublagenalis* (Davidson) and *Macrocephalites* — 0.9

3: Marl, impersistent; *M. sublagenalis*, occasional *Lopha marshii* — 0–0.08

2: Pebble bed with clasts of assorted Cornbrash lithologies ranging from 'fresh' internal moulds of bivalves to rounded pebbles, many of which heavily bored and encrusted with serpulids, oysters, bryozoa and foraminifera (*Nubeculinella*); bivalves (including myoids (*Goniomya*, *Pholadomya*, *Pleuromya*), *Chlamys*, *Lopha*, *Modiolus*, *Plagiostoma*, *Protocardia*, trigoniids); gastropods; echinoids (*Holectypus*, *Nucleolites*); ammonite nuclei — 0.15–0.3

Lower Cornbrash

1: Limestone, grey, hard, shelly to white and chalky, shell-detrital, micritic; irregular thickness; ammonites (*Clydoniceras* including *C. thrapstonense* (Arkell)); brachiopods (*Cererithyris intermedia* (J. Sowerby), *Kallirhynchia yaxleyensis* (Davidson) and *Obovothyris grandobovata* S.S. Buckman); bivalves (*Ceratomya*, *Entolium*, *Meleagrinella echinata* (Wm Smith), *Modiolus*, *Pholadomya*, *Pleuromya*, *Pseudolimea*, *Pseudotrapezium*, *Protocardia*, trigoniids and other pectinids); also echinoids (*Holectypus*, *Nucleolites*, *Pygurus*); sharp base — 0–0.13

Blisworth Clay Formation

Clay, purplish, varicoloured, lithologically uniform, very poorly fossiliferous; layer of brown limonitic ironstone nodules at base — 2.5

Blisworth Limestone Formation

Limestone, finely shell-detrital, ooidal, shelly, micritic, with sporadic marl beds; bivalves predominant including *Anisocardia*, *Ceratomya concentrica* (J. de C. Sowerby), *Eocallista antiopa* (Thevenin), *Eomiodon angulatus* (Morris and Lycett), *Homomya gibbosa* (J. Sowerby), *Modiolus imbricatus* J. Sowerby, *Praeexogyra hebridica* (Forbes), *Pseudolimea duplicata* (J. de C. Sowerby) and *Pseudotrapezium cordiiforme* (Deshayes); also *Nucleolites* — *c.* 4.5

Interpretation

The shelly limestones of the Blisworth Limestone Formation, at the base of the section, are thought to have been deposited in a marine, shallow-water, protected, carbonate lagoon in which a stable substrate favoured a flourishing, dominantly bivalve fauna. The sporadic marl beds indicate occasional influxes of clastic muddy sediment, derived presumably from the London Landmass to the east. The rootlets recorded in the uppermost 0.25 m of the formation indicate that a phase of emergence followed deposition of the Blisworth Limestone Formation, during which saltmarsh vegetation colonized the soft, exposed substrate. The occurrence of rootlets is of particular significance because they have been observed at this level at several localities in the East Midlands, reflecting the wide geographical extent of this emergent episode.

The succeeding marine transgression initiated deposition of the overlying, wholly clastic, argillaceous Blisworth Clay Formation. Its lithological uniformity suggests a persistently stable depositional environment. The bright, varied colours of the clay are presumed to be a consequence of varying states of oxidation of iron compounds and may be pedogenic; they are usually regarded as being indicative of a fluviatile origin and their deposition would seem to require an enclosed basin or lagoon into which open marine waters did not penetrate, except during the initial marine transgression (Taylor, 1963). This interpretation is substantiated by the investigations of Fenton (1980) who identified essentially non-marine palynofloras throughout the Blisworth Clay Formation at both Thrapston and nearby **Irchester Old Lodge Pit** (see GCR site report, this volume). This contrasts with the succession farther north at Oundle (TL 0335 8855) and Paston (TF 1902 0216) where diverse marine assemblages of Late Bathonian age were found in the basal beds. There, however, the formation is clearly regressive, for it is rootleted at the top. Thrapston offers one of the best exposures of the Blisworth Clay Formation in its most typical development and, following Cripps (1986, who named it the 'Thrapston Clay'), is taken as the formation's type section. **Blisworth Rectory Farm** (see GCR site report, this volume) itself is unsuitable as a type locality as it lies in the transition zone close to the limit of the facies. In addition, Sharp's (1870) original usage of the term at **Blisworth Rectory Farm** related to oyster-rich clays that may in part belong to the Blisworth Limestone Formation (Cripps, 1986).

Deposition of the succeeding Lower Cornbrash followed a further major marine transgression. Its lithology is indicative of a shallow marine, carbonate shelf-environment in which current activity was relatively subdued. The fauna is typical of stabilized carbonate sands and is dominated by epifaunal and deep-burrowing organisms. In the quarry at Thrapston, the Lower Cornbrash is of variable thickness and only 0.13 m at most, probably because of pre-Upper Cornbrash erosion, a conclusion supported by the presence of a conglomeratic bed at the base of the Upper Cornbrash containing pebbles and fossils reworked from the Lower Cornbrash that are encrusted by serpulids, bryozoa and small oysters, and bored by bivalves.

The occurrence of the ammonite *Clydoniceras thrapstonense* in the Lower Cornbrash, together with the diagnostic brachiopods *Cererithyris intermedia* and *Obovothyris grandobovata*, serve to confirm that it belongs to the Upper Bathonian Discus Zone and Subzone. Rare *C. discus*, found anomalously in the basal pebble bed of the Upper Cornbrash, must be reworked from the Lower Cornbrash, to judge by their heavy encrustation. The ammonite nuclei with which they occur most closely resemble *Macrocephalites terebratus* (Phillips) transient β of Callomon *et al.* (1989) which indicates the Lower Callovian Herveyi Zone, Terebratus Subzone; this subzone is also indicated by *Macrocephalites* ex gr. *terebratus* (Phillips) in Bed 4. The presence in old collections of *Macrocephalites kamptus* transient γ of Callomon *et al.* (1989) in a matrix typical of Bed 5 indicates that this bed belongs to the Kamptus Subzone, and the base of Bed 5 has been nominated by Page (1989) as an international reference section for the base of the subzone.

Conclusions

The section at Thrapston exposed a succession ranging from the upper part of the Upper Bathonian Blisworth Limestone Formation to the basal part of the Lower Callovian Kellaways Formation, including the Blisworth Clay and Cornbrash formations. The locality is particularly important for its exposure of the Cornbrash Formation, which has yielded an abundant and characteristic fauna, including age-diagnostic ammonites, and within which lies the Bathonian–Callovian stage boundary. The latter is highlighted by an erosional surface associated with a pebble-bed containing reworked, heavily encrusted and bored material derived from the Bathonian Lower Cornbrash; sediments of the Lower Callovian Herveyi Zone, Keppleri Subzone have been removed by the erosion. The section has been nominated as international reference section for the base of the Kamptus Subzone (Herveyi Zone) (Page, 1989). It is also an important reference section for the brachiopod biozones of the Upper Cornbrash, in an area once famous for its Cornbrash Formation fossils (cf. Blake, 1905). The type section of the underlying Blisworth Clay Formation exhibited the strikingly varicoloured but otherwise characteristically uniform lithology of this wholly non-marine formation in Northamptonshire, and the Blisworth Limestone Formation below features a locally developed rootlet bed at the top, demonstrating a transient emergent episode.

PETERBOROUGH BRICKPITS, CAMBRIDGESHIRE (TL 165 940, TF 210 025, TF 248 978)

K.N. Page

Introduction

Small brickpits working the Oxford Clay Formation have been in operation around Peterborough from at least the 18th century. The discovery that the clays of the lower part of the formation (now called the 'Peterborough Member'; Cox *et al.*, 1992) were sufficiently plastic to be 'dry' pressed into moulds and sufficiently organic-rich to part-fire themselves led to the establishment of the 'Fletton Process' in the 1880s. A massive industry producing cheap bricks subsequently developed; fuel costs for firing were much reduced and the bricks could be produced all year round, even in wet winter weather (Hillier, 1981). At various times, different pits have been operational south and east of the city, following the Oxford Clay Formation outcrop (Horton *et al.*, 1974; Horton, 1989) (Figure 4.24). Many areas are now worked out and recent production has focused on two areas, near Whittlesey east of Peterborough and Orton to the south, although working at the latter pit (Figure 4.25) ceased in January 1998.

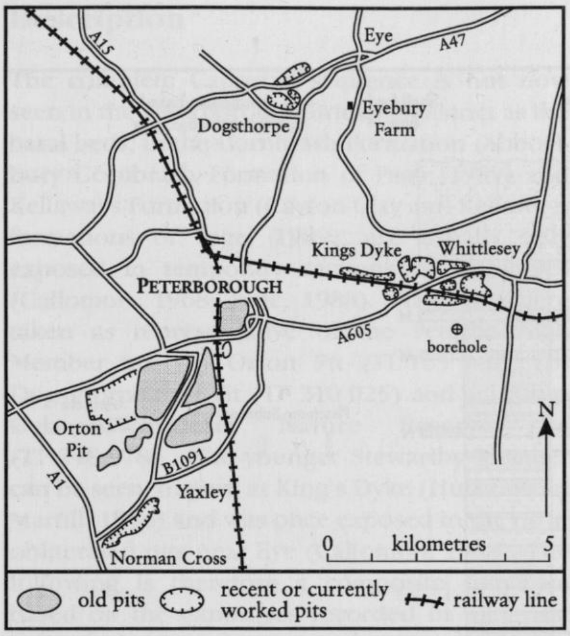


Figure 4.24 Sketch map showing the location of some Oxford Clay Formation sites (past and present) around Peterborough (Peterborough Brickpits GCR site). (After Hudson and Martill, 1994.)

Nevertheless, the Peterborough Member is, in general, remarkably uniform throughout the area, and observations on one site can equally well be applied to another. The area has long been famous for its fossil faunas (Martill and Hudson, 1991) and much work, notably by Andrews (1895, 1909a,b, 1910–1913), Brinkmann (1929a,b), Leeds (1956), Duff (1975, 1978) and Martill (1984, 1985a–c, 1986a,b, 1988a,b, 1989a,b, 1990a,b), has focused on the palaeontology.

The stratigraphy of the Oxford Clay Formation in the Peterborough Brickpits has been reported by Woodward (1895) and Arkell (1933), more fully described by Callomon (1955, 1964, 1968) and reviewed by Hudson and Martill (1994) (Figure 4.26). The Lower Callovian part of the sequence was re-described by Page (1988). More recently, much work has focused on the sedimentary geochemistry of the Peterborough Member (Williams, 1988; Hudson and Martill, 1991; Anderson *et al.*, 1994; Belin and Kenig, 1994; Hudson, 1994, Kenig *et al.*, 1994; Macquaker, 1994; Norry *et al.*, 1994); some of this work is summarized by Hudson (2001).

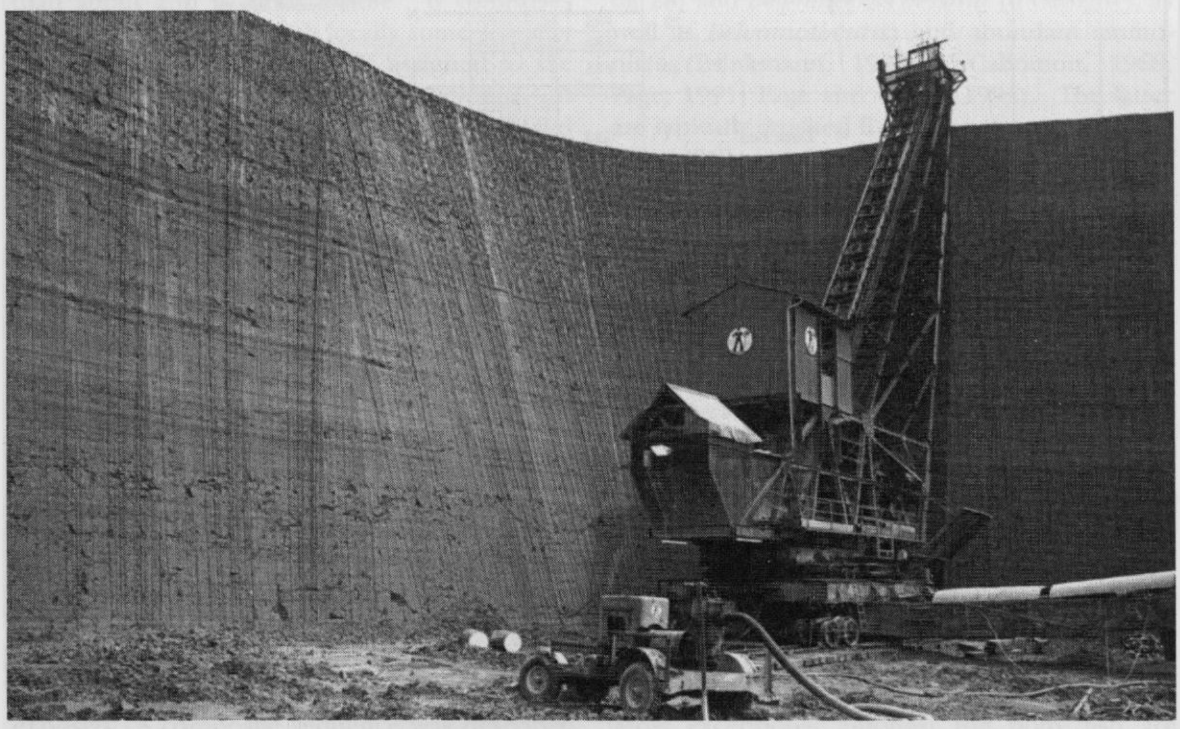


Figure 4.25 King's Dyke Pit, Whittlesey. Shale-planar excavator digging the Oxford Clay Formation for brick-making. The section illustrates the marked alternations of darker, brownish-grey, organic-rich mudstone and paler, more calcareous, mudstone. The excavator works down to the lowest bed of concretions in the Oxford Clay Formation (Bed 10 of Callomon, 1968; and Hudson and Martill, 1994). (Photo: British Geological Survey, No. MN26846; reproduced with the permission of the Director, British Geological Survey, © NERC, 1987.)

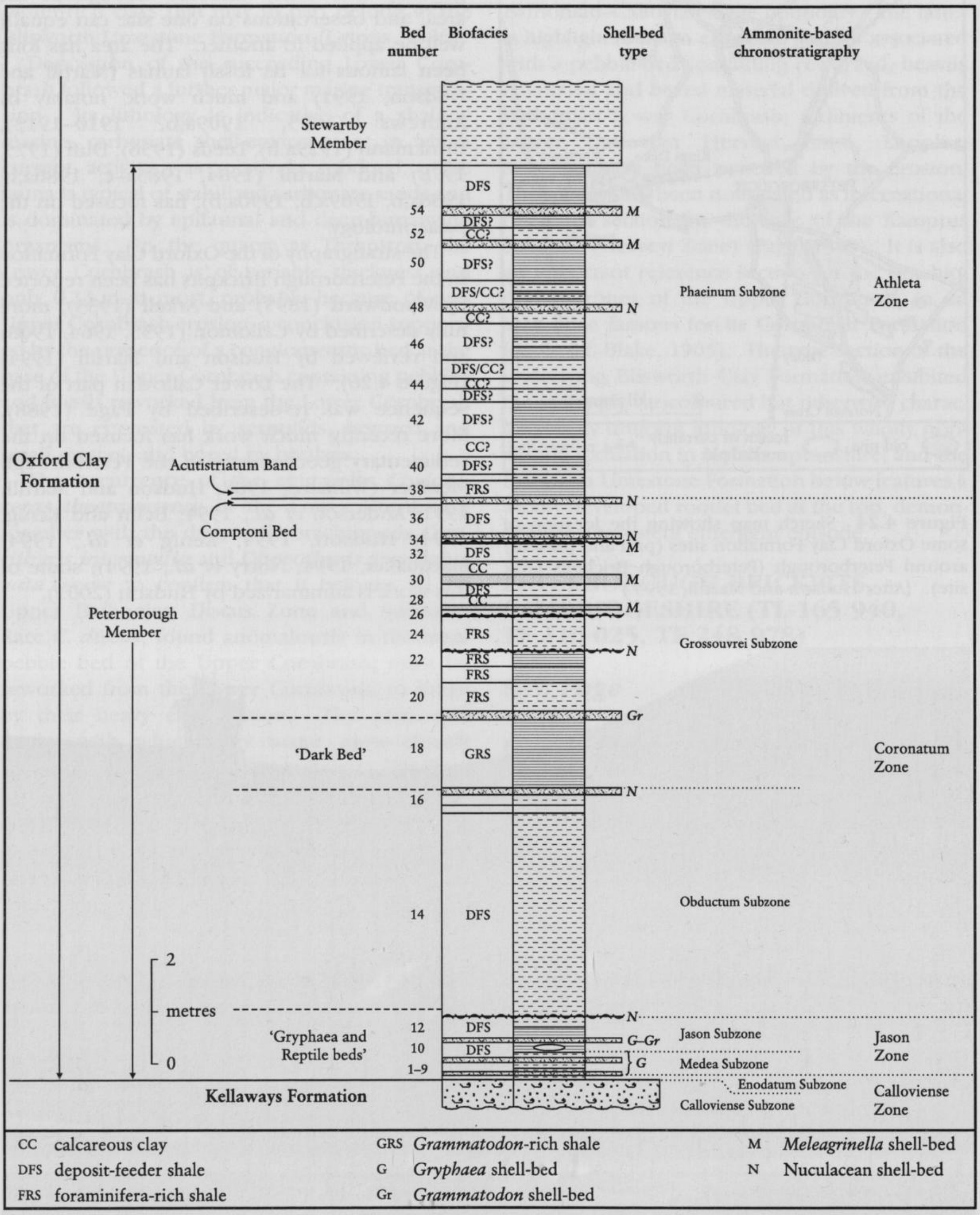


Figure 4.26 Graphic section of the Peterborough Member of the Oxford Clay Formation in the Peterborough district. (After Hudson and Martill, 1994; and Duff, 1975; bed numbers follow Hudson and Martill, 1994.)

Description

The complete Callovian sequence is not now seen in the Peterborough Brickpits district as the basal beds, in the Cornbrash Formation (Abbotsbury Cornbrash Formation of Page, 1989) and Kellaways Formation (Cayton Clay and Kellaways formations of Page, 1989), are usually only exposed in temporary sections or boreholes (Callomon, 1968; Page, 1988). The sites here taken as representative of the Peterborough Member are (a) Orton Pit (TL 165 940), (b) Dogsthorpe Star Pit (TF 210 025) and (c) Kings Dyke, Whittlesey Nature Reserve site (TF 248 978). The younger Stewartby Member can be seen, in part, at King's Dyke (Hudson and Martill, 1994) and was once exposed in the now-obliterated pits near Eye (Callomon, 1968). The following is therefore a composite sequence based on the exposures recorded in pits, past and present.

Kellaways Formation

The Kellaways Formation is occasionally seen in sumps at the base of working brickpits but more than about 2 m is rarely visible. It comprises olive-grey sand or silt with locally some soft silty sandstone ('sandrock'), and is assigned to the Kellaways Sand Member. Preservation of aragonitic-shelled fossils is usually poor and invariably specimens are crushed or distorted. Bivalves, including *Pleuromya*, *Pholadomya*, *Modiolus* and *Oxytoma*, are common, and *Gryphaea* and belemnites (*Cylindroteuthis*) occur in shell beds. Large blocks of calcareous sandstone, sometimes laminated, with bands of *Gryphaea* and *Cylindroteuthis* have been seen amongst material cleared from construction areas at the Orton site. Occasional ammonites, including *Kepplerites* (*Gowericeras*), large *Proplanulites* and *Sigalocerus* ex gr. *calloviense* (J. Sowerby), have been recorded in the district (Callomon, 1968; Page, 1988).

Oxford Clay Formation

Only the lower part (Peterborough Member) of the overlying Oxford Clay Formation is generally exposed. A composite sequence was described by Callomon (1968), and Hudson and Martill (1994) provided additional sedimentological and palaeontological detail (the latter based, in part, on Duff, 1975, 1978) as well as a detailed measured section of the exposure at King's Dyke, Whittlesey. The Peterborough Member is dominated by brownish-grey fossiliferous organic-rich mudstone, alternating with paler, more calcareous levels with shell-rich beds at a number of levels. In the lower part of the sequence, a distinctive marker band of calcareous septarian concretions is present (Bed 10 of Callomon, 1968); these were regularly visible in the base of Orton Pit and in rock piles cleared from development areas at that site. Hudson (1978) and Hudson *et al.* (2001) described the petrography and geochemistry of these concretions. Hudson and Martill (1994) highlighted local differences in the details of the basal beds in the Peterborough area.

The benthic fauna is of relatively low diversity and dominated by bivalves including *Gryphaea* (mainly in the lowest part), *Meleagrinella braamburiensis* (Phillips), *Mesosaccella*, *Bositra*, *Grammatodon* and *Oxytoma*. Gastropods (*Procerithium* and *Dicroloma*) are also common (Duff, 1975, 1978, 1991). The nektonic fauna is dominated by cephalopods with belemnites (common *Cylindroteuthis puzosiana* (d'Orbigny) (Page and Doyle, 1991, pl. 28) and *Belemnopsis bessina* (d'Orbigny), as well as *Belemnotheutis*) and abundant ammonites (Brinkmann, 1929a,b; Callomon, 1968; Page, 1991; Page and Doyle, 1991). The latter are typically crushed flat in the clays; uncrushed or partially crushed specimens generally only occur in the septarian concretions of Bed 10. Nautilids are, in contrast, very rare and few (including *Paracenoceras calloviense* (Oppel) (Page and Doyle, 1991, pl. 31, fig. 1)) have been recorded. Ostracods, foraminifera and other microfossil groups are also present.

The vertebrate fauna (Martill, 1991a) is exceptionally rich with diverse fish including sharks and rays (*Hybodus*, *Asteracanthus*, *Notidanus*, *Protospinax*, *Paracestracion*, *Heterodontus*, *Orectoloboides* and *Spathobatis*), chimaerids (*Ischyodus*, *Brachymylus*, *Pachymylus*, *Leptacanthus*) and bony fish (*Mesturus*, *Lepidotes*, *Heterostrophus*, *Caturus*, *Osteorachis*, *Asthenocormus*, *Leedsichthys*, *Hypsocormus*, *Aspidorhynchus* and *Pholidophorus*) (Martill, 1989a, 1991b; Woodward, 1888, 1890, 1896, 1928). Most exceptional amongst the bony fish are parts of the giant *Leedsichthys*, a genus possibly reaching more than 10 m in length (Woodward, 1890; Martill, 1985b, 1988b). Most fish remains are fragmentary but articulated specimens are occasionally recovered and the area has been the source of many type specimens.

The reptile fauna is also very diverse and internationally famous for marine species. Plesiosaurs (*Muraenosaurus*, *Tricleidus*, *Cryptoclidus*) (Seeley, 1874; Andrews, 1895, 1909a,b, 1910–1913; Charig and Horrell, 1971; Brown, 1981; Martill, 1991c), pliosaurs (*Liopleurodon*, *Simolestes*, *Peloneustes*, '*Pliosaurus*') (Andrews, 1910–1913; Brown, 1981; Martill, 1991c) and ichthyosaurs (*Ophthalmosaurus*) (Appleby, 1956, 1958; Martill, 1991c) are particularly prominent, accompanied by frequent sea-crocodiles (*Steneosaurus*, *Metriorhynchus*) (Lydekker, 1890; Andrews, 1909b, 1910–1913; Adams-Tresman, 1987a,b; Martill, 1991c). Remarkable but rare dinosaur and pterosaur (*Rhamphorhynchus*) remains are also present. The dinosaurs include sauropods (*Cetiosauriscus*, *Ornithopsis*), ornithopods (*Callovosaurus*), stegosaurs (*Lexovisaurus*), ankylosaurs (*Sarcolestes*) and a possible theropod (Hulke, 1887; Lydekker, 1893; Martill, 1984, 1988a, 1991d). A remarkable number of articulate large marine reptiles has been recovered from Bed 10.

Interpretation

The Peterborough Brickpits are most important as the type locality of the Peterborough Member (formerly known as the Lower Oxford Clay) for which Cox *et al.* (1992) proposed the working clay-pit at Kings Dyke Pit, Whittlesey (TL 23 97) as the reference section (Hudson and Martill, 1994). In addition, the member here provides stratotypes for the Subboreal Middle Callovian Substage, its two ammonite-based zones (Jason and Coronatum) and their subzones (Medea, Jason, Obductum and Grossouvrei; Callomon, 1964, 1968; Cox, 1990; Page, 1991). The ammonites from this interval were investigated by Brinkmann (1929a,b) whose work remains one of the most detailed and famous layer-by-layer studies of morphological evolution (Callomon, 1995). Brinkmann measured the diameter of numerous ammonites collected centimetre-by-centimetre through the brickpit sequence and analysed the ribbing density and other features. His classification involving assignment of macroconchs ([M]) and microconchs ([m]) of a single species to different species, subspecies or subgenera confuses the evolutionary interpretation but nevertheless his work accurately demonstrates the progressive small changes within a single evolutionary lineage. One remarkable observation was that the size of mature (adult) specimens often 'jumps' across shell beds, thereby suggesting that such levels represent small non-sequences, interrupting otherwise continuous sedimentation (Callomon, 1955; Raup and Crick, 1982).

The sequence of these ammonite faunas in this interval is as follows (based on Callomon, 1968, and observations by the present author), using Brinkmann's (1929a,b) '0 cm' level as equating with the base of the Peterborough Member and Callomon's (1968) bed numbers:

LOWER CALLOVIAN
Calloviense Zone, Enodatum Subzone
0–20 cm (Bed 4): *Sigaloceras* (*Catasigaloceras*) *anterior* (Brinkmann) ([M] and [m], including the holotype (Brinkmann, 1929b, pl. 3, fig. 1)) = *anterior* Biohorizon (stratotype, part).

The Enodatum Subzone is remarkably complete at Peterborough and the following three-fold succession of ammonite faunas (biohorizons) has been recognised: *S. pagei* (Mitta) (= *S. enodatum* (Nikitin) α Callomon and Page in Callomon *et al.*, 1989) followed by *S. enodatum* β Callomon and Page (in Callomon *et al.*, 1989) (= *S. enodatum* Nikitin *sensu stricto*) followed by *S. anterior* (Brinkmann) including the specimens figured by Page (1991, pl. 14, fig. 1, pl. 15, fig. 2). At Peterborough, the first two biohorizons are entirely within the Kellaways Sand Member.

MIDDLE CALLOVIAN (stratotype)
Jason Zone (stratotype), Medea Subzone (stratotype)
20–55 cm (beds 5–9): *Kosmoceras* (*Gulielmiceras*) *medea* Callomon ([M], including the specimen figured by Page (1991, pl. 15, fig. 3) and the holotype of *K. nodosum* Callomon (= Tintant, 1963, pl. 34, fig. 1) and [m]); ?*Homeoplanulites*/'*Indosphinctes*' sp.

Jason Zone, Jason Subzone (stratotype)
55–78 cm (Bed 10): *Kosmoceras* (*G.*) ex gr. *jason* auctt. early form ([M], including Tintant, 1963, pl. 25, fig. 1, and [m]); rare *Reineckeia* (*R.*) ex gr. *anceps* (Reinecke) (recorded by Callomon (1968) as *R.* aff. *stuebeli*, *R.* cf. *rehmanni*, *R. grossouvrei* and *R. tyranniformis*); *Cadoceras* cf. *compressum* (Nikitin) (Page, 1991, pl. 17, fig. 3) preserved in septarian concretion = '*jason*' α Biohorizon (stratotype nov.).

78–135 cm (beds 11–13): *Kosmoceras* (*G.*) ex gr. *jason* auctt. ([M] and [m]); including late transient forms (*K. conlaxatum*) = '*jason*' β) Biohorizon (stratotype nov.).

Coronatum Zone (stratotype), Obductum Subzone (stratotype)
135–559 cm (beds 14–16): *Kosmoceras (Zugokosmoceras) obductum* (S.S. Buckman) ([M], including the types of *K. pollucinum* (Tintant, 1963, pl. 43, fig. 1) and *K. castor anterior* Brinkmann (Tintant, 1963, pl. 40, fig. 2), and [m] including *K.* aff. *'gulielmi'* (J. Sowerby) and *K. castor* (Reinecke)); *Erymnoceras coronatum* (Bruguière) (including large [M]).

Coronatum Zone, Grossouvrei Subzone (*sensu* Callomon, 1964, 1968) (stratotype)
559–854 cm (beds 17–18): *Kosmoceras* (*Z.*) [*obductum*] *posterior* Brinkmann ([M] and [m], the latter including *K. 'gulielmi'* and *K. castor* (Reinecke) (including the type of *K. castor* (Reinecke) *castor* Brinkmann (Tintant, 1963, pl. 40, fig. 3) at level 610 cm) = *posterior* α Biohorizon (stratotype nov.); upper 61 cm with *K. pollux* (Reinecke) only = *posterior* β Biohorizon (stratotype nov.).

854–895 cm (beds 19–20): *K.* ex gr. *grossouvrei* (Douvillé) ([M] and [m], including *K.* cf. *posterior* only in shell bed at base and the microconch forms *K. castor* and *K. pollux*); *Erymnoceras* sp. = *grossouvrei* α Biohorizon (stratotype nov.).

895–1054 cm (Bed 21): *K.* (*Z.*) ex gr. *grossouvrei* (Douvillé) ([M] and [m], the latter including the forms *K. castor* and *K. pollux*, and occasional specimens with 'bundled ribs', including the holotype of *K. fasciculatum* Tintant (1963, pl. 41, fig. 5 = *K. aculeatum anterior* Brinkmann) at level 988 cm = *grossouvrei* β Biohorizon (stratotype nov.).

1054–1093 cm (Bed 22): *K.* ex gr. *grossouvrei* (Douvillé) ([M] and ([m], as Bed 21); *Binatisphinctes comptoni* (Pratt) ([M] and [m] common); *Hecticoceras* (*Sublunuloceras*) cf. *lonsdali* (Pratt) ([M] and [m] frequent) = *comptoni* Biohorizon.

UPPER CALLOVIAN
Athleta Zone, Phaeinum Subzone
1093–1135 cm (Bed 23): *Kosmoceras* (*Lobokosmokeras*) ex gr. *phaeinum* (S.S. Buckman) ([M] and [m], the latter including the form *K. acutistriatum* (S.S. Buckman) = '*acutistriatum*' Biohorizon.

At least a further 5.8 m of Peterborough Member have been recorded in the district (Hudson and Martill, 1994). This is also referrable to the Phaeinum Subzone with a similar ammonite fauna to that of Bed 23 given above. It has yielded the types of *Kosmoceras aculeatum* (Eichwald) *aculeatum* Brinkmann (Tintant, 1963, pl. 43, fig. 3) at level 1277 cm, and *K. proniae* (Teisseyre) *duplicosta* (Quenstedt) (Tintant, 1963, pl. 32, fig. 1) at level 1291 cm.

Older horizons of the Lower Callovian Substage are represented in the Kellaways Formation. The ammonites recovered from the Kellaways Sand Member (see 'Description' above) indicate the Calloviense Zone and Subzone and the underlying Koenigi Zone, but a macroconch specimen of *Macrocephalites polyptychus* Spath in Buntings Lane Borrow Pit, near Stanground (TL 200 958; Page, 1988) suggests that the lowest levels of this member may still belong to the Herveyi Zone (Kamptus Subzone, *polyptychus* Biohorizon).

The diversity and exceptional preservation of much of the fossil fauna in the Peterborough Brickpits has led to both taphonomic and ecological studies. Duff (1975) first investigated the succession using a quantitative analysis of the benthic macrofauna and trophic nucleus analysis. He recognized ten biofacies (some of which are shown in Figure 4.26), reflecting minor variations in bottom oxygenation, sediment consistency and other factors, such as winnowing leading to the development of shell beds. A number of clues as to trophic relationships between the diverse elements of the Peterborough Member fauna (Figure 4.27) include cephalopod hooklets in the stomach contents of *Metriorhynchus* (Martill, 1986b) and *Peloneustes* (Martill *et al.*, 1994), supposed semionotid fish bite-marks on an ammonite shell (Martill, 1990a), ?pliosaur bite-marks on plesiosaur bones (Martill *et al.*, 1994), and a *Metriorhynchus* tooth embedded in a bone of *Leedsichthys* (Martill, 1985b). These, with other more circumstantial evidence, have facilitated the reconstruction of complex food webs (Martill *et al.*, 1994). Aspects of the taphonomy of the fauna, especially vertebrates, are discussed by Martill (1985c, 1986a) and Hudson and Martill (1991).

The establishment of an international Oxford Clay Formation Working Group in the late 1980s led to the application of a wide range of new geochemical analytical techniques to studies of the organic-rich mudrock of the Peterborough Member of the Peterborough Brickpits district (Hudson, 1994). Anderson *et al.* (1994) investigated the nature of the Peterborough Member sea by studying carbon and oxygen isotopic compositions of calcareous and phosphatic fossils. They concluded that the Peterborough Member was deposited in 'normal' continental-shelf seawater. The oxygen isotope palaeotemperatures are compatible with thermal stratification provided that the ammonite *Kosmoceras*

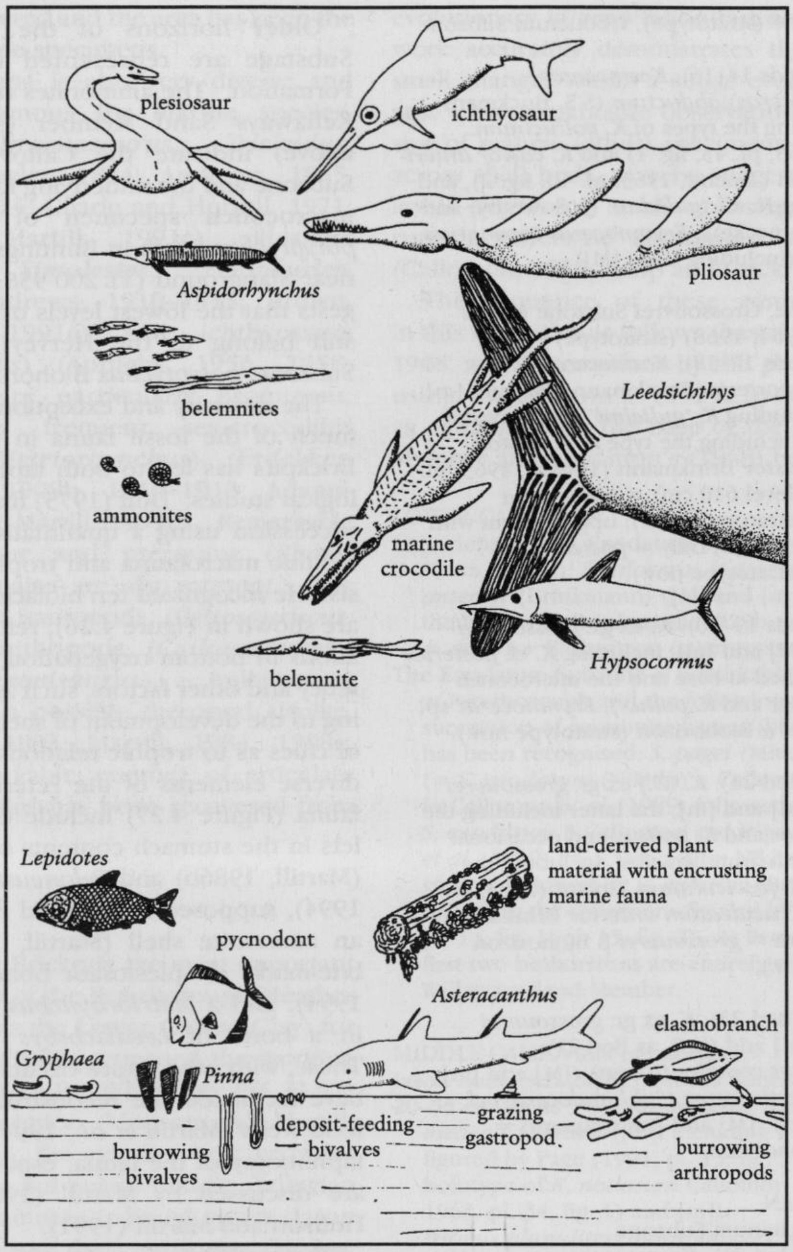


Figure 4.27 Diagrammatic representation of the Peterborough Member faunal community. (After Hudson and Martill, 1991.)

inhabited warmer near-surface waters (mean temperature 21°C, with a range of 16–28°) and that belemnites (*Cylindroteuthis*), indicating cooler temperatures (15°C mean, 12–19°C range), were nekto-benthic or migrated (?seasonally) from cooler waters. As benthic bivalves (nuculaceans and *Gryphaea*) give a similar palaeotemperature range to the belemnites and as the latter include a range of growth stages from juvenile to adult, the nekto-benthic lifestyle is perhaps most likely.

Bulk geochemical analysis has revealed that the Peterborough Member is remarkably immature as regards its organic component (Kenig *et al.*, 1994). Some 75–95% of the amorphous organic matter is of marine origin and the contribution of terrestrial material is limited (Belin and Kenig, 1994). The variations in content partly coincide with ammonite subzonal boundaries, and also correspond to the biofacies (based on macrofaunal assemblages) of Duff (1975). The latter reflect environmental changes and are therefore significant. In particular, the deposit-feeder shales of Duff (1975), which were deposited under dysaerobic conditions are more organic-rich than the shell beds which formed under more aerobic conditions. Important constituents of the organic material include phytane and pristane, derived from the degradation of chlorophyll. The petrography and isotopic composition of the organic material indicates a marine source but no molecular biomarkers specific to any individual marine primary producers could be analysed (Kenig *et al*., 1994).

Belin and Kenig (1994) demonstrated that the sediments of the Peterborough Member have a microbioturbated texture indicating that the sea floor was never completely anoxic for long periods. The high organic content and its limited alteration, despite this reworking, indicate a very high productivity in the waters above and the most organic-rich levels, such as Bed 10, are rich in coccolith-containing faecal pellets confirming enhanced trophic activity. The presence of organic material, interpreted by Belin and Kenig (1994) as cyanobacterial coatings, indicates that the depositional environment was relatively shallow, certainly not greater than the photic zone.

Whole-rock elemental geochemistry and mineralogical analysis carried out by Norry *et al*. (1994) indicated that the mineral assemblage of the clays is mostly in-situ detrital material, with little diagenetic alteration. However, the presence of some heavy minerals may facilitate the identification of sources of the sediment. Macquaker (1994) indicated that the clay is dominated by illite, mixed layer illite–smectite and kaolinite mixed with the amorphous organic material. Minor components include authogenic pyrite, silt-sized quartz grains, calcareous nannoplankton (mainly disarticulated coccolith plates) and a variety of early carbonate cements. Some mudstones contain abundant foraminifera which is compatible with the observation of Kenig *et al*. (1994) that the seabed was at least intermittently oxygenated. However, recent work by Kenig and collaborators (summarized by Hudson, 2001) reveals the presence of the biomarker isorenieratane. This is derived from green sulphur bacteria that are photosynthetic but anaerobic, and shows that the water column was, at times, anoxic within the photic zone. Therefore, the Peterborough Member sea was characterized by an alternation between oxic and anoxic states, and the relative durations of these strongly influenced the benthic faunas.

Conclusion

The famous exposures of the Peterborough Member of the Oxford Clay Formation near Peterborough (its type locality) yield rich fossil faunas of the upper Lower Callovian and Middle Callovian substages. They include reference sections for the entire Middle Callovian Substage, including its component Medea and Jason subzones (Jason Zone), and the Obductum and Grossouvrei subzones (Coronatum Zone). It is therefore of considerable international stratigraphical importance. In addition to stratigraphically and palaeontologically important ammonite faunas, diverse molluscan assemblages allow palaeoecological studies. The area is also world famous for its vertebrate faunas including fish, marine reptiles and rare dinosaurs. Recent sedimentary geochemical studies have revealed unusually well-preserved organic molecules, indicating a globally very rare preservational environment that contributed to the preservation of the rich invertebrate and vertebrate faunas.

COLLYWESTON, NORTHAMPTONSHIRE (TF 000 030)

B.M. Cox

Introduction

Collyweston, in Northamptonshire, is renowned for a local development of fissile sandstone or sandy limestone, known as 'Collyweston Slate', within the basal beds of the Lincolnshire Limestone Formation. It has been exploited hereabouts since Roman times, but its extraction is now confined to Collyweston village itself, the type locality. Traditionally, quarrying took place only during December and January when the rock could be laid out to allow the winter frosts to split it along its natural cleavage (Figure 4.28). When first exploited, it was dug from opencast workings but subsequently (until 1964), it was mined from faces up to about 10 m long in underground tunnels or galleries running from the bottom of an open, *c.* 2.5 m^2 shaft. The slates are renowned for their durability, and have

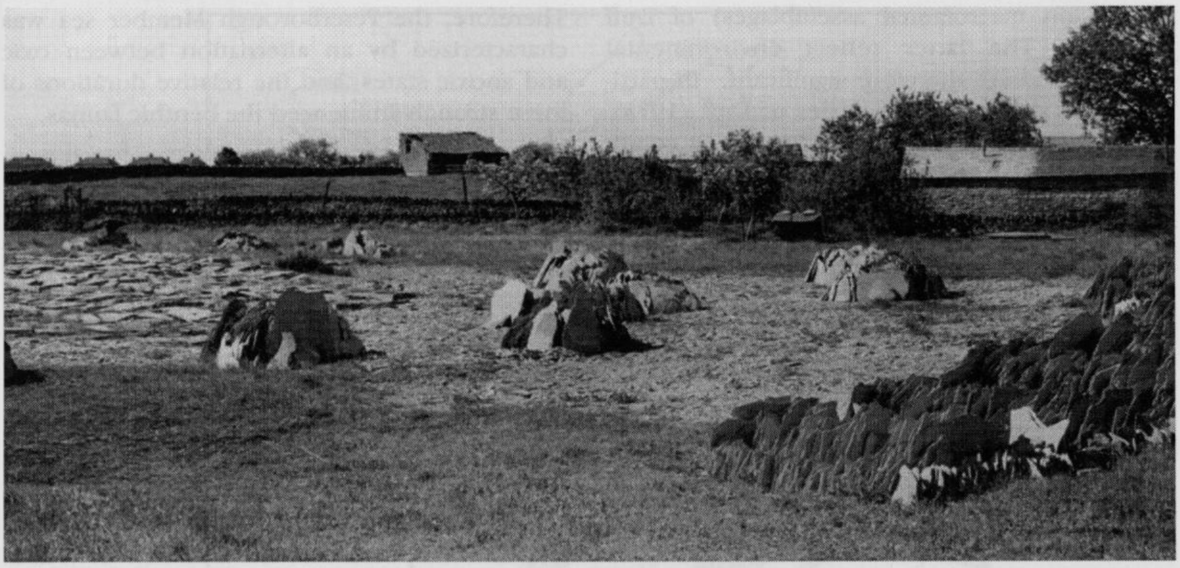


Figure 4.28 Collyweston Slate workings showing slates stacked before trimming and slabs laid out for 'frosting'. (Photo: British Geological Survey, No. A8333, 1949.)

a pleasing colour (Arkell, 1947c). They tend to be larger and thinner than Stonesfield or Cotswold slates (other sources of Jurassic roofing material; see **Stonesfield** and **Huntsman's Quarry** GCR site reports, this volume), and a roof made from them is therefore relatively less heavy (Clifton-Taylor and Ireson, 1994). They can be seen on many local buildings (e.g. in the villages of Collyweston and Easton-on-the-Hill) as well as farther afield (e.g. on old college buildings in Cambridge, including the 1965 re-slating of the Master's Lodge of Trinity College; Purcell, 1967). In the 17th century, they were used widely in the town of Stamford, in place of thatch, in order to lessen the risk of the spread of fire. By the early 20th century, the industry was in decline partly for economic reasons but also because of a number of mild winters that prevented the frosting process. The main Collyweston Quarry – known as 'The Deeps' – is now a nature reserve leased to the Wildlife Trust for Northamptonshire by Burghley Estates (Johnson, 1994) but a section is still visible in an old shaft, known as 'Spall's Mine', which constitutes the GCR site. A new quarry, opened at Collyweston about 10 years ago by Bullimores Sand & Gravel Ltd, now provides a more accessible source of the slate. Although most of the production is used as aggregate and roadstone, about 0.01% goes into roofing which is still carried out by a few craftsmen (Anonymous, 1994).

Description

The following section is based on Ashton and Hudson (1979).

	Thickness (m)
Lincolnshire Limestone Formation	
6: Limestone, ooidal and peloidal, bioclastic	1.7
5: Limestone, sandy, peloidal; concretions in lower part	1.75
4: Limestone, bioclastic, ooidal; peloidal in basal part; basal erosion surface scouring down into underlying bed	0.8–0.9
3: Limestone, hard, brown, sandy, peloidal, forming roof of mine; pockets of shell debris and carbonaceous fragments; interburrowed junction at base	1.0–1.15
2: *Collyweston Slate*: Sandstone, fine- and very fine-grained, trough cross-bedded, calcareous; troughs broad (1–3 m) and shallow (up to 0.25 m); fossils, particularly bivalves (including *Gervillella*, *Meleagrinella*, *Pinna* and pectinids), quite common mainly in layers paralleling lamination within troughs	up to 0.5
1: Sandstone, soft, friable, yellow, fine grained, calcareous, weathering to loose sand with trough cross-beds containing large concretions (2.0 m × 0.20 m) in lower part, and pale and dark (carbonaceous) parallel laminae in upper part; some burrows	seen to 0.7

According to Ashton and Hudson (1979), beds 4–6 are rather poorly exposed in the shaft; the above description has been deduced from their graphic log. Woodward (1894), in a generalized section for Collyweston, described these upper beds as 0.9 m of sand with concretionary nodules and 'thin irregular slabs in undulating layers' overlain by 3.0–3.7 m of marly and 'oolitic' limestones with occasional sandy beds.

The fauna of the Collyweston Slate is abundant with bedding planes covered with fossils. Bivalves include *Astarte*, *Camptonectes*, *Ceratomya*, *Ctenostreon*, *Cucullaea*, *Entolium*, *Eopecten*, *Gervillella*, *Goniomya*, *Homomya*, *Isognomon*, *Lucina*, *Meleagrinella*, *Modiolus*, *Neocrassina*, *Oxytoma*, *Parallelodon*, *Pholadomya*, *Pinna* (the 'crow's beak' of the slate-workers), *Placunopsis*, *Pleuromya*, *Propeamussium*, *Protocardia*, *Pteroperna*, *Trigonia* and *Vaugonia*, of which *Gervillella acuta* (J. Sowerby) and *Trigonia compta* (Lycett) are particularly common. Gastropods include the rather rare *Phyllochilus bentleyi* (Morris and Lycett), known locally as the 'water-spider' (Woodward, 1894; Richardson, 1939b; Sylvester-Bradley, 1968; Figure 4.29). The belemnite *Belemnopsis bessina* (d'Orbigny) is also recorded, together with worm-tracks, burrows, fish and plant remains (Judd, 1875). An extensive species list is given in Woodward (1894). However, the fauna lacks the insects, crustaceans, reptiles and mammals that are found amongst the otherwise similar fauna of the slates at **Stonesfield** (see GCR site report, this volume) (Brodie, 1850).

Interpretation

The lithostratigraphical position and age of the Collyweston Slate have been the subjects of discussion but there now seems to be general agreement about both. The lower part of the Lincolnshire Limestone Formation becomes progressively more sandy and shows a downward passage into the Grantham Formation. The Collyweston Slate occurs in this lithological transition (called the 'Collyweston facies' by Ashton and Hudson, 1979) where there are indurated sandy layers and concretionary masses within a variable sequence of alternating sand and sandy limestone. The more massive and fissile of these concretionary masses are the Collyweston Slate which hereabouts varies from less than 0.1 m up to about 1 m in thickness (Purcell, 1967). The current view is that the Collyweston Slate belongs in the basal division of the Lincolnshire Limestone Formation (near the southern limit of that formation) as a lateral facies variation within the Sproxton Member of Ashton (1980) or the Blue Beds of Richardson (1939b). According to Ashton and Hudson (1979), the yellow sands of

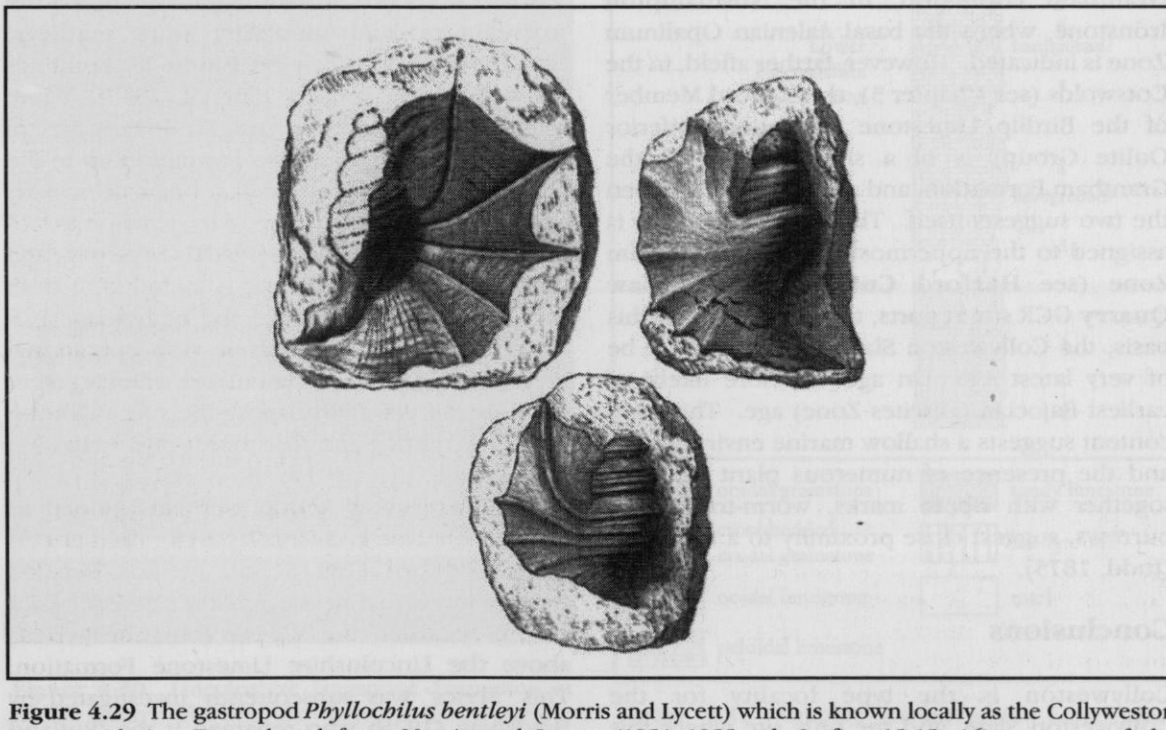


Figure 4.29 The gastropod *Phyllochilus bentleyi* (Morris and Lycett) which is known locally as the Collyweston 'water-spider'. (Reproduced from Morris and Lycett (1851–1855, pl. 3, figs 15,15a,16) courtesy of the Palaeontographical Society.) All natural size.

Bed 1 are elsewhere seen to pass laterally into typical, well-cemented Collyweston Slate; they therefore belong to the 'Collyweston facies' of the Lincolnshire Limestone Formation rather than the underlying Grantham Formation. Elsewhere, interdigitation of the respective facies of these two formations has been recorded (Ashton and Hudson, 1979). Throughout the 'Collyweston facies', the degree of cementation varies with friable quartz sand passing into hard, calcareous sandstones and sandy peloidal limestones. Selective decalcification has also affected the lithologies. Differential cementation produces a spectacular range of concretions including those known locally as 'potlids' (Ashton and Hudson, 1979).

Although molluscs are otherwise well represented in the fauna, ammonites, as in many parts of the Lincolnshire Limestone Formation, have not been recorded. Age dating in terms of the standard ammonite-based chronostratigraphy is therefore speculative. Above the Collyweston Slate, the Greetwell Member of Ashton (1980) (the Little Ponton Beds of Kent (1941)), which overlies the Sproxton Member (Blue Beds) in south Lincolnshire, has yielded an ammonite fauna indicative of the Lower Bajocian Discites Zone. The nearest ammonite fauna from below occurs, beneath the largely non-marine Grantham Formation, in the Northampton Ironstone, where the basal Aalenian Opalinum Zone is indicated. However, farther afield, in the Cotswolds (see Chapter 3), the Harford Member of the Birdlip Limestone Formation (Inferior Oolite Group) is of a similar facies to the Grantham Formation, and a correlation between the two suggests itself. The Harford Member is assigned to the uppermost Aalenian Concavum Zone (see **Harford Cutting** and **Jackdaw Quarry** GCR site reports, this volume). On this basis, the Collyweston Slate could therefore be of very latest Aalenian age or, more likely, of earliest Bajocian (Discites Zone) age. The fossil content suggests a shallow marine environment, and the presence of numerous plant remains, together with ripple marks, worm-tracks and burrows, suggest close proximity to a shoreline (Judd, 1875).

Conclusions

Collyweston is the type locality for the Collyweston Slate, and the only site where this unusual facies of the basal Lincolnshire Limestone Formation occurs and is still worked. The range of lithologies within the 'Collyweston facies' is as much a function of diagenesis as original depositional environment although its stratigraphical relationships and diverse array of sedimentary structures testify to a complex palaeoenvironment. In recent years, planning authorities, conservation officers, English Heritage, the National Trust, and discerning individuals are keeping alive the demand for natural stone as a roofing material of which the Collyweston Slate is a fine example. The site also has historical interest as it gives some insight into the traditional methods of slate extraction.

KETTON QUARRY, RUTLAND (SK 970 060)

M.G. Sumbler

Introduction

The extensive Ketton Quarry GCR site is a complex of quarries in the county of Rutland, 5 km to the west of Stamford, Lincolnshire. Workings here date back many centuries. Initially, the quarries exploited the 'Ketton Stone', fine freestones from the Upper Lincolnshire Limestone, which have been valued for their even texture, 'carveability' and durability since medieval times, and which can be found in buildings throughout the country (Purcell, 1967). More recent working of beds from the lowest part of the Lincolnshire Limestone Formation up to the Blisworth Clay Formation has been principally for cement. Thus, over the years, a major part of the Middle Jurassic succession has been exposed and for this reason the site is included in both the Aalenian–Bajocian and the Bathonian GCR blocks. The site adjoins a vast operational quarry run by Castle Cement Ltd where current sections (SK 980 070) expose the succession up to and including the Cornbrash and Kellaways formations.

The quarries at Ketton were mentioned as early as Ibbetson and Morris (1848), Judd (1875) and Woodward (1894), but the first detailed description is that by Richardson (1939a). Aslin (1965) recorded the 'Upper Estuarine Series', above the Lincolnshire Limestone Formation. This 'Series' was subsequently investigated by Bradshaw (1978) who renamed it the 'Rutland Formation'; the site is its type section. The succeeding Blisworth Limestone Formation was investigated by Cripps (1986). Useful summaries of the succession are given by Sylvester-Bradley *et al.* (1965), Sylvester-Bradley (1968), Ashton and Hudson (1979), and Bradshaw and Cripps (1983). Recently, a small area adjoining the southern part of the site (SK 978 053) has been preserved as the 'Ketton Geological Trail' which shows the succession from the upper part of the Lincolnshire Limestone Formation to the lower part of the Blisworth Clay Formation (Dawn, 1995).

Description

The following composite section is based on several sources. The section of the Lincolnshire Limestone Formation is based on Aslin (in Sylvester-Bradley, 1968), and Ashton (in Ashton and Hudson, 1979) with bed numbers following Ashton (Figure 4.30 and 4.31); that of the Rutland Formation is based on Aslin (in Sylvester-Bradley, 1968), Bradshaw (1978) and Bradshaw and Cripps (1983) with bed numbers following Aslin (in Sylvester-Bradley, 1968) (Figures 4.32 and 4.33). The section of the remaining beds is based on Aslin (in Sylvester-Bradley, 1968), with some additional data from Cripps (1986).

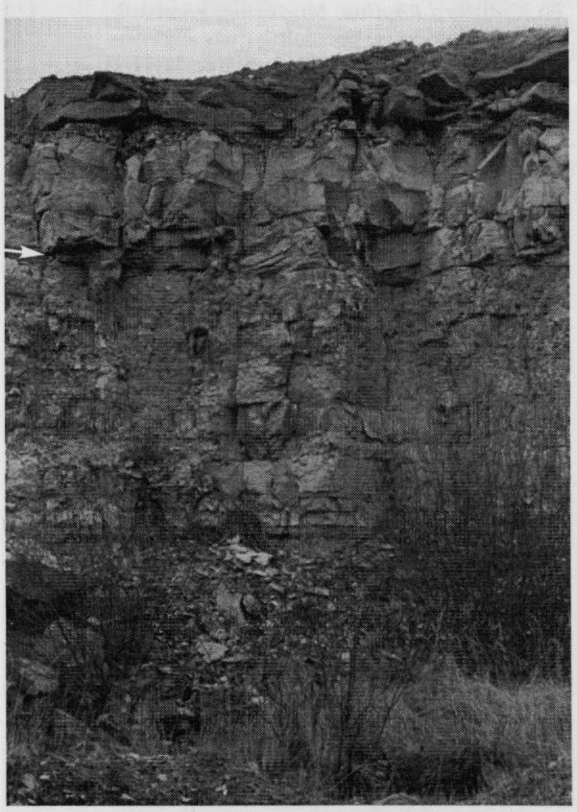


Figure 4.30 Lincolnshire Limestone Formation at Ketton Quarry. The boundary between the Lower and Upper Lincolnshire Limestone is marked by a white arrow. (Photo: M.G. Sumbler.)

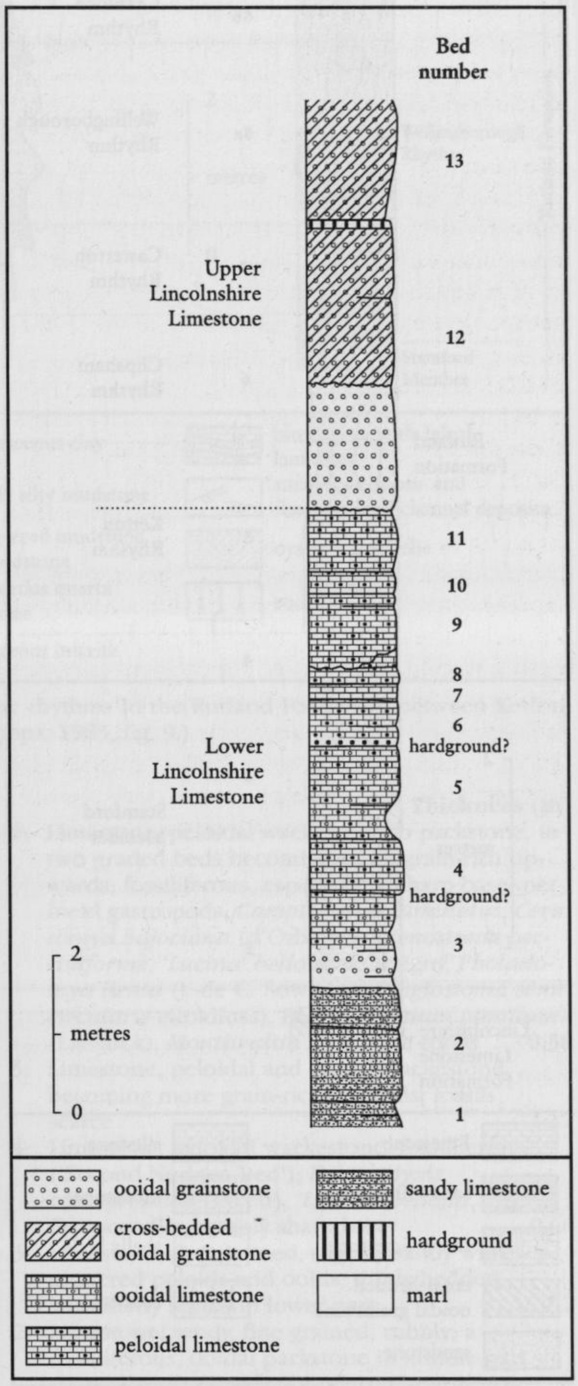


Figure 4.31 Graphic section of the Lincolnshire Limestone Formation at Ketton Quarry. (After Ashton in Ashton and Hudson, 1979.)

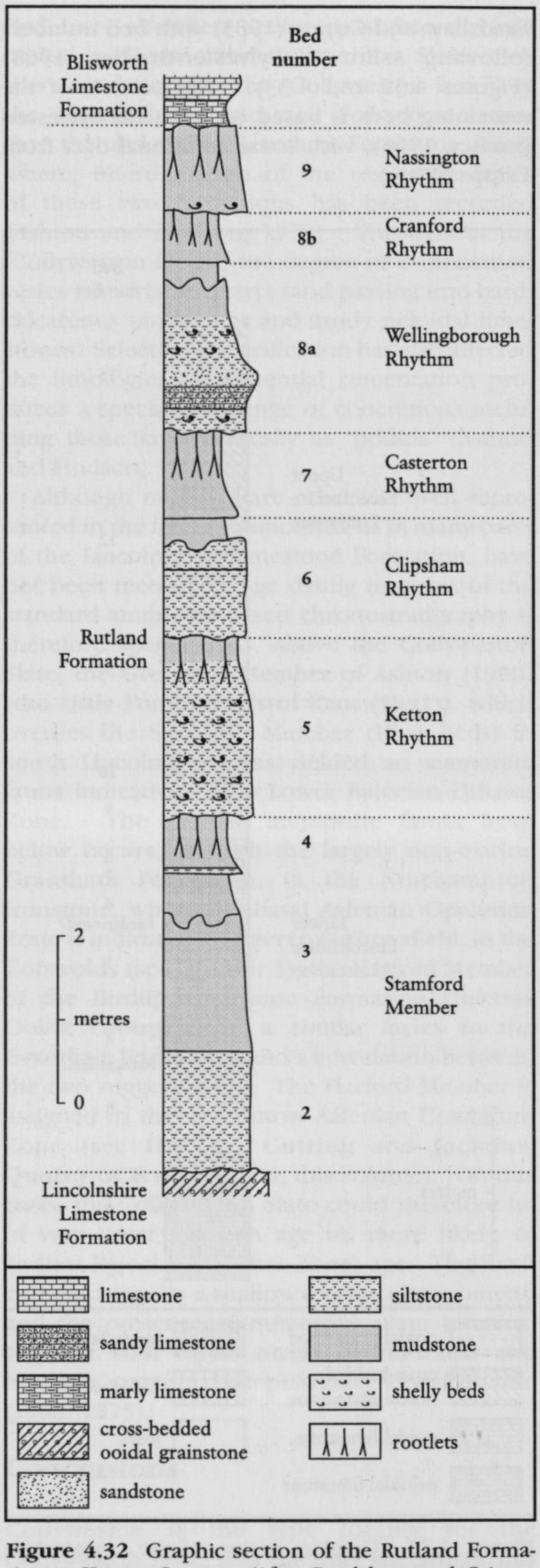


Figure 4.32 Graphic section of the Rutland Formation at Ketton Quarry. (After Bradshaw and Cripps, 1983, fig. 5.)

	Thickness (m)
Blisworth Clay Formation	
8: Clay passing up into subsoil	seen to 1.52
Blisworth Limestone Formation	
7: Layers of fibrous calcite ('beef')	0.02–0.05
6: Limestone, thinly bedded to rubbly, packed with *Praeexogyra hebridica* (Forbes), also *Modiolus imbricatus* J. Sowerby, *Placunopsis socialis* and other fossils	0.71
5: Limestone, hard with *P. hebridica*	0.30–0.38
4: Clay, with *P. hebridica*	0.05–0.08
3: Limestone, hard, with *M. imbricatus*, *P. hebridica*; very irregular base	0.53
2: Limestone, rubbly, thinly interbedded with clay; common *P. hebridica* and other bivalves; sporadic *Kallirhynchia sharpi* Muir-Wood in lower *c.* 0.4 m	1.52
1: Limestone, hard, massive, though decomposing to soft marl in basal *c.* 0.3 m; very fossiliferous with *Bactroptyxis*, *Natica*, *M. imbricatus*, *P. hebridica*, *Pholadomya*, *Pleuromya*, *Protocardia subtrigona* Morris and Lycett, *Epithyris oxonica* Arkell, *Clypeus muelleri* Wright	0.76
Rutland Formation	
9: *Nassington Rhythm*: Mudstone, green to orange-brown, sandy; sporadic rootlets in upper part; thin layers of shell fragments at base	0.90–1.22
8b: *Cranford Rhythm*: Mudstone, green, homogeneous, becoming carbonaceous with rootlets in upper part; interlayered with silt at base	0.30–0.60
8a: *Wellingborough Rhythm*: Mudstone, purple-brown and green, very dark and carbonaceous with rootlets at top, passing down into sandstone to sandy limestone, hard, blue-hearted, cross-bedded, interlayered with mudstone, locally very shelly in lower part	1.90
7: *Casterton Rhythm*: Mudstone, green and black with rootlets passing down into mudstone, dark-green with sandy, shelly layers	1.22
6: *Clipsham Rhythm*: Mudstone, purple-brown and green, black and carbonaceous at top; sandy and with rootlets in upper part; becoming less homogeneous with sandy and shelly seams in lower part	1.3–1.52
5: *Ketton Rhythm*: Mudstone; ironstone concretions and rootlets near top, passing down into mudstone, grey and green, interlayered with shelly sand and silt in lower half; very fossiliferous with fauna including *Lingula* near base	1.83-2.0
Stamford Member	
4: Mudstone, green to black, with rootlets, passing down into siltstone, white, interlaminated with mudstone	0.38–0.46
3: Mudstone, grey-mauve to brown, silty; black and carbonaceous at top; thin, carbonaceous seam at base	2.03-2.23
2: Siltstone, white to buff, with rootlets throughout; limonite nodules (and ?pebbles) in basal *c.* 0.4 m	1.37–1.95

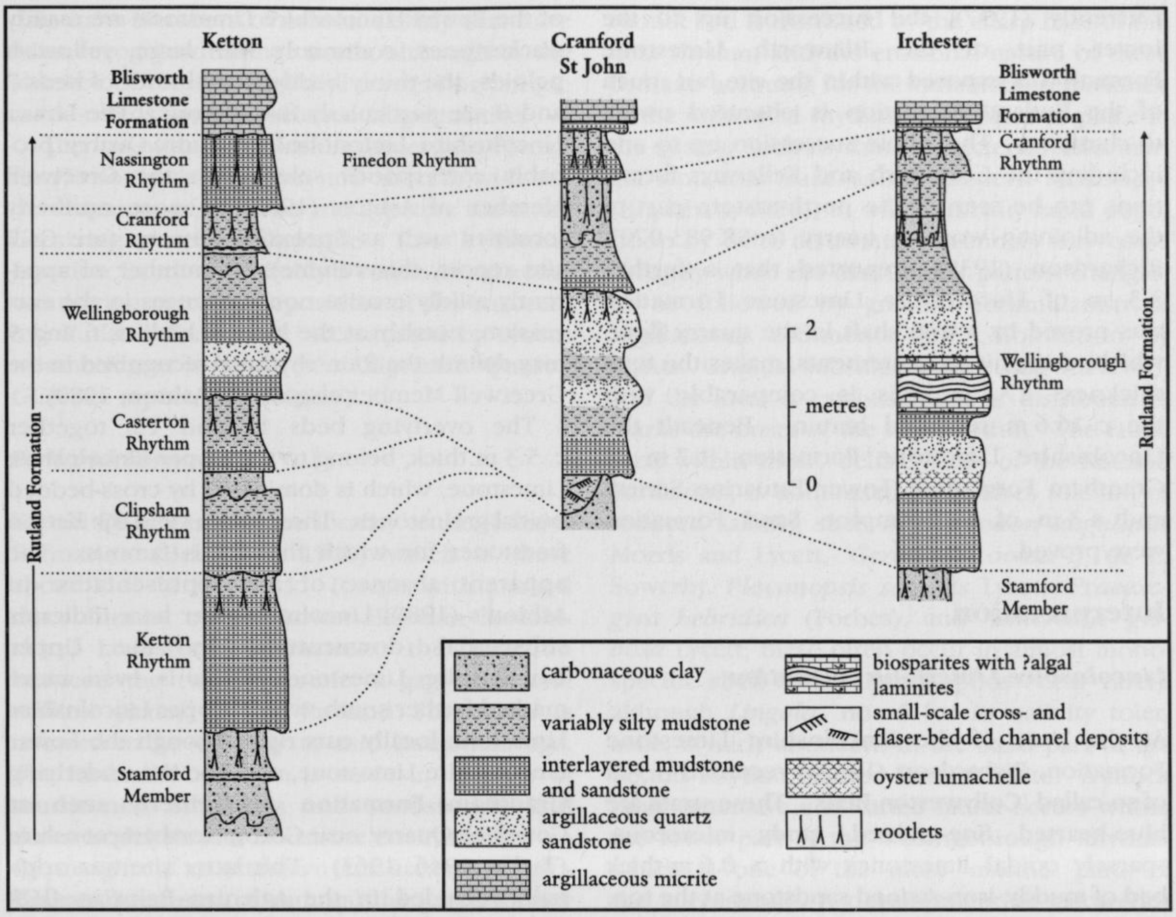


Figure 4.33 Graphic sections showing correlation of the rhythms in the Rutland Formation between Ketton, Cranford St John and Irchester. (After Bradshaw and Cripps, 1983, fig. 9.)

Thickness (m)

Lincolnshire Limestone Formation

Upper Lincolnshire Limestone

13: Limestone, flaggy, cross-bedded, ooidal grainstone, full of broken shells; *Camptonectes laminatus* (J. Sowerby), *Eopecten abjectus* (Phillips), *Gervillella*, *Catinula ampulla* (d'Archiac), *Oxytoma*, *Plicatula*, *P. seudolimea duplicata* (J. de C. Sowerby), *Microrhynchia barnackensis* Muir-Wood, terebratulids, echinoids 1.60

12: Limestone, massive, blue-hearted, pinkish, even-grained ooidal grainstone, cross-bedded in parts; notable hardground at top with annelids and *Lithophaga* borings, and encrusting oysters 3.20–3.60

Lower Lincolnshire Limestone

11: Limestone, wackestone with large yellow-stained peloids becoming more dominant towards top; *Ctenostreon pectiniforme* (Schlotheim) 0.80–1.04

10: Limestone, packstone with large yellow peloids 0.25

9: Limestone, sparsely peloidal, bioturbated wackestone; sharp, ?channelled base up to 0.90

8: Limestone, sparsely peloidal wackestone up to 0.38

7: Limestone, calcilutite, fossiliferous 0.20

Thickness (m)

6: Limestone, peloidal wackestone to packstone, in two graded beds becoming more grain-rich upwards; fossiliferous, especially at sharp base; nerineid gastropods, *Camptonectes laminatus*, *Ceratomya bajociana* (d'Orbigny), *Ctenostreon pectiniforme*, *'Lucina' bellona* d'Orbigny, *Pholadomya lirata* (J. de C. Sowerby), *Plagiostoma semicircularis* (Goldfuss), *Propeamussium pumilum* (Lamarck), *Montlivaltia* and other corals 0.58

5: Limestone, peloidal and ooidal wackestone becoming more grain-rich upwards; fossils scarce 1.12

4: Limestone, peloidal wackestone, fossiliferous ('Second Nerinea Bed'); *Bactroptyxis cotteswoldiae* (Lycett), *'Lucina' bellona*, *Protocardia*; notably sharp base 0.66

3: Limestone, fine grained, slightly sandy with scattered peloids and ooids, thinly bedded with marly seams in lower part *c.* 1.2

2: Limestone, sandy, fine grained, rubbly; a fossiliferous, ooidal packstone in middle part ('First Nerinea Bed'); abundant *Bactroptyxis cotteswoldiae*, *Gervillella* cf. *acuta* (J. Sowerby), *G. verviformis* Cox, *'Lucina' wrighti* Oppel 0.90

1: Limestone, fine grained, sandy 0.40

Currently (1997), the succession up to the lower part of the Blisworth Limestone Formation is exposed within the site but much of the Rutland Formation is obscured owing to slumping. The whole succession up to and including the Cornbrash and Kellaways formations can be seen in the north-eastern part of the adjoining working quarry (*c.* SK 983 070). Richardson (1939a) reported that a further 3.3 m of Lincolnshire Limestone Formation was proved by a trial shaft in the quarry floor, which, using his measurements, makes the total thickness 17.2 m; this is comparable with the *c.* 16.6 m recorded herein. Beneath the Lincolnshire Limestone Formation, 1.7 m of Grantham Formation (Lower Estuarine Series) and 4.3 m of Northampton Sand Formation were proved.

Interpretation

Lincolnshire Limestone Formation

At the base of the Lincolnshire Limestone Formation, Richardson (1939a) recorded 3.3 m of so-called 'Collyweston Beds'. These strata are blue-hearted, fine-grained, sandy, micaceous, sparsely ooidal limestones with a 0.6 m-thick bed of muddy, iron-stained sandstone at the top. The latter probably corresponds with the fine-grained sandy limestone ('Blue Beds') forming the floor of the quarry as recorded by Aslin (in Sylvester-Bradley, 1968). These sandy strata probably equate with the 'Collyweston facies' of **Collyweston** (see GCR site report, this volume), which lies only 3 km to the south-east, although the characteristically fissile beds of the Collyweston Slate seem not to be well developed at Ketton Quarry where the lithologies more resemble the Sproxton Member of Ashton (1980), albeit rather thicker than at the type locality some 22 km to the north-west (see **Sproxton Quarry** GCR site report, this volume).

Together with the 'Blue Beds', the succeeding *c.* 8 m of strata belong to the Lower Lincolnshire Limestone (beds 1–11). This part of the succession is dominated by peloidal wackestones and packstones, in which individual beds commonly show an upward grading to more grain-rich lithologies. Fossils, notably nerineid gastropods, are common at some levels, particularly in the upper part of Bed 2 and in Bed 4 (i.e. the First and Second Nerinea beds of Aslin, in Sylvester-Bradley, 1968). The succeeding beds of the Lower Lincolnshire Limestone are mainly wackestones, commonly with large, yellowish peloids; the thinly bedded calcilutites of beds 7 and 8 are particularly fossiliferous. The Lower Lincolnshire Limestone of Ketton Quarry probably corresponds solely with the Greetwell Member of Ashton (1980) at more northerly localities such as **Sproxton Quarry** (see GCR site report, this volume). A number of apparently mildly erosive non-sequences in the succession, notably at the base of beds 4, 6 and 9 may delimit the four 'rhythms' recognized in the Greetwell Member elsewhere (Ashton, 1980).

The overlying beds 12 and 13, together *c.* 5.3 m thick, belong to the Upper Lincolnshire Limestone, which is dominated by cross-bedded ooidal grainstones. These strata yield the Ketton freestones for which the site is famous. The apparent absence of any representative of Ashton's (1980) Lincoln Member here indicates substantial downcutting by the Upper Lincolnshire Limestone, which is even more marked farther south, where Upper Lincolnshire Limestone locally cuts right through the Lower Lincolnshire Limestone, and into the underlying Grantham Formation as formerly seen at Cowthick Quarry, near Corby, Northamptonshire (Taylor, 1946, 1963). This latter site was originally included in the Aalenian–Bajocian GCR Block but its primary interest has now been excavated away. However, the site, now a RIGS, exposes Lincolnshire Limestone Formation faulted against Rutland Formation, and is often visited by educational parties.

At the base of the Upper Lincolnshire Limestone at Ketton Quarry, well-sorted, even-grained oolites pass upwards into more poorly sorted, shelly limestones, which are capped by a bored and oyster-encrusted hardground, at the top of Bed 12. This is succeeded by brown-weathered, shell-fragmental oolites of Bed 13, with some cross-bedding foresets picked out by strings of mudstone clasts. The two units of the Upper Lincolnshire Limestone correspond with the 'Ketton Beds' and succeeding 'Weldon Beds' of Aslin (in Sylvester-Bradley, 1968). Aslin included the former unit in his Lower Lincolnshire Limestone, because it is capped by a hardground, the most striking stratigraphical break in the Lincolnshire Limestone Formation succession here, although the beds themselves are of markedly different facies to the predominantly micritic rocks below. The two units may conceivably correspond with the Sleaford and

Clipsham members of Ashton (1980) that have been recognized farther north, although in the absence of biostratigraphical control or unique marker beds, such correlation is speculative.

The top of the Lincolnshire Limestone Formation is somewhat uneven and altered, with the development of limonite and gypsum, the latter occurring as veins of selenite. This 'Ironstone Junction Band' is probably a result of subaerial weathering prior to deposition of the succeeding Rutland Formation, accentuated by recent weathering at outcrop (see **Clipsham Quarry** GCR site report, this volume).

Rutland Formation

Ketton Quarry is the type locality of the Rutland Formation (Bradshaw, 1978) which is there about 11.7–12.5 m thick. It rests with marked disconformity on the Lower Bajocian Lincolnshire Limestone Formation; the junction between the two represents a gap of several million years, as the Rutland Formation is inferred to be of early to mid Bathonian age. The Rutland Formation is made up entirely of mudstones, siltstones and sandstones, laid down in deltaic and lacustrine environments on the margins of an extensive land area (the Anglo-Brabant Landmass of authors); hence its former name of 'Upper Estuarine Series'. Within this succession, a number of sedimentary rhythms have been recognized (Aslin, 1965; Bradshaw, 1978) which enable correlation within the formation right across the East Midlands.

The lower part, *c.* 3.8–4.6 m thick, is known as the 'Stamford Member' (Bradshaw, 1978). It is entirely non-marine, and is thought to represent the infilling of a shallow, but extensive, freshwater lake. Clean siltstones at the base, representing the first influx of fluvial sediments, pass upwards into carbonaceous clays with plant remains; these accumulated as shallowing proceeded, and the open lacustrine environment gradually transformed into a swamp. Above the Stamford Member, some six separate sedimentary rhythms have been recognized, and are named in the section above (following Bradshaw, 1978). All are essentially similar; they typically comprise a basal sandy unit, often of interbedded sands and muds with a marine to brackish-water shelly fauna, which passes upwards into more homogeneous, sparsely fossiliferous muds, and thence into plant-rich, carbonaceous muds with rootlets. The topmost rootlet bed is truncated by the sharp base of the next rhythm, and the erosional nature of these contacts accounts for the variability in thickness of the individual rhythms from place to place in the quarry. Such rhythms characterize delta margin situations such as the modern Mississippi (Bradshaw, 1978), in which initially rapid deposition by delta distributary channels may cease abruptly when the distributary pattern changes, to be followed by gradual accumulation of argillaceous sediments and colonization by plants. Gradual subsidence (or rising sea level), and the local re-establishment of distributaries marks the onset of the next rhythm. The fauna seen within these 'deltaic' beds of the Rutland Formation, is dominated by bivalves tolerant of reduced salinity, such as *Eomiodon angulatus* Morris and Lycett, '*Gervillella ovata*' J. de C. Sowerby, *Placunopsis socialis* Lycett, *Praeexogyra hebridica* (Forbes), and '*Tancredia*' *gibbosa* Lycett; these often occur in almost monospecific shell beds. Brachiopods occur rarely, although *Lingula*, noted for its salinity tolerance, is fairly abundant in the basal part of the Ketton Rhythm, named from this site. A much more extensive and varied fauna occurs within the lower part of the Wellingborough Rhythm, which is one of the most 'marine' parts of the succession. A development of calcareous sandstone–sandy limestone within the rhythm is better developed farther south (see **Finedon Gullet** and **Irchester Old Lodge Pit** GCR site reports, this volume) where it is distinguished as the Wellingborough Member.

Blisworth Limestone Formation

The Blisworth Limestone Formation (the Great Oolite Limestone of Richardson, 1939a), some 3.9–4.2 m thick, represents the deposits of a marine transgression that overwhelmed the deltas of the Rutland Formation. The lower *c.* 1.2 m of the succession (Bed 1 and the lower part of Bed 2) are mainly massive, cream-coloured, peloidal wackestones, often intensely bioturbated. These beds probably represent the Sharpi Beds that are better developed farther south (e.g. **Cranford St John**, see GCR site report, this volume; Cripps, 1986), although Torrens (1967) considered that this unit was absent at Ketton Quarry. Overlying beds, no longer well exposed at Ketton Quarry, are mainly argillaceous wackestone and packstones with common clay seams and with a fauna that is markedly dominated by oysters (*P. hebridica*), which form lumachelles at some levels. These beds, termed the Longthorpe Member by Cripps (1986), are typical of the Blisworth Limestone Formation in the northern part of the East Midlands region.

Blisworth Clay Formation

The Blisworth Limestone Formation is succeeded by clays, which are no longer exposed within the GCR site but which are now (1998) exposed very well in the adjoining working part of the quarry complex (Castle Cement Quarry). They are also better seen at localities such as **Thrapston** and **Roade Railway Cutting** (see GCR site reports, this volume).

Conclusions

Ketton Quarry has, over the years, exposed a major part of the Middle Jurassic succession, and currently offers good exposures of much of the Lincolnshire Limestone, Rutland and Blisworth Limestone formations. The extent and stratigraphical range of the exposures make the site one of the most important for understanding the stratigraphy and sedimentology of the Bajocian and Bathonian succession in the East Midlands.

CLIPSHAM QUARRY, RUTLAND (SK 977 150)

M.G. Sumbler

Introduction

The Clipsham Quarry GCR site in the county of Rutland, lies some 9 km north-west of Stamford, and little more than 3 km from **Castle Bytham** (see GCR site report, this volume) in adjoining Lincolnshire. It is representative of the extensive complex of quarries that, for many centuries, have produced the famous Clipsham building stone from the Upper Lincolnshire Limestone. The Clipsham Stone is a valued freestone with an excellent resistance to weathering. There are many old quarries in the vicinity of the GCR site, where the stone has been extracted since Roman times. As well as in local buildings, it has been used farther afield, for example in various Cambridge colleges and Windsor Castle (Purcell, 1967). In more recent years, it has been much used in restoration work, for example being used in preference to the more local Cotswold and Bath stones in some of the Oxford colleges (Arkell, 1947c). However, the principal target of quarrying is now the micritic limestone of the Lower Lincolnshire Limestone that is marketed mainly as aggregate.

Description

The section within Clipsham Quarry itself exposes some 6.5 m of Lincolnshire Limestone Formation, all of which belongs to Ashton's (1980) Clipsham Member of the Upper Lincolnshire Limestone, overlain by Rutland Formation (Figure 4.34). The Lincolnshire Limestone Formation here is made up almost entirely of yellowish-brown, well-sorted, medium- to coarse-grained, more-or-less shell-fragmental, ooidal grainstones, which often show spectacular cross-bedding structures. Deeper exposures immediately to the north in the conjoined Clipsham Old Quarry (SK 977 153) indicate that the full thickness of the Clipsham Member is probably about 7 m. Underlying strata of the Lower Lincolnshire Limestone are well exposed in the working quarry where a section was recorded by Kent (in Torrens, 1968b) and figured by Ashton (1980, figs 6,9). A description of the overlying 'Upper Estuarine Series' (Rutland Formation (Bathonian)) was given by Richardson (1939a).

Interpretation

The Clipsham Member is apparently the sole representative of the Upper Lincolnshire Limestone here and its lithologies contrast markedly with the paler, creamy-grey, flat-bedded micritic rocks (wackestones and packstones) that characterize the Lower Lincolnshire Limestone. The only ammonite recorded from the member appears to be a '*Hyperlioceras*' found 'a short distance beneath the Upper Estuarine Beds [Rutland Formation]' (Kent, 1970). Frustratingly, this specimen now appears to be lost (Ashton, 1977) but it is likely that the identification is incorrect, as *Hyperlioceras* is characteristic of the lowest part of the Lincolnshire Limestone Formation (Lower Bajocian, Discites Zone; e.g. see **Greetwell Quarry** GCR site report, this volume), whereas the Clipsham Member probably belongs to the Lower Bajocian

Figure 4.34 Rutland Formation overlying the Upper Lincolnshire Limestone (Clipsham Member) at Clipsham Quarry. (Photo: M.G. Sumbler.)

Laeviuscula Zone (cf. Ashton's (1980) Sleaford Member; see **Castle Bytham** GCR site report, this volume) or possibly even younger horizons.

At Clipsham Quarry, the Upper Lincolnshire Limestone (Clipsham Member) is *c.* 7 m thick but, in the adjoining Clipsham Old Quarry, Kent (in Torrens, 1968b) recorded as little as 3.65 m, a fraction of its thickness elsewhere. This dramatic and rapid thickness variation of the Upper Lincolnshire Limestone from place to place is a result of three principal non-sequences (Ashton, 1980). First, deep channelling at the base of the Upper Lincolnshire Limestone, accounts for the thickest successions (e.g. see **Copper Hill** GCR site report, this volume). Secondly, non-sequences within the Upper Lincolnshire Limestone, such as that at the base of Ashton's (1980) Clipsham Member, account for the absence of his Sleaford Member at Clipsham Quarry. The undulating, channelled base of the Clipsham Member is strikingly displayed in the adjoining working quarry, where it rests on Lower Lincolnshire Limestone, and at other sites such as **Copper Hill** (see GCR site report, this volume) where it cuts into the Sleaford Member. Thirdly, erosion of the top of the Lincolnshire Limestone Formation prior to deposition of the succeeding Rutland Formation may account for some of the thinnest Lincolnshire Limestone Formation successions. This last-named non-sequence represents a 'gap' of several million years of Bajocian and earliest Bathonian time (Parsons, 1980a), during which the Lincolnshire Limestone Formation was probably subjected to subaerial erosion, as suggested by its uneven, ferruginized, apparently karstified top surface. The development of selenite (clear, megacrystalline gypsum) in the topmost bed is a more recent weathering phenomenon resulting from the action of acidic leachates that form by oxidation of pyrite in the mudstones of the succeeding Rutland Formation.

Underlying the Clipsham Member in the quarry complex, Kent (in Torrens, 1968b) recorded 2.44 m of pink-buff, fine-grained, marly, ooidal limestone with abundant brachiopods including *Zeilleria wilsfordensis* Muir-Wood. He equated these beds with Richardson's (1939a) 'Roadstone' of **Castle Bytham Quarry** (i.e. the Sleaford Member of Ashton, 1980; see **Castle Bytham Quarry** GCR site report, this volume). However, according to Ashton's (1980) synthesis, this member is absent at Clipsham Quarry, and the strata (Ashton, 1980, fig. 9, beds 5–7) actually belong to the Castle Bytham Beds, the topmost rhythm of his Lincoln Member of the Lower Lincolnshire Limestone. Ashton (1980, fig. 6) recorded a further 4.2 m (beds 1–4) of Lincoln Member below the Castle Bytham Beds. These comprised mainly ooidal and peloidal wackestones, the greater part of which are thought to belong to the Scottlethorpe Beds, the second sedimentary rhythm of his Lincoln Member (see **Castle Bytham** GCR site report, this volume).

Conclusions

Clipsham Quarry shows a fine section of the Upper Lincolnshire Limestone together with the succeeding Rutland Formation (Bathonian in age; see Ketton Quarry GCR site report, this volume). The karstified top surface of the Lincolnshire Limestone Formation is well displayed. The contrasting facies of the Lower and Upper Lincolnshire Limestone, and the channelled base of the latter are particularly apparent in the adjoining working quarry. The site is thus an important one for sedimentological, palaeoenvironmental and palaeogeographical investigations.

CASTLE BYTHAM, LINCOLNSHIRE (SK 990 180)

M.G. Sumbler

Introduction

The disused quarry at Castle Bytham, 11 km NNW of Stamford, Lincolnshire, is a key exposure showing much of the upper part of the Lincolnshire Limestone Formation (Figure 4.35). It is the type locality for Ashton's (1980) Clipsham Member in the Upper Lincolnshire Limestone, and of the Castle Bytham Beds in the upper part of his Lincoln Member (Lower Lincolnshire Limestone). Perhaps most importantly, it has yielded several ammonites crucial to the dating of the Lincolnshire Limestone Formation. The quarry (the 'Castle Lime Works') was alluded to by Hollingworth and Taylor (1951) and described by Richardson (1939a) who recorded some 14 m or so of strata. Kent (in Sylvester-Bradley, 1968) gave slightly more detail; an extended and further elaborated section by Ashton (1977, 1980) forms the basis of Figure 4.36.

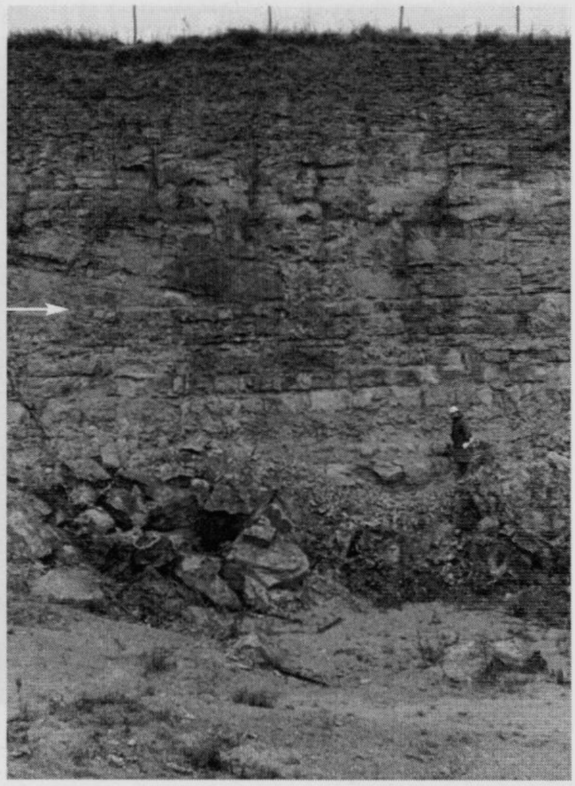


Figure 4.35 Lincolnshire Limestone Formation in the quarry at Castle Bytham. The boundary between the Lower and Upper Lincolnshire Limestone is marked by a white arrow. (Photo: M.G. Sumbler.)

Description

The succession is described in general terms below, with lithostratigraphical terminology and bed numbering following Ashton (1980).

	Thickness (m)
Lincolnshire Limestone Formation	
Upper Lincolnshire Limestone	
Clipsham Member	
15–18: Limestone, pale greyish-brown, cross-bedded (sometimes on giant scale), ooidal grainstone, shelly in parts	seen to 4.8
Sleaford Member	
10–14: Limestone, pale-greyish to brownish, variable; shelly, cross-bedded; massive oolite; well bedded, fossiliferous, fine grained	5.0
Lower Lincolnshire Limestone	
Lincoln Member	
5–9: *Castle Bytham Beds*: Limestone, grey to off-white, ooidal	2.9
3–4: *Scottlethorpe Beds*: Limestone, grey, thinly to massively bedded, fossiliferous, varying from ooidal grainstone to carbonate mudstone	2.8
1–2: Limestone, sparsely ooidal and peloidal wackestone, becoming more massive and ooidal below	1.8

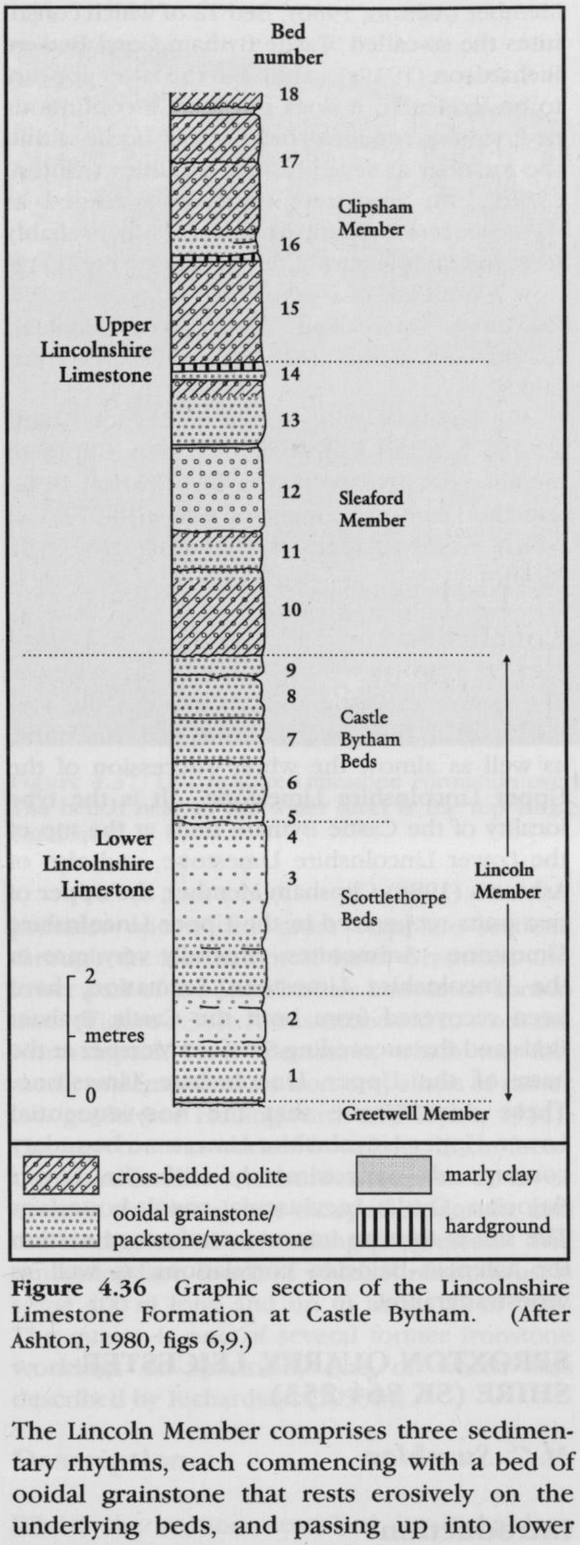


Figure 4.36 Graphic section of the Lincolnshire Limestone Formation at Castle Bytham. (After Ashton, 1980, figs 6,9.)

The Lincoln Member comprises three sedimentary rhythms, each commencing with a bed of ooidal grainstone that rests erosively on the underlying beds, and passing up into lower energy facies packstones and wackestones. The basal unit of the member (Bed 1) is quite fossiliferous at the base, notably with corals such as *Thecosmilia*. Much of the middle rhythm of the Lincoln Member (beds 3 and 4), named the 'Scottlethorpe Beds' by Ashton (1980), comprises sparsely peloidal wackestones. The topmost bed (Bed 4) is an oolite with corals, bivalves, nerineid gastropods and brachiopods including *Acanthothiris crossi* (Walker). This bed probably represents the Crossi Bed[s] of Richardson (1939a) and Kent (in Sylvester-Bradley, 1968), which was the lowest unit seen by them.

Beds 5–9 (the Castle Bytham Beds) represent the topmost rhythm of the Lincoln Member. The basal and top parts are ooidal grainstones although, as in the underlying Scottlethorpe Beds, the middle part of the unit includes lower-energy lithofacies, with bi-modal packstones and sparsely peloidal wackestones. The fauna, which is particularly common in the lower part of the unit, includes bivalves such as *'Lucina' bellona* d'Orbigny, brachiopods (mainly terebratulids), gastropods (mainly nerineids) and corals including *Montlivaltia* and *Thamnasteria*. Most importantly, at least three ammonites have been obtained from the uppermost part of the unit (Richardson, 1939a; Kent, 1966; Ashton, 1977), probably from Bed 8.

The succeeding beds, 10–14, belong to Ashton's (1980) Sleaford Member, the basal unit of the Upper Lincolnshire Limestone. These beds, corresponding approximately with the Roadstone of Richardson (1939a), are mainly ooidal grainstones, cross-bedded in parts, and rest sharply on an erosion surface on the underlying strata. In addition, Bed 12, in the middle of the unit, is a rather nodular, pale-grey, sparsely ooidal wackestone containing common recrystallized corals as well as nerineid gastropods, bivalves and sporadic brachiopods such as *Zeilleria*. The top of the Sleaford Member is an eroded hardground, with a bored and oyster-encrusted surface, of which more details are given by Marshall and Ashton (1980).

Some 4.78 m of the Clipsham Member, probably representing almost its full thickness (?*c*. 6–7 m), are recorded beneath the succeeding Rutland Formation that crops out just beyond the boundary of the quarry. The member is composed of well-sorted, ooidal and shell-fragmental grainstones. Both the basal and uppermost parts of the succession are particularly coarse-grained and rich in shell debris. Most of the succession is markedly cross-bedded, with individual sets up to 2 m thick. Ashton (1980) noted that foreset orientations indicate bi-polar currents, trending variously towards the south-west and north-east. Fauna, mostly as broken debris, is dominated by gastropods and bivalves, but also includes echinoderms, corals and bryozoa. An oyster-encrusted hardground occurs about 2 m above the base, and is succeeded by a structureless, bioturbated oolite (Bed 16).

Interpretation

From beneath Bed 1, signs of marly clay are thought to mark the top of Ashton's (1980) Greetwell Member. The characteristic facies of his Leadenham Member, which, in central Lincolnshire, overlies the Greetwell Member (see **Metheringham** and **Greetwell Quarry** GCR site reports, this volume) are absent in south Lincolnshire (but see **Sproxton Quarry** GCR site report, this volume), and thus beds 1–9 are assigned to his Lincoln Member. This unit, classified as Middle Lincolnshire Limestone by Ashton (1980), is herein considered to be the topmost part of the Lower Lincolnshire Limestone. Within the Lincoln Member, the Scottlethorpe Beds probably correlate with the Kirton Shale of central and north Lincolnshire (see **Cliff Farm Pit** GCR site report, this volume). The 'Crossi Bed or Beds', defined by the occurrence of *A. crossi*, were at one time thought to be a regionally correlative unit, used by some workers to subdivide the Lincolnshire Limestone Formation, but *A. crossi* is now known to be of limited biostratigraphical value (Ashton, 1979). 'Crossi Beds' occur at different stratigraphical levels and are of no great stratigraphical significance. The quarry is the type locality of the succeeding Castle Bytham Beds (beds 5–9), which regional correlation (Ashton, 1980, fig. 4) suggests correspond with Ashton's (1980) Metheringham Member (?and Blankney Member) of central Lincolnshire (see **Metheringham** GCR site report, this volume). At Castle Bytham, this unit was termed the 'Bastard Freestone' by Richardson (1939a), and included in the 'Ancaster Beds' by Kent (in Sylvester-Bradley, 1968). The ammonites that probably come from Bed 8 were originally identified merely as *Sonninia* sp. and assigned to the Discites Zone, but the specimens were subsequently determined as *Sonninia* (*Fissilobiceras*) cf. *ovalis* (S.S. Buckman ex Quenstedt) indicating the Lower Bajocian Ovalis Zone (Parsons, 1974b, 1980a; Ashton, 1977).

The quarry at Castle Bytham is designated a reference section for the overlying Sleaford Member (Ashton, 1980), Bed 12 of which constitutes the so-called 'Castle Bytham Coral Bed' of Richardson (1939a). Although the latter appears to be lenticular, it does not form a continuous bed; similar coralline 'patch reefs' occur within the member at several other localities (Ashton, 1980). An ammonite originally recorded as ?*Hyperlioceras* (Spath in Kent, 1966) probably from the middle part of the member (?Bed 12) is now identified as *Shirburnia* cf. *fastigata* S.S. Buckman, indicating the Lower Bajocian Laeviuscula Zone (Ashton, 1977; Parsons, 1980a).

The topmost part of the succession (beds 15–18) belongs to Ashton's (1980) Clipsham Member (Richardson's (1939a) Clipsham Beds, and the Creeton Member of Ashton (1977)) of which Castle Bytham is the designated type locality.

Conclusions

The quarry at Castle Bytham exposes the topmost part of the Lower Lincolnshire Limestone, as well as almost the whole succession of the Upper Lincolnshire Limestone. It is the type locality of the Castle Bytham Beds at the top of the Lower Lincolnshire Limestone, and also of Ashton's (1980) Clipsham Member, the upper of two units recognized in the Upper Lincolnshire Limestone. Ammonites, generally very rare in the Lincolnshire Limestone Formation, have been recovered from both the Castle Bytham Beds and the succeeding Sleaford Member at the base of the Upper Lincolnshire Limestone. These demonstrate that the non-sequential Lower–Upper Lincolnshire Limestone boundary corresponds approximately with the Lower Bajocian Ovalis–Laeviuscula zonal boundary. The site is thus an important reference section for Aalenian–Bajocian correlations as well as lithostratigraphy.

SPROXTON QUARRY, LEICESTERSHIRE (SK 864 253)

M.G. Sumbler

Introduction

Sproxton Quarry, in Leicestershire, approximately 12 km south-west of Grantham in adjoining Lincolnshire, is an abandoned and partially flooded ironstone quarry (Figure 4.37) that

Figure 4.37 Lincolnshire Limestone Formation overlying Northampton Sand Formation at Sproxton Quarry. The bench near to the water level is the top surface of the Northampton Sand Formation. (Photo: M.G. Sumbler.)

provides one of the more complete sections through the Northampton Sand, Grantham and lower part of the Lincolnshire Limestone formations (Figure 4.38). It was excavated to work the Northampton Sand Formation, which was formerly in demand as an iron ore, albeit of rather low grade (see Hollingworth and Taylor, 1951). The iron ore was worked from long, linear faces, the considerable overburden (up to 20 m or more in thickness) was dumped alongside, and the land restored as working progressed. The remaining face, much of which is precipitous, is some 400 m long and up to about 12 m high. The quarry is one of several former ironstone workings at Sproxton, one of which was described by Richardson (1939b).

Description

Whilst the section described by Richardson (1939b) may have been some distance from the current one, it is nonetheless representative, and is depicted in Figure 4.38. The complete section that has been revealed at Sproxton Quarry is Lincolnshire Limestone Formation (seen to *c.* 17 m) overlying Grantham Formation (3.8 m) overlying Northampton Sand Formation (seen to 5.2 m).

Only the uppermost part of the Northampton Sand Formation is currently visible, forming a narrow platform just above water level at the north-western end of the site; to the south-east, it dips beneath the water. Richardson (1939b) reported that the total thickness of the Northampton Sand Formation (which rests on the mudstones of the Lias Group) was 7.0 m, of which some 4.9 m were visible in the 1960s (Sylvester-Bradley, 1968). When fresh at depth, the formation is dominated by sandy, berthierine-ooid-bearing limestone, but at outcrop it oxidizes to a rust-brown sandstone with an extensive development of limonite, which forms concentric shells around cores of less weathered material. The weathering processes tend to destroy any fossils, although poor moulds of bivalves and brachiopods may be found.

The outcrop of the succeeding Grantham Formation is concealed by rubble from the overlying Lincolnshire Limestone Formation,

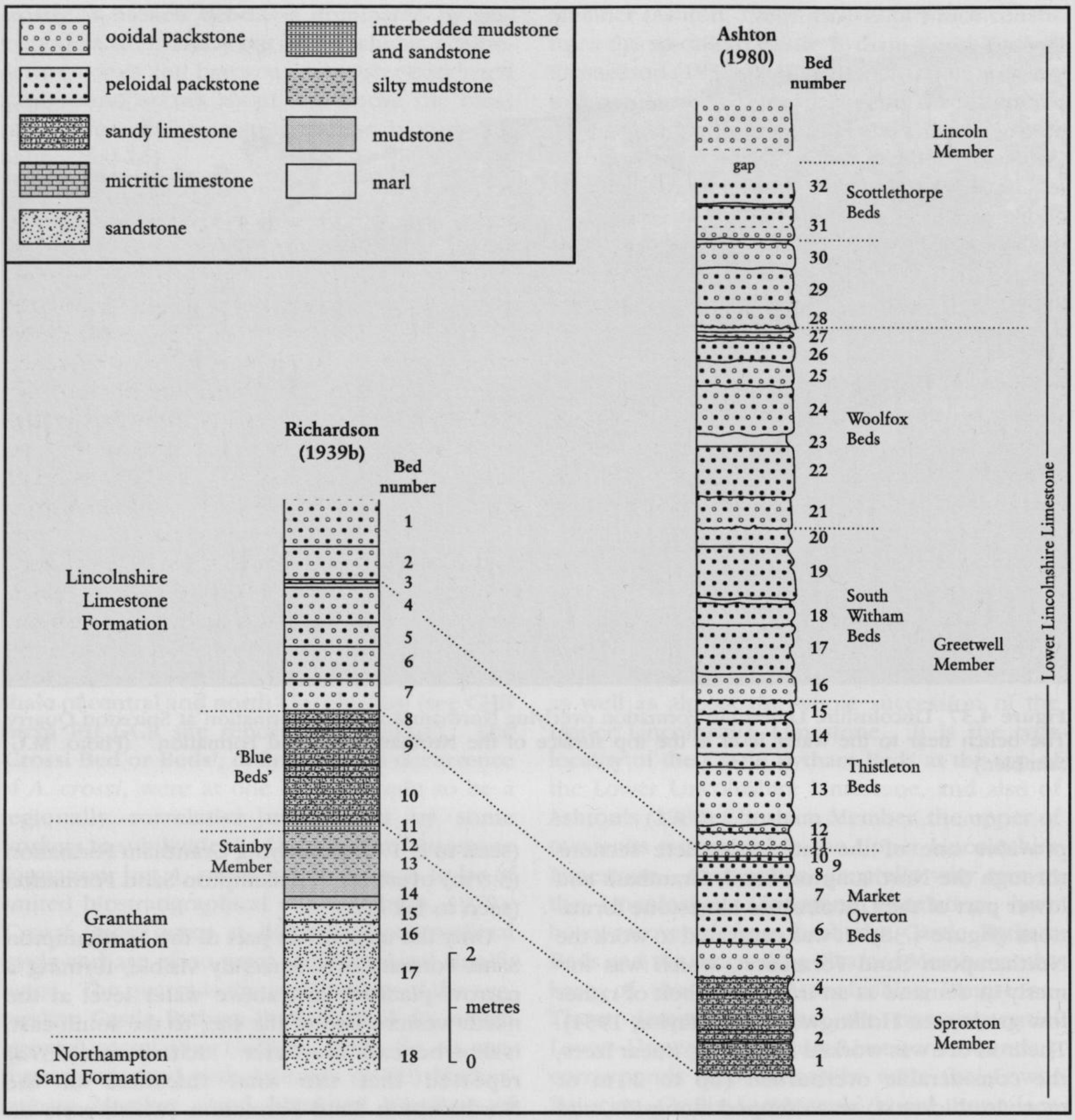


Figure 4.38 Graphic sections of the Aalenian–Bajocian succession at Sproxton Quarry. (After Richardson, 1939b, fig. 40; and Ashton, 1980, fig. 6.)

although small exposures may become visible in places from time to time. The Grantham Formation, 3.8 m thick, comprises non-marine and paralic sediments that often exhibit cyclicity. The lower part is dominated by sands, and the upper part by mudstones, the lowest bed of which (Bed 14 of Richardson, 1939b) is a variegated, unfossiliferous, seatearth-like clay. The succeeding beds 12 and 13 are dark shales with silty laminae, which belong to the Stainby Member of Kent (1975), who recorded sections in quarries (SK 867 248; SK 873 248) just to the south of the GCR site. In contrast to the rest of the Grantham Formation, the Stainby Member, developed throughout much of mid Lincolnshire, is of marine origin, and often contains abundant bivalves such as *Aviculopecten*, *Modiolus* and *Pholadomya*. The uppermost bed (Bed 11) of the Grantham Formation comprises sands and interbedded clays.

Richardson (1939b) reported only 6 m of Lincolnshire Limestone Formation (Figure 4.38) but Ashton (1980) recorded a more complete section, amounting to at least 17 m and spanning almost the whole of the Lower Lincolnshire Limestone (including his Middle Lincolnshire Limestone). The lowermost *c.* 2 m (beds 8–10, i.e. Richardson's (1939b) 'Blue Beds') comprise the Sproxton Member of Ashton (1980), which is dominated by grey, fine-grained sandy, micritic limestones. The succeeding *c.* 12 m of strata were assigned to the Greetwell Member by Ashton (1980). The member is dominated by peloidal and ooidal packstones within which, according to Ashton (1980), a succession of four sedimentary rhythms can be recognized (in ascending order, the Market Overton, Thistleton, South Witham and Woolfox beds). The top of each 'rhythm' is defined by an eroded surface, succeeded by well-sorted, ooidal grainstones. The topmost 'rhythm', the Woolfox Beds, includes white to buff wackestones and beds of marly clay, better seen in the nearby South Main Quarry (SK 865 247) (Sumbler, in manuscript).

The highest part of the Lincolnshire Limestone Formation seen at Sproxton Quarry, and exposed at the south-eastern end of the site, belongs to Ashton's (1980) Lincoln Member, which comprises several sedimentary rhythms, each commencing with ooidal grainstones that pass up into lower-energy packstones and wackestones (see **Castle Bytham** GCR site report, this volume).

At the northern end of the section, there is an additional feature of geological interest. The entire Lincolnshire Limestone Formation is cut out by a Mid Pleistocene pre-glacial valley now filled with till and partially cemented boulder gravel; the Lincolnshire Limestone Formation is cambered into this valley and the underlying Northampton Sand Formation exhibits a valley-bulge structure.

Interpretation

The seatearth-like clay (Bed 14) at the base of the mudstone-dominated upper part of the Grantham Formation was probably laid down in a marsh environment. Its base is highly carbonaceous; this may represent an incipient coal seam developed from the vegetation that grew on the hardened and ganister-like top of Bed 15, which shows abundant vertical roots. The uppermost bed (Bed 11) of the Grantham Formation was included with the Lincolnshire Limestone Formation by Richardson (1939b).

Within the Lincolnshire Limestone Formation, the beds of Ashton's (1980) Sproxton Member, of which Sproxton Quarry is the type locality, probably equate with the Collyweston Slate of the Stamford district (see **Collyweston** GCR site report, this volume). A 0.3 m-thick, dark-grey shaly clay at the top of the succession has been noted in several other sections in the Sproxton area, and as far north as **Copper Hill** (see GCR site report, this volume). Ashton (1980) designated Sproxton Quarry as a primary reference section for his Greetwell Member because the succession hereabouts differs from that in the member's type area (see **Greetwell Quarry** GCR site report, this volume). An impression of the ammonite *Graphoceras* (*Ludwigella*) from the basal bed of this member (Bed 7 of Richardson, 1939b; Figure 4.38) is consistent with the Lower Bajocian Discites Zone to which the member in its type area belongs (Ashton, 1977). The Woolfox Beds, which constitute the top part of the Greetwell Member, are reminiscent of the correlative Leadenham Member of central Lincolnshire.

Conclusions

Sproxton Quarry exposes a fine section from the upper part of the Northampton Sand Formation, through to the middle part of the Lincolnshire Limestone Formation. It is a primary reference section for the underlying Grantham Formation. The section exposes much of the lower part of the Lincolnshire Limestone Formation; it is the type locality for its basal Sproxton Member, and a key reference section for the overlying Greetwell Member.

COPPER HILL, LINCOLNSHIRE (SK 978 427)

M.G. Sumbler

Introduction

The quarry at Copper Hill, 1 km south of Ancaster, Lincolnshire, exposes an impressive section through much of the Lincolnshire Limestone Formation. Alluded to by Woodward (1894), a section here was recorded by Richardson (1939b; Newton and Scott's Quarry) and, in more detail, by Ashton (1977, 1980) and

Sumbler *et al*. (1991). In particular, the quarry at Copper Hill illustrates the erosional, channelling base of the Upper Lincolnshire Limestone.

Description

The quarry at Copper Hill exposes *c*. 20 m of strata as shown in Figure 4.39. The section has been greatly extended since it was recorded by Ashton (1980), and exposes nearly the full local succession of the Lincolnshire Limestone Formation. A borehole sited in the quarry (Berridge *et al*., 1999) shows that the base of the formation (resting, probably conformably, on the Grantham Formation) lies only 3–4 m below the floor of the quarry.

The lower part of the succession (beds 1–23 of Figure 4.39) belongs to the Lower Lincolnshire Limestone (including the Middle Lincolnshire Limestone of Ashton, 1980). It comprises a succession of peloidal or ooidal packstones to grainstones that are succeeded by lime mudstones (i.e. micrites) and wackestones. The basal beds belong to Ashton's (1980) Sproxton Member, which was proved by a borehole to be present just beneath the floor of the quarry. The member is 3.14 m thick, and comprises somewhat sandy limestones with a bed of sandy mudstone at the top. The lowest beds

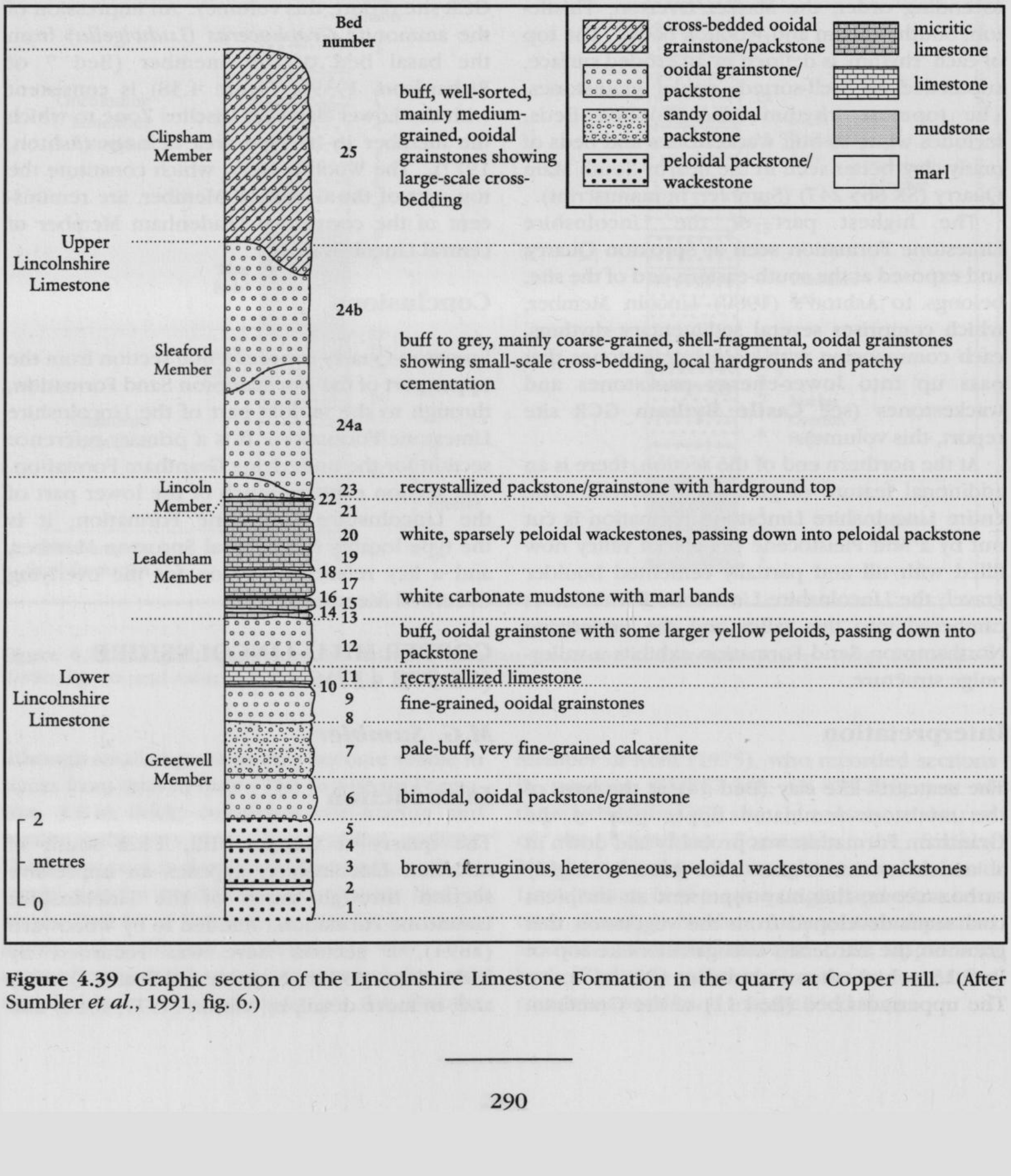


Figure 4.39 Graphic section of the Lincolnshire Limestone Formation in the quarry at Copper Hill. (After Sumbler *et al*., 1991, fig. 6.)

currently exposed belong to Ashton's (1980) Greetwell Member (see **Greetwell Quarry** GCR site report, this volume), which is, in total, some 7.8 m thick at this locality. It is dominated by peloidal and ooidal packstones with some better-sorted grainstones. Bed 7, a distinctively uniform, sandy-textured and massive, very fine-grained, slightly quartz-sandy ooidal grainstone, probably equates with the so-called 'Wragby Bed' of Ashton (1980). Bed 12 is an ooidal grainstone with some larger yellow peloids. The Greetwell Member is succeeded by white, thinly and flat-bedded, carbonate mudstones (micritic limestones) and wackestones with some thin bands of laminated and burrowed marl and clay (beds 13–22). These beds, included in the Kirton Cementstones by Richardson (1939b), constitute Ashton's (1980) Leadenham Member. The topmost clay (Bed 22) is succeeded sharply by Bed 23, a distinctive pale pinkish-brown, indurated packstone to grainstone up to *c.* 0.5 m thick and with a well-developed, oyster-encrusted hardground at the top. This bed, taken as the basal unit of the Lincoln Member, is very thin in the western part of the quarry because of downcutting of the Upper Lincolnshire Limestone.

The Upper Lincolnshire Limestone is dominated by shell-detrital, ooidal grainstones, often exhibiting spectacular cross-bedding and channelling. It is clearly divisible into two units. The lower part (Bed 24) is particularly coarse-grained and generally flat-bedded, and is capped by a recrystallized hardground. It comprises the Sleaford Member of Ashton (1980), which (at Copper Hill, at least) corresponds with the Ancaster Freestone of Richardson (1939b). The succeeding Bed 25, belonging to Ashton's (1980) Clipsham Member (Richardson's (1939b) Ancaster Rag), is somewhat finer-grained and is conspicuously cross-bedded throughout, with predominantly NE-directed foresets. Its base is somewhat erosional in character (as noted by Richardson, 1939b), cutting down locally into the underlying Sleaford Member, which, in places, has a hardground at its top (Figure 4.40).

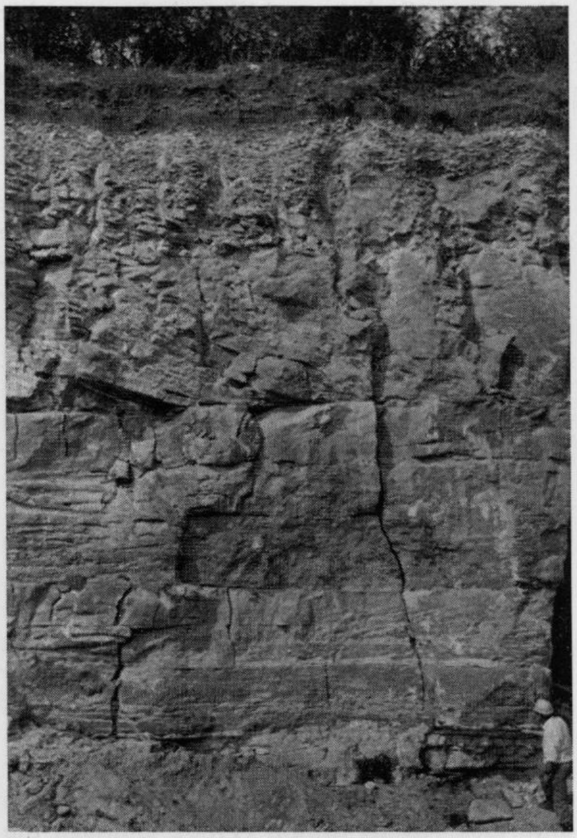


Figure 4.40 Part of the NNW face in the quarry at Copper Hill showing the Clipsham Member (with large-scale cross-bedding dipping 20–30° northwards) and the Sleaford Member of the Upper Lincolnshire Limestone resting (near the base and marked by a hammer) on Lower Lincolnshire Limestone. (Photo: British Geological Survey, No. A15099; reproduced with the permission of the Director, British Geological Survey, © NERC, 1991.)

Interpretation

The Lower Lincolnshire Limestone (beds 1–23) is dominated by low-energy, micritic limestones (mainly packstones and wackestones) laid down in a lagoonal setting, separated from the open sea by a barrier-bar complex to the east (Ashton, 1980). This part of the succession has been divided into a number of members by Ashton (1980), which, although not mappable entities (Sumbler *et al.*, 1991; Berridge *et al.*, 1999), are of some correlative value on a local, if not regional, basis.

As developed at Copper Hill, Bed 12, within the Greetwell Member, strongly resembles the basal bed of the Lincoln Member elsewhere (e.g. at **Greetwell Quarry**, see GCR site report, this volume) and was interpreted as such by Ashton (1980, Bed 1) at a time when it was the lowest bed exposed in the quarry. However, the extended succession now visible indicates that this is incorrect and that, in fact, it is the topmost bed of the Greetwell Member. This emphasizes the cyclic nature of the Lower Lincolnshire

Limestone succession, which includes a number of essentially similar 'rhythms' in which peloidal or ooidal packstones to grainstones pass upwards into lime mudstones. Each 'rhythm' represents a temporary incursion of the 'bar' environment into the lagoon.

Bed 23, at the top of the Lower Lincolnshire Limestone, is probably cut out entirely in some places as it does not appear to have been seen by Ashton (1980). Comparison with other quarry sections in the neighbourhood, in which the Lincoln Member is up to *c.* 5 m thick (Ashton 1980, fig. 60), demonstrates the markedly erosional base of the Upper Lincolnshire Limestone. In places, the eroded top of Bed 23 is heavily encrusted by oysters, indicating a hiatus before deposition of the succeeding strata.

The upper *c.* 10 m of the section (beds 24 and 25) are assigned to the Upper Lincolnshire Limestone, which is dominated by high-energy ooidal grainstones (oobiosparites) representing the barrier-bar complex itself, which gradually prograded westwards over the earlier lagoonal sediments (Ashton, 1977; Tucker, 1985). As with the Lower Lincolnshire Limestone, the Upper Lincolnshire Limestone has been subdivided into members by Ashton (1980), although the succession is highly variable from place to place. The beds were formerly worked on a large scale as a source of high-quality freestones (e.g. Ancaster and Clipsham stones), but at Copper Hill most of the stone was crushed for aggregate. Parts of the succession show herring-bone-type cross-stratification, suggesting fluctuating, bi-directional tidal currents. A number of hard-grounds have been noted in the succession (e.g. within and at the top of Bed 24), but all seem to be laterally impersistent and of little or no correlative value.

The quarry at Copper Hill is designated as the type locality of the Sleaford Member (Ashton, 1980), although the name is inappropriate, as the town of Sleaford, 10 km to the north-east, is situated on the outcrop of the Great Oolite and Ancholme groups that succeed the Lincolnshire Limestone Formation.

Conclusions

Copper Hill exhibits an impressive section showing almost the whole of the Lincolnshire Limestone Formation. The contrasting facies of the Lower (low-energy micritic packstones and wackestones) and Upper (high-energy ooidal grainstones) Lincolnshire Limestone are particularly well displayed, as is the undulating erosion surface between the two divisions. The site is thus an important one for palaeoenvironmental and palaeogeographical reconstructions showing the relationship between a mobile barrier-bar complex (Upper Lincolnshire Limestone) and the older lagoonal sediments (Lower Lincolnshire Limestone) over which it gradually prograded.

METHERINGHAM, LINCOLNSHIRE (TF 054 615)

M.G. Sumbler

Introduction

The GCR site at Metheringham, Lincolnshire, shows a section through the middle part of the Lincolnshire Limestone Formation and is the type locality of the Metheringham and Blankney members of Ashton (1977, 1980).

Description

The quarry at Metheringham is probably close to, or incorporates, the sections briefly described by Richardson (1940) when only the upper part of the succession was exposed. A greatly extended section totalling some 20 m of Lincolnshire Limestone Formation is depicted by Ashton (1977, 1980) (see Figure 4.41) as summarized below.

	Thickness (m)
Lincolnshire Limestone Formation	
Upper Lincolnshire Limestone	
Sleaford Member	
29: Limestone, grey-brown, thinly bedded, flaggy, poorly sorted, cross-bedded, pisoidal, ooidal grainstone	2.50
Lower Lincolnshire Limestone	
Blankney Member	
28: Limestone, yellowish-brown-weathering, well-bedded, very fine-grained, ooidal grainstones, markedly sandy, with very sandy partings particularly in the lower part where some beds decalcify to loose sand; nerineid gastropods	2.13
Metheringham Member	
25–27: Limestone, grey to pinkish-buff, massive, well-bedded and flat-bedded, hard, sandy, ooidal grainstones and packstones with scattered, coarser pebbles particularly in topmost bed; basal erosion surface with derived pebbles	2.36
Kirton Shale Member	
24: Shale, dark blue, indurated where fresh	0.95

	Thickness (m)
Lincoln Member	
21–23: Limestone, blue-hearted, ooidal and peloidal wackestone, more densely ooidal towards base; *Entolium*, *Acanthothiris crossi* (Walker), *Parvirhynchia*	2.0
Leadenham Member	
15–20: Limestone, white to pale-brown, thinly bedded, carbonate mudstone and sparsely peloidal wackestone with marly clay interbeds	1.9
Greetwell Member	
2–14: Limestone, pale-brown, massive, well-bedded, shelly, ooidal and peloidal wackestone with pale-grey, micrite burrow-fills; more grain-rich (packstones) at both top and bottom; recrystallized corals and nerineid gastropods common towards top	7.3
Sproxton Member	
1: Limestone, pale-grey, weathering brown, massive, silty and slightly sandy with clayey lenses; plant debris; micrite-filled burrows towards top	up to 0.2

Currently (1997), the lower part of the succession is largely obscured owing to tipping and the cumulative effects of motorcycle scrambling. However, excellent sections of the Lincoln Member and succeeding beds are still available.

Bed 24, the Kirton Shale Member, is a conspicuous marker bed in the face (Figure 4.42). It averages about 1 m in thickness, but reaches nearly 2 m at the eastern end of the site.

Interpretation

Bed 1, up to *c.* 1.2 m of which was formerly exposed in the deepest part of the pit, probably represents almost the whole of Ashton's (1980) Sproxton Member. This unit, transitional in facies between the Lincolnshire Limestone Formation and the underlying Grantham Formation, is well developed throughout south Lincolnshire (see **Sproxton Quarry** GCR site report, this volume). At Metheringham, the top of the member is developed as a hardground suggesting a break in deposition; this hiatus is more marked at **Greetwell Quarry** (see GCR site report, this volume) where both the Sproxton Member and Grantham Formation are absent, and the succeeding unit of the Lincolnshire Limestone Formation rests unconformably on the Northampton Sand Formation.

The succeeding Greetwell Member, some 7.5 m thick, is substantially thicker than at the type locality (see **Greetwell Quarry** GCR site report, this volume), although it thickens still more to the south (Ashton, 1980, fig. 6; see **Sproxton Quarry** GCR site report, this volume). Near the base, a conspicuous bed of brownish silty and sandy limestone (Bed 6), known as

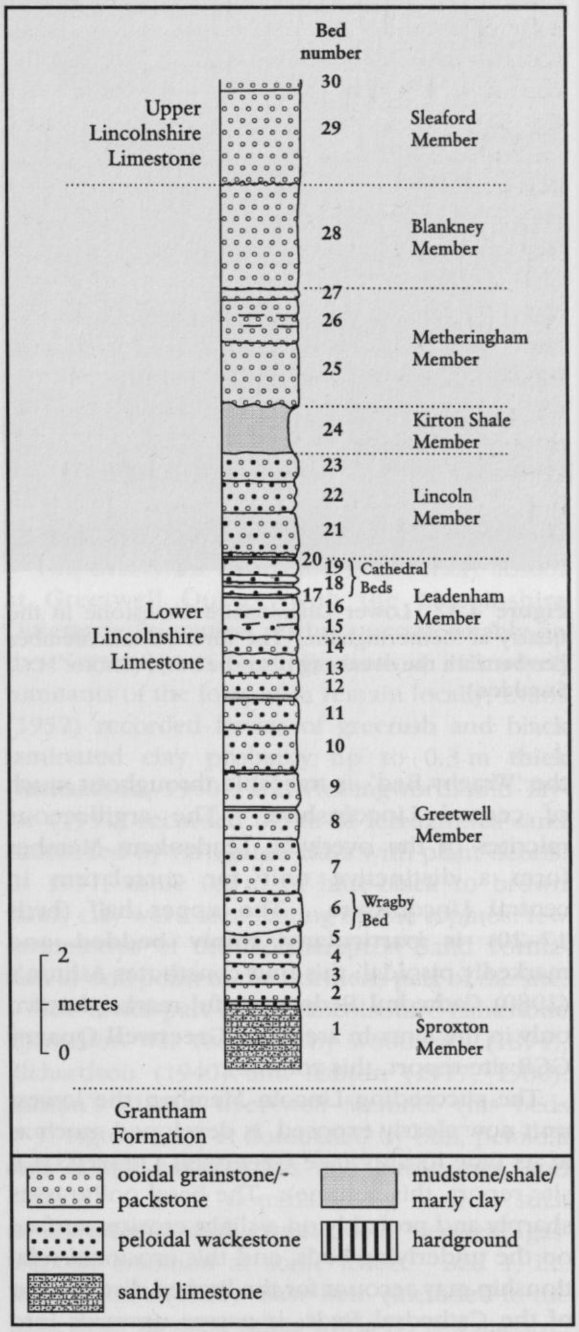


Figure 4.41 Graphic section of the Lincolnshire Limestone Formation in the quarry at Metheringham. (After Ashton, 1980, figs 6,9.)

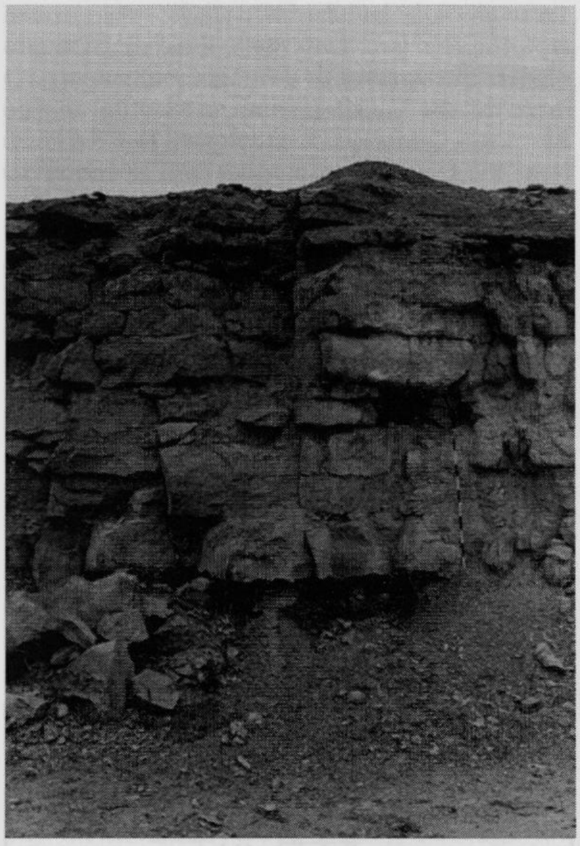


Figure 4.42 Lower Lincolnshire Limestone in the quarry at Metheringham. The Kirton Shale Member lies beneath the overhang near the base. (Photo: M.G. Sumbler.)

the 'Wragby Bed', is traceable throughout much of central Lincolnshire. The argillaceous micrites of the overlying Leadenham Member form a distinctive unit for correlation in central Lincolnshire. The upper half (beds 17–20) is particularly thinly bedded and markedly pisoidal; this unit constitutes Ashton's (1980) Cathedral Beds, a useful marker known only in the Lincoln area (see **Greetwell Quarry** GCR site report, this volume).

The succeeding Lincoln Member, the lowest unit now clearly exposed, is developed much as at its type locality (see **Greetwell Quarry** GCR site report, this volume). The basal oolite rests sharply and probably on a slight erosion surface on the underlying beds, and this erosional relationship may account for the limited distribution of the Cathedral Beds; it passes upwards into sparsely peloidal wackestones. Because of the contrast in facies with adjoining strata, the Lincoln Member is one of the few units defined by Ashton (1977, 1980) that have proved to be mappable (Sumbler *et al.*, 1991; Sumbler, 1993). It yields sporadic *Acanthothiris crossi* (Walker) and appears to correspond with the *A. crossi* Beds of Evans (1952), which, because of the presence of this brachiopod, he included in the Upper Lincolnshire Limestone. However, *A. crossi* is no longer regarded as biostratigraphically significant (see **Castle Bytham** GCR site report, this volume).

The Kirton Shale Member dies out rapidly to the south (Ashton, 1980), probably being cut out beneath the basal erosion surface of the succeeding Metheringham Member, as seen at **Greetwell Quarry** (see GCR report, this volume).

Prior to the work of Ashton (1977, 1980), the Metheringham and Blankney members were not recognized as separate units, but were included in the Upper Lincolnshire Limestone (Hibaldstow Beds) (Evans, 1952; Kent, 1966). The distinctive characteristics of these beds were described by Richardson (1940), at which time they were the lowest strata exposed. Ashton (1977, 1980) grouped them, together with his Kirton Shale and Lincoln members, as 'Middle Lincolnshire Limestone', which, in the bipartite classification adopted herein, forms the uppermost part of the Lower Lincolnshire Limestone. Ashton's (1980) Sleaford Member contrasts quite markedly with the lower-energy, flat-bedded, mainly micritic rocks lower in the succession, and is now taken as the basal unit of the Upper Lincolnshire Limestone. Regionally, the base of the Upper Lincolnshire Limestone is markedly erosive (see **Copper Hill** GCR site report, this volume).

Conclusions

The quarry at Metheringham formerly exposed the greater part of the Lincolnshire Limestone Formation, including virtually the entire Lower Lincolnshire Limestone, as well as the basal part of the Upper Lincolnshire Limestone. The succession is more complete and somewhat expanded compared with that at **Greetwell Quarry** (see GCR site report, this volume). The site is the type locality of Ashton's (1980) Metheringham and Blankney members of the Lower Lincolnshire Limestone, and exposes the 'Cathedral Beds' (in the upper half of the Leadenham Member), which form a useful marker known only in the Lincoln area.

GREETWELL QUARRY, LINCOLNSHIRE (SK 998 727–TF 010 719)

M.G. Sumbler

Introduction

Greetwell Quarry, on the eastern outskirts of the city of Lincoln, is one of the most historically significant exposures in the Lincolnshire Limestone Formation, and has yielded many of the limited number of ammonites known from the formation. The extensive quarry lies within an area of old ironstone workings dug for the Northampton Sand Formation. Iron ore extraction at this site has a long history; there were extensive workings in the last century (Ussher *et al.*, 1888) and there is even a suggestion of Roman workings here (Evans, 1952). Extraction took place by means of both underground mines and adits, and by open quarrying. The later operations removed the ore from beneath a considerable overburden of Lincolnshire Limestone Formation, but most ironstone extraction ceased in 1938, essentially because of exhaustion; a fault immediately to the east of the site throws the ironstone down to a depth that precluded further economic working and, in any case, the ore thins and degenerates rapidly in this direction (Hollingworth and Taylor, 1951; Evans, 1952). Subsequent operations worked the Lincolnshire Limestone Formation, principally for aggregate; this is currently (1997) continuing on a large scale in the southern part of the site.

Description

The Greetwell Quarry GCR site is close to the Greetwell Road Quarry of Woodward (1894) and the Bowling Green Quarry (SK 995 727) recorded by Richardson (1940), and probably incorporates Grundy's and Greetwell opencast ironstone workings referred to by Hollingworth and Taylor (1951), and the Greetwell Hollow Quarry of Evans (1952). These quarries exposed beds from the top of the Lias Group into the lower part of the Lincolnshire Limestone Formation. A slightly extended section of the Lincolnshire Limestone Formation was recorded by Ashton (1980) (Figure 4.43). By the 1990s, the working face had been extended to expose higher levels of the Lincolnshire Limestone Formation than recorded by Ashton (1980); the highest beds now exposed may be up to 19 m above the base of the formation, but the lowest part of the succession has been largely obscured by tipping. The full Middle Jurassic succession that has been exposed at Greetwell Quarry is Lincolnshire Limestone Formation (*c.* 19 m) overlying Grantham Formation (0–*c.* 0.6 m) overlying Northampton Sand Formation (2.6–3.1 m).

The Northampton Sand Formation is somewhat variable in thickness. It was 2.9 m thick in the Bowling Green Quarry (Richardson, 1940), and Hollingworth and Taylor (1951) recorded 2.6 m at the entrance to Wilson's Mine (SK 998 724). The formation is a finely sandy, ooidal ironstone with some more calcareous beds, as well as lenses of sand and silt. Where fresh, the rock is a dark bluish-green colour, with berthierine-rich ooids set in a siderite–berthierine 'mud' matrix. Where weathered, as is generally the case at or near outcrop, the rock is oxidized to a limonitic ironstone with a 'boxy' structure, with occasional cores of less altered material. This oxidation process tends to destroy much of the original structure of the rock, and sedimentary structures and fossils may be hard to discern.

The Grantham Formation is generally absent at Greetwell Quarry, with the Lincolnshire Limestone Formation resting unconformably on the Northampton Sand Formation. However, remnants of the formation remain locally; Evans (1952) recorded lenses of greenish and black laminated clay probably up to 0.3 m thick (Richardson, 1940), and Hollingworth and Taylor (1951) recorded 0.3 m of ferruginous sand succeeded by variegated clays with plant debris. In 1997, some 0.2 m of blue-black to brown sandy clay were seen resting on the topmost few centimetres of the Northampton Sand Formation at one point in the northern part of the site.

The lower part of the Lincolnshire Limestone Formation was recorded by Woodward (1894), Richardson (1940) and Ashton (1977, 1980). Ashton's (1980) Greetwell Member (his beds 1–5; Figure 4.43) is dominated by buff, peloidal and ooidal wackestones and packstones, and contains a fauna dominated by bivalves such as *Gervillella* and *Pinna*, with nerineid gastropods common at some levels. Bed 1, i.e. Richardson's (1940) 'Base Bed' (included in the Blue Beds by most other workers) is a massive, creamy-buff to rust-brown-weathering, coarse-grained, peloidal, ooidal and shell-fragmental packstone to grainstone. It is somewhat

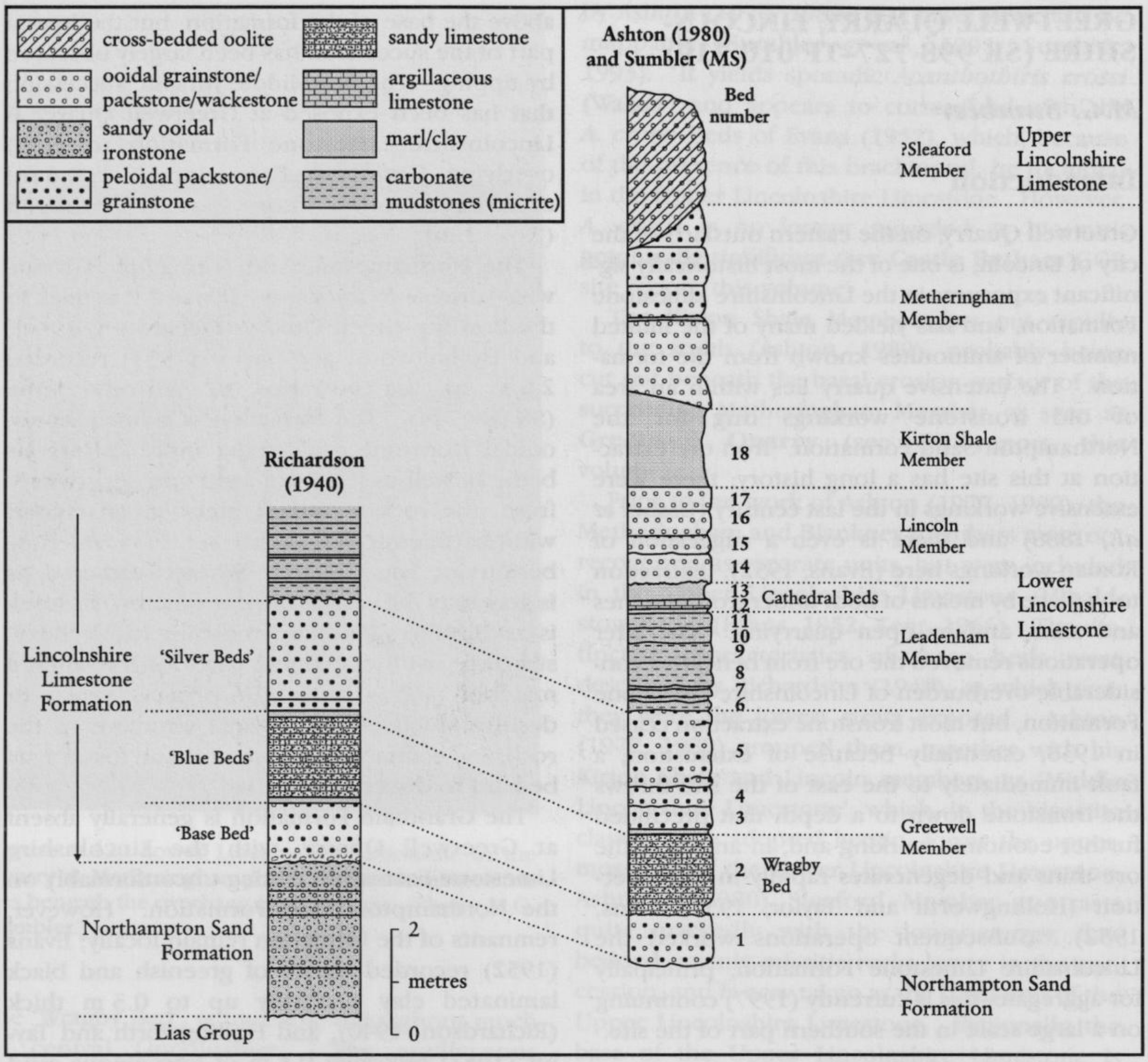


Figure 4.43 Graphic sections of the Lincolnshire Limestone Formation and underlying beds at Greetwell Quarry. (Based mainly on Richardson, 1940, fig. 29; and Ashton, 1980, fig. 6; with the highest beds as recorded by M.G. Sumbler in 1997.)

conglomeratic at the base, with sporadic pebbles of ironstone (presumably reworked from the underlying Northampton Sand Formation) and phosphatic material. Bed 2 is the so-called 'Wragby Bed' of Ashton (1980). It is a blue-hearted, orange-yellow-weathering, massive, uniform sandy limestone, containing scattered large peloids, and often decalcifying to a loose sand at the base. It forms a valuable marker bed throughout central Lincolnshire.

The succeeding Leadenham Member of Ashton (1980) (beds 6–13) is composed mainly of white, thinly bedded carbonate mudstones (micrites) with marl and clay partings, and forms a distinctive marker that can be traced around the entire pit (Figure 4.44). The basal bed (Bed 14) of his overlying Lincoln Member is a distinctive blue-hearted, ooidal grainstone, which grades up into grey wackestones with *Gresslya* and *Plagiostoma* (beds 15 and 16). At the top of the member, Bed 17 is a grey, ooidal packstone with sporadic *Acanthothiris crossi* (Walker) and other fossils. Bed 18, the Kirton Shale ('Kirton Shale Member' of Ashton, 1980), comprises grey, brown-weathering, marly, shaly clay with some more calcareous bands. It contains poorly preserved bivalves, and forms a conspicuous marker bed in the quarry face. It is up to 2 m thick in

Figure 4.44 Lower Lincolnshire Limestone at Greetwell Quarry. The Wragby Bed in the Greetwell Member is the massive bed on the left of the photograph in the lower part of the face; the paler unit in the upper part of the face is the Leadenham Member and the Kirton Shale (Kirton Shale Member of Ashton, 1980) lies near the top. The fold structure is probably a result of collapse over an ironstone mine in the Northampton Sand Formation, the top of which is visible at bottom left. (Photo: M.G. Sumbler.)

the northern and eastern faces of Greetwell Quarry but is absent in the southernmost part, apparently having been cut out by downward channelling of the succeeding beds. A more localized disappearance in the eastern face of the quarry is due to the development of a small reef-knoll, about 75 m in diameter. Composed of white to pale-grey wackestones, locally packed with shells and corals, this reef is up to *c.* 5 m in thickness, and replaces the topmost *c.* 1 m of the Lincoln Member, as well as the Kirton Shale, into which it passes by interdigitation. The succeeding Metheringham Member of Ashton (1980) is draped over the top.

Some 6 m of overlying beds are exposed in the eastern face of the quarry; these are mainly ooidal and peloidal packstones and grainstones. A typical section in the eastern part of the quarry (TF 005 721), recorded by the present author in January 1997, showed the following:

	Thickness (m)
Upper Lincolnshire Limestone	
Limestone, buff, very well-sorted, medium- to coarse-grained, ooidal grainstone, weathering to flaggy rubble in subsoil; large-scale, low-angle cross-bedding; sharp, basal erosion surface	*c.* 3
Lower Lincolnshire Limestone	
Limestone, pale-grey to white, sparsely shell-fragmental and peloidal wackestone; cut out by overlying beds northwards	0–0.80
Limestone, fawn, poorly sorted, peloidal and ooidal packstone to grainstone; massive but with cryptic cross-bedding; sharp, ?erosional base	0.75
Limestone, fawn, poorly sorted, peloidal and ooidal packstone	0.55
Marl and marly limestone, fawn to brown, ferruginous	0.08
Limestone, pinkish-buff and brown, poorly sorted, coarse-grained, shell-fragmental and ooidal grainstone, becoming better-sorted upwards; massive, flat-bedded; sharp, flat or locally loaded basal boundary with Kirton Shale	1.50

Throughout most of Greetwell Quarry, the Metheringham Member rests on the Kirton Shale with little sign of erosion, but in the southernmost part it rests directly on the Lincoln Member, having (presumably) channelled through the Kirton Shale; unfortunately the critical part of the section, which would clarify relationships, is obscured. The succeeding cross-bedded, 'millet-seed' oolites are of typical Upper Lincolnshire Limestone type. These may belong to the Sleaford Member of Ashton (1980), although correlation at this level is uncertain.

Interpretation

The principal interest of Greetwell Quarry is in the sections of the Lincolnshire Limestone Formation. The basal part of the succession (beds 1–5), 4.88 m thick, constitutes the type section of Ashton's (1980) Greetwell Member, which corresponds with the Blue and Silver beds of previous accounts. This part of the Lincolnshire Limestone Formation is much thinner than the corresponding beds farther south (see, for example, **Metheringham** and **Copper Hill** GCR site reports, this volume); Ashton (1980) suggested that it may be condensed, and it is likely that the oldest part of the Lincolnshire Limestone Formation is missing beneath the basal non-sequence. The Wragby Bed (Bed 2) corresponds with the Blue Beds *sensu* Richardson (1940); these should not be confused with the Blue Beds of south Lincolnshire, which there equate with the Sproxton Member (see **Sproxton Quarry** GCR site report, this volume), thought to be absent at Greetwell Quarry. The succeeding beds 3–5 equate with the Silver Beds of authors that locally include good freestones much used in the construction of the city of Lincoln, although these are not developed at Greetwell Quarry, where the succession is composed entirely of buff wackestones with scattered peloids. These beds have yielded a number of ammonites over the years (see Kent, 1966); most probably came from the lower part of the unit (Bed 3, or the 'Lower Silver Bed' of Richardson, 1940). As reassessed by Ashton (1977), the taxa recorded are *Darellia polita* S.S. Buckman, *Hyperlioceras* aff. *rudidiscites* S.S. Buckman, *H. subsectum* (S.S. Buckman), *H.* cf. *subdiscoideum* S.S. Buckman and *Sonninia* aff. *marginata* S.S. Buckman, an assemblage that indicates the Lower Bajocian Discites Zone.

Beds 6 to 13 are assigned to the Leadenham Member (Ashton, 1977, 1980), which forms the basal part of the Kirton Cementstones of many previous accounts of the Lincoln district; the latter are essentially equivalent to the Kirton Cementstone Member of north Lincolnshire and Humberside (see **Manton Stone Quarry** and **Cliff Farm Pit** GCR site reports, this volume), although Evans (1952) appears to have used the term in a more restricted sense. A loose specimen of ?*Darellia* cf. *coela* (previously recorded as *Hyperlioceras* aff. *discites* (Waagen)) probably came from this unit (Kent, 1966). The topmost *c.* 0.5 m of the member (beds 12 and 13) comprises brownish, argillaceous limestone and shale that characteristically contain scattered buff pisoids, commonly up to 8 mm or more in diameter; these are very similar to those from the Pea Grit of the Cotswolds (see **Crickley Hill** GCR site report, this volume). This distinctive pisoidal unit is restricted to the Lincoln area but, despite the name, these so-called 'Cathedral Beds' do not yield building stone. They were named by Ashton (1977, 1980) from their development in the Cathedral (or Dean) and Chapter Pit (SK 977 734).

Beds 14 to 17, totalling 1.85 m in thickness, constitute the type section of Ashton's (1977, 1980) Lincoln Member, which forms the upper part of the Kirton Cementstones of most previous accounts. The Lincoln Member (with the succeeding Kirton Shale, Metheringham Member and Blankney Member) was included in the Middle Lincolnshire Limestone by Ashton (1980), although in the bipartite scheme used in the present account, the last-named unit forms the upper part of the Lower Lincolnshire Limestone. The topmost bed (Bed 17) of the Lincoln Member is the so-called 'Lower Crossi Bed' of Kent (1966). Earlier, Evans (1952) appears to have included the whole of the Lincoln Member (together with the succeeding Kirton Shale) in his *A. crossi* Beds, which he took as the basal unit of the Upper Lincolnshire Limestone (see **Metheringham** GCR site report, this volume).

Bed 18, the Kirton Shale (or Kirton Shale Member of Ashton, 1980) is a valuable marker for correlation that can be traced throughout much of north and central Lincolnshire (see **Metheringham**, **Manton Stone Quarry** and **Cliff Farm Pit** GCR site reports, this volume). In north Lincolnshire, it forms the upper part of the Kirton Cementstone Member.

The oolites above the Kirton Shale have been included with the 'Hibaldstow Beds' by most workers. The lower *c.* 3 m are mainly flat-bedded, ooidal packstones to grainstones similar to those of the Metheringham Member at its type locality (see **Metheringham** GCR site report, this volume), now regarded as the uppermost part of the Lower Lincolnshire Limestone. To the north of Lincoln, recognition of the Metheringham Member becomes difficult and it may be most practical to include all of the strata above the Kirton Shale in the Upper Lincolnshire Limestone (Hibaldstow Member).

Conclusions

Greetwell Quarry formerly exposed the whole Middle Jurassic succession of central Lincolnshire from the Northampton Sand Formation up to the higher part of the Lower Lincolnshire Limestone. The section of the latter here is particularly important as it has yielded many of the relatively rare age-diagnostic Bajocian ammonites known from the formation. The extant sections here show the distinctive Kirton Shale (Kirton Shale Member of Ashton, 1980), a valuable marker for correlations in central and north Lincolnshire, and overlying beds in the topmost part of the Lower, and lowermost part of the Upper, Lincolnshire Limestone.

CLIFF FARM PIT, EAST RIDING (SE 942 009)

B.M. Cox

Introduction

The GCR site known as 'Cliff Farm Pit' exposes the upper part of the Lincolnshire Limestone Formation, and overlaps with and continues upward the succession exposed at **Manton Stone Quarry** (see GCR site report, this volume), sited *c.* 1.2 km farther north (Figure 4.45). According to the lithostratigraphical classification of Gaunt *et al.* (1992), the section at Cliff Farm Pit exposes the upper division of the Kirton Cementstone Member (the 'Kirton Shale' or 'Kirton Cement Shale' of many authors). The section displays one of the thickest and most extensive exposures of this unit, with its well-known coral 'patch reefs', within the type area. The upper part of the section comprises the Hibaldstow Limestone Member.

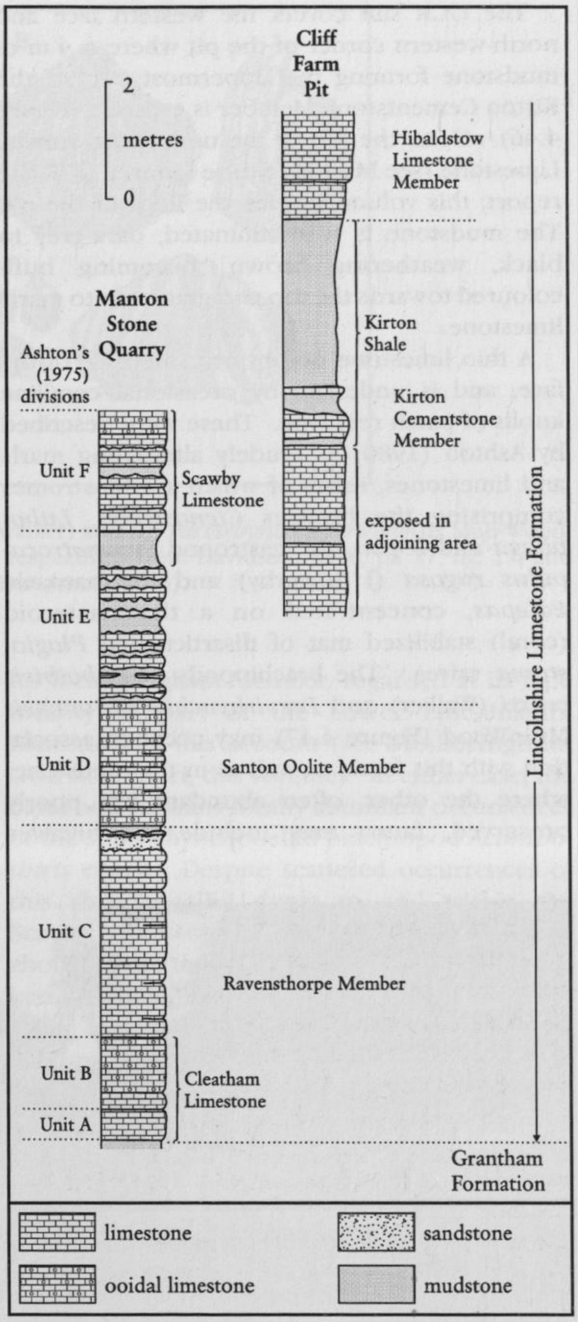


Figure 4.45 Graphic sections of the Lincolnshire Limestone Formation at Cliff Farm Pit and **Manton Stone Quarry**. (Based partly on Ashton, 1975, fig. 3; lithostratigraphy based on Gaunt *et al.*, 1992.)

Description

The following description is based largely on files held by English Nature but the lithostratigraphical classification follows Gaunt *et al.* (1992).

The GCR site covers the western face and north-western corner of the pit where *c.* 4 m of mudstone forming the uppermost part of the Kirton Cementstone Member is exposed (Figure 4.46). Here, the top of the underlying Scawby Limestone (see **Manton Stone Quarry** GCR site report, this volume) forms the floor of the pit. The mudstone is well laminated, dark-grey to black, weathering brown, becoming buff-coloured towards the top and grading into marly limestone.

A thin limestone occurs near the base of the face, and is underlain by occasional coralline knolls of patch reef type. These were described by Ashton (1980) as crudely alternating marls and limestones, many of which are biostromes comprising the bivalves *Ctenostreon*, *Lithophaga* and *Lopha*, the gastropod *Symmetrocapulus rugosa* (J Sowerby) and the barnacle *Eolepas*, concentrated on a thamnasteroid (coral) stabilized mat of disarticulated *Plagiostoma* valves. The brachiopods *Acanthothiris crossi* (Walker) and *Parvirhynchia kirtonensis* Muir-Wood (Figure 4.47) may occur in association with this fauna as well as in the mudstone, where the other, often abundant but poorly preserved, fauna may include the bivalves *Camptonectes*, *Pseudotrapezium*, *Pteroperna* and *Trigonia hemisphaerica* Lycett.

The basal bed of the overlying Hibaldstow Limestone Member is a *c.* 0.6 m thick, hard, prominent, pale-coloured, shelly, argillaceous, ooidal calcarenite. As well as the brachiopod *Acanthothiris crossi*, it has yielded cerithiid gastropods and the bivalve *'Lucina' bellona* d'Orbigny; the base may be burrowed with *Thalassinoides*. The overlying beds (up to *c.* 2 m thick) are poorly fossiliferous, white, weathering buff, ooidal grainstones.

Since the site was originally designated, quarrying in an adjoining area has exposed *c.* 4 m of the underlying beds. These comprise the Scawby Limestone, with its basal oncoidal mudstone (also seen at **Manton Stone Quarry**, see GCR site report, this volume), which is here developed as a tabular-bedded, chalky-white calcilutite with bivalves, corals and gastropods.

Interpretation

Following the nomenclature of Richardson (1940) and Kent (1941), the mudstone exposed at Cliff Farm Pit has been called the 'Kirton Cement Shale' or 'Kirton Shale' (of member

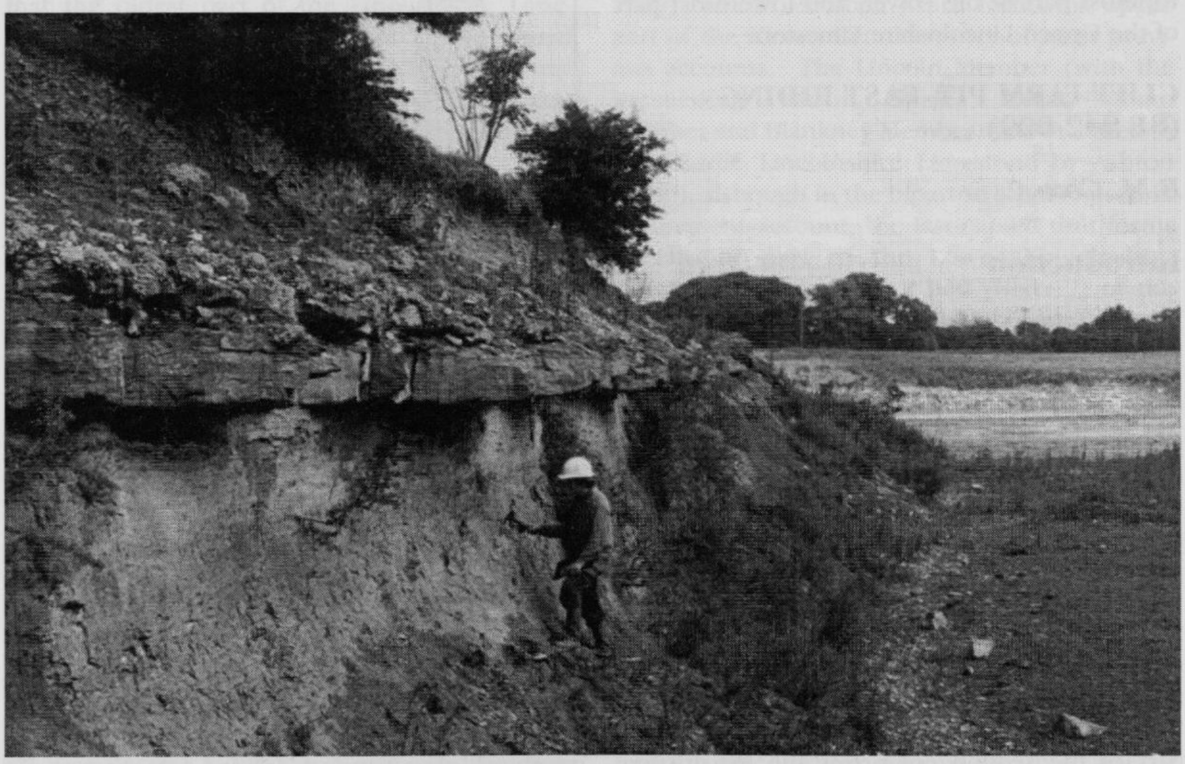


Figure 4.46 Kirton Shale overlain by Hibaldstow Limestone Member at Cliff Farm Pit. (Photo: M.G. Sumbler.)

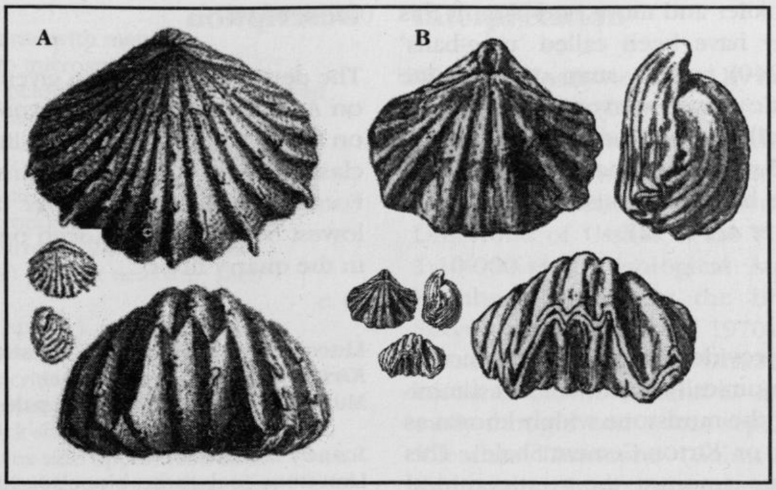


Figure 4.47 The brachiopods (A) *Acanthothiris crossi* (Walker) and (B) *Parvirhynchia kirtonensis* Muir-Wood; both shown at natural size and enlarged. (Reproduced respectively from Davidson, 1878, pl. 27, fig. 17; and Muir-Wood, 1939, fig. 42, 3A–C (courtesy of The Geologists' Association)).

status) by most authors. It has been an important local resource for the manufacture of cement and, in the past, has been exploited in numerous quarries around Kirton in Lindsey; more recently, it has been replaced for this purpose by mudstones of the Lias Group. Although, following their 1:10 000 scale geological survey of the Humberside area, Gaunt *et al.* (1992) chose to include it as an unnamed unit within the Kirton Cementstone Member, usage of the term 'Kirton Shale' or 'Kirton Cement Shale' is bound to continue. Its type locality is at Cleatham Quarry (SE 940 014), just 350 m to the north, where the section has been described by Richardson (1940). Unlike the underlying beds, it extends southwards into the Lincoln area (see **Metheringham** and **Greetwell Quarry** GCR site reports, this volume).

The overlying Hibaldstow Limestone Member is based on the Hibaldstow Beds of Ussher *et al.* (1890) herein taken to represent the Upper Lincolnshire Limestone dominated by high-energy oolites. However, Ashton (1980) believed that, unlike the lower part of the Lincolnshire Limestone Formation, there was no significant difference between the middle and upper parts of the formation in the Humberside area and those of the Lincoln and more southerly areas. He therefore chose to apply his new 'southern' nomenclature to the beds above the Kirton Cementstone Member (*sensu* Gaunt *et al.*, 1992). In Ashton's (1980) terminology, the highest beds exposed at Cliff Farm Pit belong to his Metheringham Member, regarded at its type locality as part of the Lower Lincolnshire Limestone of this account (see **Metheringham** GCR site report, this volume). In either case, the basal bed contains locally abundant occurrences of the spiny rhynchonellid brachiopod *Acanthothiris crossi*. Despite scattered occurrences of this rhynchonellid down to and within the Scawby Limestone, it has proved useful hereabouts to use this fossil as an index taxon for the bed in which it is abundant. Gaunt *et al.* (1992) chose to call it, informally, the 'Crossi Bed' but Ashton (1980) referred to it as the 'Upper Crossi Bed' following Kent (1966) who had differentiated it from a lower level of abundance beneath the Kirton Shale. Ashton (1977, 1979) concluded that although the first appearance or acme occurrence of *Acanthothiris crossi* could not be considered a synchronous event for correlation purposes, the general occurrence of this taxon in large numbers does provide a useful marker for the middle part of the Lincolnshire Limestone Formation (see also **Castle Bytham** GCR site report, this volume).

Within the Kirton Shale as a whole, the reef-like masses or coral knolls, many of which were produced by micritic cementation around colonies of corals or large bivalves, appear to occur randomly at various stratigraphical levels. The quarrymen referred to them as 'false formations' because they generally dip contrary to the limestone strata above and below. They may be stacked directly above each other and become progressively smaller and more pod-like; in this latter state, they have been called 'crog-balls' (Richardson, 1940), which may overlap one another with little or no intervening mudstone. In this way, small conical knolls up to 2 m in diameter and 1.5 m in height have been built up; elsewhere, these have been mistaken for burial mounds (Gaunt *et al.*, 1992).

Conclusions

Cliff Farm Pit provides an important section through the economically important but diminishing reserves of the mudstone widely known as the 'Kirton Shale' or 'Kirton Cement Shale'. This stratum is unique amongst the stratigraphical divisions of the Lincolnshire Limestone Formation in not being predominantly limestone. The presence of coralline knolls is of particular interest. The succession overlaps with that exposed at **Manton Stone Quarry** (see GCR site report, this volume) to give a nearly complete section through the Lincolnshire Limestone Formation, which, at least in the lower part, is differently developed hereabouts compared with the area to the south of Lincoln.

MANTON STONE QUARRY, EAST RIDING (SE 940 025)

B.M. Cox

Introduction

The succession at Manton Stone Quarry, in the East Riding of Yorkshire (formerly Humberside), was first described by Ashton (1975) when the section exposed the lower part of the Lincolnshire Limestone Formation and the boundary with the underlying Grantham Formation (see Figure 4.45). The lithological character of the lower part of the Lincolnshire Limestone Formation hereabouts is different from that of the Lincoln, and other more southerly, areas (see **Greetwell Quarry**, **Metheringham** and **Castle Bytham** GCR site reports, this volume), and the section at Manton Stone Quarry provided the first opportunity to determine the stratigraphy of the variable package of strata referred to by Kent (1966) as the 'Santon Oolite and Ravensthorpe Beds' (now the Santon Oolite Member and the Ravensthorpe Member), as well as the overlying Kirton Cementstone Member.

Description

The details of the section given below are based on Ashton (1975) and a recorded section held on file by English Nature; the lithostratigraphical classification of the Lincolnshire Limestone Formation follows Gaunt *et al.* (1992). The lowest beds have been seen only in excavations in the quarry floor.

	Thickness (m)
Lincolnshire Limestone Formation	
Kirton Cementstone Member	
Mudstone, grey, weathered to pale-brown	0.6
Scawby Limestone	
Limestone (pelsparite–biopelsparite), hard, massive, fine grained, grey, weathering honey-yellow, minor marl–mudstone intercalations; ooids and oncoids most common in upper part, those in brown-weathering shale, about 1 m from base, weather from white to brown; most beds have gradational soft, brown, shaly bases; diverse and patchily abundant fauna, mainly bivalves ('*Lucina*' *bellona* d'Orbigny, 'myids' in growth position, oysters, trigoniids), cerithiid gastropods and recrystallized corals; shell debris including bryozoans, echinoderms and serpulids	2.0
Mudstone, dark-grey, weathering brown, well laminated, slightly bituminous; abundant white, weathering brown, ooids and oncoids	0.6
Limestone (pelsparite usually with micrite–microspar matrix), hard, grey, splintery, thinly bedded or nodular, poorly fossiliferous, alternating with black or dark blue-grey mudstone–marl; limestones have subsidiary amounts of shell debris, accretionary grains, silt-grade, angular to subrounded quartz grains, and wood, are strongly bioturbated, with rare *Pleuromya*; abundant *Chondrites* in both limestones and mudstones, especially at their bed boundaries; mudstones have rich microfauna of ostracods and juvenile oysters, large amounts of montmorillonite, and minor amounts of mica, kaolinite and quartz; small, black, ooid-like grains in lower mudstone beds	2.35
Santon Oolite Member	
Limestone (oopelmicrite with recrystallized matrix), blue-hearted, weathering honey-yellow; well-preserved wood, sometimes bored, in pieces up to 1 m long; elaborate and dense burrow-systems including horizontal, vertical and oblique forms with individual burrows varying up to 10 mm in diameter and highly variable in length	*c.* 0.7

	Thickness (m)
Limestone (pelmicrite with matrix recrystallized to microspar), cream-coloured with peloids, and sparsely scattered ooids; fossils (mainly concentrated in pockets) including bivalves such as bakevelliids and *Pholadomya* (in growth position), *Natica*, *Nerinaea*, cerithiid and other gastropods, serpulids and crustaceans; burrows (*Thalassinoides* and *Zoophycos*) present near top; shell debris	*c.* 0.9
Limestone (bio-oosparite), yellowish-brown; minor amounts of peloids; becoming increasingly micritic towards top; shelly with bivalve, gastropod and echinoderm debris, and thick-shelled bivalves, mainly preserved convex-side uppermost; beds have retort-shaped burrows in their top *c.* 0.15 m; gradational base	*c.* 0.4
Ravensthorpe Member	
Variable sequence of buff-coloured limestone (similar to underlying unit but with less quartz), brown clay, and orange-green sand with silt and clay lenses, and wood; *Chondrites* and large horizontal burrows	*c.* 1.1
Limestone (variably recrystallized micrite), grey, silty (quartz) with micaceous and clay-rich layers; clays with kaolinite dominant, minor quartz, mica and montmorillonite, and traces of felspar and pyrite; poorly fossiliferous except for abundant burrows (most common in upper part) such as *Chondrites*, *Thalassinoides*, *Zoophycos*	*c.* 1.3
Mudstone, calcareous, grey with ooid-like grains at base; very shaly at top; mainly kaolinite with minor mica and quartz, and trace of montmorillonite; poorly fossiliferous with small oysters, serpulids and isolated *Chondrites*	*c.* 1.3
Cleatham Limestone	
Limestone (bio-oosparite), blue-grey, weathering honey-yellow, passing down with decreasing numbers of ooids into biomicrite; micritic matrix largely recrystallized; shell fragments, particularly bivalves and gastropods (notably cerithiids); burrows including *Chondrites*; oyster-rich, shaly base	*c.* 1.0
Limestone (biomicrite), hard, grey, porcellaneous	*c.* 0.3
Limestone (pelmicrite with matrix variably recrystallized), fine grained, silty, grey, weathering yellow-brown; shelly at base with bivalves (small oysters and trigoniids), belemnites and serpulids; trace fossils including large, horizontal burrows; less shelly above with serpulids predominant, and with shell debris, peloids, silt-grade, angular, detrital quartz grains and minor amounts of mica	0.53
Grantham Formation	
Mudstone	

Interpretation

When originally described by Ashton (1975), the basal 0.53 m (Unit A) of the Lincolnshire Limestone Formation was classified as Basal Hydraulic Limestone Member (following Kent, 1966). This member was based on the Hydraulic Limestone of Ussher *et al.* (1890). However, 1:10 000 scale geological surveying of the Humberside area by the British Geological Survey in the 1960s and 1970s showed that the Lincolnshire 'Hydraulic Limestone' of previous accounts did not extend as far north as previously thought and it was separately named the 'Cleatham Limestone' (Gaunt *et al.*, 1980). In the Manton Stone Quarry section, Gaunt *et al.* (1992) assigned Ashton's (1975) Unit A and Unit B to this stratum, which they considered as part of the Ravensthorpe Member. Originally, Ashton (1975) had identified his Unit B as the lower limb of the Santon Oolite Member which interfingered with the Ravensthorpe Member, and he proposed the site as the type locality for these two members as well as the underlying Basal Hydraulic Limestone Member.

Gaunt *et al.* (1992) also named separately a predominantly limestone unit (the Scawby Limestone), which formed the upper half of Ashton's (1975) Kirton Cementstones Member (this member based on Wilson, 1948) (Figure 4.48). This new unit comprised Ashton's Unit F plus the underlying 0.6 m of dark-grey, brown-weathering oncoidal mudstone, which was included because of its close cyclical relationship with the overlying limestones. The small thickness of mudstone at the top of the section was assigned by Ashton (1975) to the Kirton Cement Shale [Member] following the nomenclature of Richardson (1940), although this term had been published earlier by Muir-Wood (1939). Later, Ashton (1980) modified the name to 'Kirton Shale Member', following Kent (1941). However, Gaunt *et al.* (1992) treated this unit as an unnamed third division (above the Scawby Limestone) of the Kirton Cementstones Member. This unit, which is famous for the coral 'patch reefs' that it contains, is fully developed at the nearby **Cliff Farm Pit** (see GCR site report, this volume). At Manton Stone Quarry, coral knolls have been mapped out within the GCR site boundaries (BGS archives). In his unpublished thesis, Ashton (1977) figured one of them that had been left as an isolated upstanding remnant during the early working of the quarry.

Figure 4.48 Kirton Cementstone Member with Scawby Limestone at Manton Stone Quarry. (Photo: M.G. Sumbler.)

According to Ashton (1975), the section at Manton Stone Quarry provided evidence that the carbonate sea regime, in which the Lincolnshire Limestone Formation was deposited, was at times interrupted by the influence of the delta that occupied the area of North Yorkshire at that time. Supported by observed variations in the quartz content within the succession, and differences in the clay mineralogy between the more clastic-rich (with kaolinite dominant) and carbonate (with montmorillonite dominant) deposits, he suggested that either by southwards prograding or by channel-switching, immature terrigenous clastic sediments were introduced from the north, and not until the retreat or further switching of the delta did carbonate sedimentation re-establish itself.

There are no reliably age-diagnostic fossils reported from this site although, according to Ashton (1975), the brachiopod *Acanthothiris crossi* (Walker) is widely recorded from the uppermost bed of his Unit F (= Scawby Limestone). Gaunt *et al.* (1992) cited an ammonite of '*Witchellia* type' from that stratum at a locality (SK 9685 9348) near Atterby, some 9 km south of Manton Stone Quarry, suggesting that there it belongs to the Ovalis Subzone of the Laeviuscula Zone (now the Ovalis Zone). These authors also considered that the Cleatham Limestone of this area belonged to the Discites Zone, based on ostracod faunas recovered from other localities by Bate in Gaunt *et al.* (1980); at the time of Ashton's (1975) work, practically the whole of the Lincolnshire Limestone Formation was considered to belong to that zone. The precise relationship of the beds exposed at Manton Stone Quarry with the standard ammonite-based zonation must be considered tentative.

Conclusions

Manton Stone Quarry provides a rare section through the lower part of the Lincolnshire Limestone Formation that is unlike the lower part of that formation in the Lincoln, and more southerly, areas. The site is of considerable importance for the interpretation of the local and regional stratigraphy of the formation, as well as palaeoenvironmental analysis that involves the interplay of southerly influenced carbonate deposition and northerly influenced clastic deposition.

EASTFIELD QUARRY, EAST RIDING (SE 916 323)

B.M. Cox

Introduction

Eastfield Quarry (now known as 'Everthorpe Quarry'), near South Cave in the East Riding of Yorkshire (formerly Humberside) (Figure 4.49), exposes the shelly, ooidal limestone with sand intercalations known, since Phillips (1835), as the 'Cave Oolite Member' (Figure 4.50). This stratum has been used locally as a building stone and aquifer. The quarry was greatly enlarged during the Second World War, and Sylvester-Bradley's (1947) subsequent account of the section established the site's importance for understanding the local and regional stratigraphy, in particular the relationship of the Cave Oolite Member to the succession farther north in the Cleveland Basin, and farther south in Lincolnshire. Not only is the Cave Oolite Member well developed here (up to *c.* 8 m thick) and more fossiliferous than elsewhere, but the site has also distinguished itself by yielding an ammonite that is otherwise unknown from these beds (Senior and Earland-Bennett, 1973).

Description

The following section is based on that recorded by G.D. Gaunt (BGS archives) during the 1:10 000 scale geological survey of the South Cave area in 1969–1971, with additional information, particularly of the beds above and below the Cave Oolite Member, from Sylvester-Bradley (1947), Bate (1967b), Brasier and Brasier (1978) and Gaunt *et al.* (1992). Bate's (1967b) section, with its extensive lists of ostracod species, is itself based on an unpublished detailed section recorded by Sylvester-Bradley in 1947. As with many sections, there is considerable variance between the different records but the so-called 'shell sands' allow some comparisons (Figure 4.51). The section has also been reported by De Boer *et al.* (1958), and Bisat *et al.* (1962), and cited by Penny and Rawson (1969). The lithostratigraphical classification follows Gaunt *et al.* (1992). Their informal tripartite division of the Cave Oolite Member into lower, middle and upper, which they considered to be a basis for descriptive and correlative purposes, is also shown.

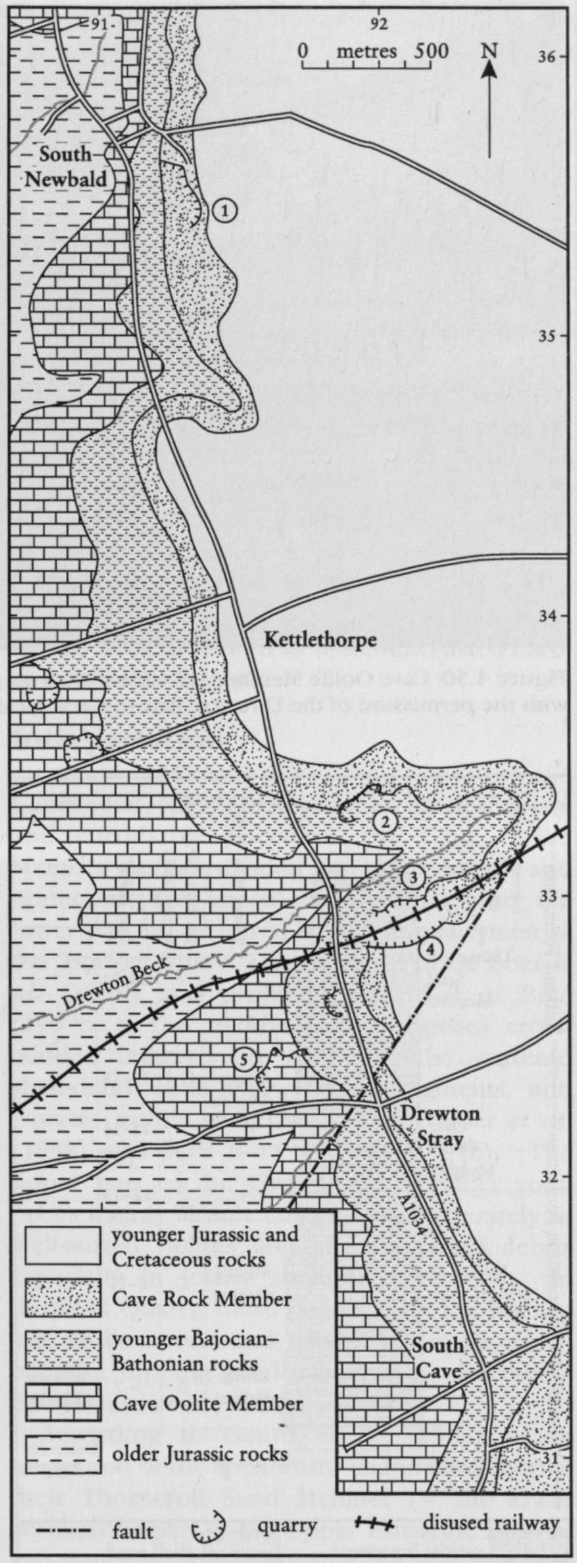
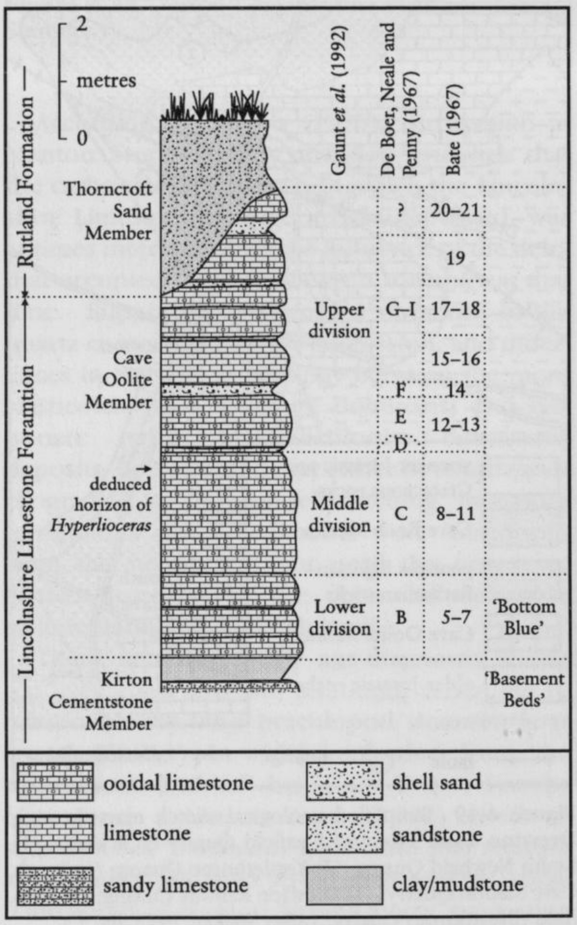


Figure 4.49 Simplified geological sketch map showing **Drewton Lane Pits** and Eastfield Quarry GCR sites. (1) South Newbald Quarry; (2) Kettlethorpe Quarry; (3) South Cave Station Quarry; (4) Drewton Railway Cutting; (5) Eastfield (Everthorpe) Quarry. (After Walker, 1972, fig. 1.)

Figure 4.50 Cave Oolite Member at Eastfield Quarry. (Photo: British Geological Survey, No. L2947; reproduced with the permission of the Director, British Geological Survey, © NERC, 1982.)



◂**Figure 4.51** Graphic section of the Bajocian succession at Eastfield Quarry showing the approximate relationship of different authors' bed numbers and subdivisions.

	Thickness (m)
Rutland Formation	
Thorncroft Sand Member	
Variegated sands and clays; limestone pebbles, shell fragments including occasional belemnites, pisoliths and ooids derived from underlying beds; base cuts down 1.8 m into underlying limestone to produce channel-like profile 8 m wide	seen to *c.* 1.2
Lincolnshire Limestone Formation	
Cave Oolite Member	
Upper division	
Limestone, pale greyish-brown, pinkish and purplish in parts, massive, poorly sorted, ooidal, with abundant shell-debris and rare wood	0.48
'Shell sand', pale yellowish-brown, partially cemented, ooidal	0.25
Limestone, well sorted, compacted, ooidal, with sporadic fine shell-debris at certain horizons; fine grained, pale greyish-brown, purplish at top and in lowest 0.05–0.10 m; medium-grained and cream-coloured in middle; in places, pale and grey-hearted; middle beds cross-bedded to east, north-east and south-east	0.84
'Shell sand', pale-brown, unconsolidated	0.06
Limestone, pale greyish-brown, pinkish in parts, hard, thin-bedded, well sorted, compacted, very fine-grained, ooidal; thin, shell-debris rich parting near top	0.28

	Thickness (m)
'Shell sand', pale-brown, crumbly, with some white bands containing traces of ooidal structure	0.01
Limestone, pale grey-brown, pinkish in parts, hard, thin-bedded, well sorted, compacted, very fine-grained, ooidal	0.58
'Shell sand', pale-brown, unconsolidated	0.03
Limestone, pale greyish-brown, slightly grey-hearted in middle and upper parts; well sorted, compacted, fine grained, with rare shell- and wood-debris in middle and upper parts; poorly sorted, medium-grained in lower part	0.76
'Shell sand', partially cemented, slightly ooidal, with mottled rusty-brown concretionary patches and thin lenses of limestone	0.25
Limestone, pale greyish-brown; upper part pinkish and purplish, poorly sorted, compacted coarse oolite (pisolithic); lower parts partly grey-hearted, fine- to medium-grained with scattered fine to coarse (pisolithic) ooids, shell fragments and debris; two impersistent partings of 'shell sand' (up to 0.01 m thick) in middle part	0.91
'Shell sand', pale-brown and slightly yellowish-orange, unconsolidated, with rare shell-fragments	0.05
Middle division	
Limestone, pale brownish-cream, grey-hearted in upper 0.3–0.45 m, medium sorted, compacted, fine to medium ooidal with rare shell-fragments; fairly massive but weathering into harder and softer bands and with thin impersistent lenses of unconsolidated 'shell sand'	2.13
Lower division	
Limestone, pale yellowish grey-brown mottled, grey-hearted in places, poorly sorted, fine to coarse (pisolithic) ooidal, with abundant shell-debris, sporadic larger fragments, rare whole shells and wood fragments	0.56
Limestone, pale greyish-cream, poorly sorted, fine to coarse (pisolithic) ooidal, with scattered shell-debris and rare whole shells	0.56
Limestone, pale yellowish-brown, soft, poorly sorted, fine to medium ooidal, with sporadic shell-debris; grey 'silty' limestones in lower part and thin grey mudstone beds, lenses and laminae in lowest 0.08 m	0.33
Kirton Cementstone Member	
Mudstone, pale-grey and brown, bedded and shaly in places, with rare, white, crumbly shell-fragments; upper 0.10 m contains sporadic thin beds and lenses containing white ooids, and is also slickensided; lower part contains rare ferruginous concretions	0.41
Limestone, pale-grey and brown mottled, with ferruginous 'earthy' ?silty and/or sandy appearance, and with sporadic shell-debris and ?ooids	seen 0.2

The majority of fossils found at Eastfield Quarry are bivalves, including *Ceratomya bajociana* (d'Orbigny), *Gervillella scarburgensis* (Paris), *Lima*, pectinids and *Trigonia hemisphaerica* Lycett, but the sandier partings often yield quite well-preserved specimens of the echinoid *Pygaster semisulcatus* (Phillips) (= *Plesiechinus ornatus* (J. Buckman)). Other echinoderms, in the form of pentacrinoid columnals, are abundant in some beds (Bate, 1967b). The bryozoan *Collapora straminea* (Phillips) and brachiopods (*Acanthothiris*) have also been recorded. Although fossils are relatively common, they are difficult to extract, except from the thin, soft, sandy partings between the limestone beds, and are usually fragmentary and poorly preserved (De Boer *et al.*, 1958; Penny and Rawson, 1969). Brasier and Brasier (1978) recorded the trace fossils *Arenicolites* and *Thalassinoides* in the Cave Oolite Member as well as oyster-encrusted hardgrounds near its top.

Interpretation

Gaunt *et al.* (1992) believed that, for descriptive and correlative purposes, the Cave Oolite Member was best divided into lower, middle and upper parts (see above). At Eastfield Quarry, the lower part was referred to by the quarrymen as the 'Bottom Blue'. This is Unit B of De Boer *et al.* (1958) and probably beds 5–7 of Bate (1967b). The middle part comprises cross-bedded oolites with some pisoids, scattered shell-debris and a few wood fragments, and equates mainly with Unit C of De Boer *et al.* (1958) and beds 8–11 of Bate (1967b). The upper part of the Cave Oolite Member comprises mainly closely compacted, moderately to well-sorted oolites and contains shell debris especially in 'marly shell-sand' partings. In Eastfield Quarry, these oolites form the highest 4 m of limestone and exhibit low-angle cross-bedding dipping predominantly to the north-east (Gaunt *et al.*, 1992).

According to Gaunt *et al.* (1992), close inspection of the apparently 'channelled' base of their Thorncroft Sand Member (= the lower arenaceous part of the Upper Estuarine Beds of previous authors) shows that the thin bedding, laminations and small-scale cross-bedded layers within that member are parallel to the junction with the Cave Oolite Member. From this, they deduced that these features are not part of a channel-fill but, having originally been deposited on a level surface, the beds have subsided into a hollow at the top of the Cave Oolite Member, presumably owing to solution of the limestone by acidic groundwater. Within the quarry, three large masses of Thorncroft Sand Member have been reported with their bases down to 3 m below the general top of the Cave Oolite Member, and Gaunt *et al.* (1992) suggested that these probably also occupy solution hollows. The Thorncroft Sand Member is now classified with the Rutland Formation, and is probably equivalent to the Stamford Member thereof (see Figure 4.2).

Although found loose, the specimen of *Hyperlioceras* (Figure 4.52) reported by Senior and Earland-Bennett (1973) is believed to come from the middle division. These authors identified it as *H. rudidiscites* S.S. Buckman but Parsons (1974b, 1980a) challenged this, believing that the specimen was too fragmentary and distorted for the species to be identified; however, Senior and Earland-Bennett (1974) upheld their original identification and deduced that it came from the upper part of Bate's (1967b) Bed 11 (i.e. near the top of the middle division) thereby providing the first tangible piece of evidence for the stratigraphical position of the Cave Oolite Member. If correctly identified, the specimen is suggestive of the Lower Bajocian Discites Zone, as first surmised by Richardson (1911a), although an open position within that substage might be a more reasonable diagnosis (see below).

De Boer *et al.* (1958) reckoned that their units A and B could be compared with the upper part of the Lower Lincolnshire Limestone, and units C to I could be compared lithologically with the Upper Lincolnshire Limestone, and Gaunt *et al.* (1992) included the Cave Oolite as a member of that formation. The latter authors correlated it with the upper part of the Kirton Cementstone Member and the Hibaldstow Limestone Member of the succession south of the Humber (see **Cliff House Pit** GCR site report, this volume). They believed that the lower division (the so-called 'Bottom Blue') was the lateral equivalent of the Scawby Limestone (see **Manton Stone Quarry** GCR site report, this volume). Since they considered that the Cave Oolite Member was equivalent in part to the upper part of the Kirton Cementstone Member, above the Scawby Limestone, they queried the zonal implications of the *Hyperlioceras* found at Eastfield Quarry (see above), which conflicted with the zonal evidence of other rare ammonite specimens found south of the Humber (see Figure 4.2).

The relative stratigraphical position and the macrofaunal assemblage, including the bryozoan *Collapora* (formerly *Millepora*), have led to a correlation of the Cave Oolite Member

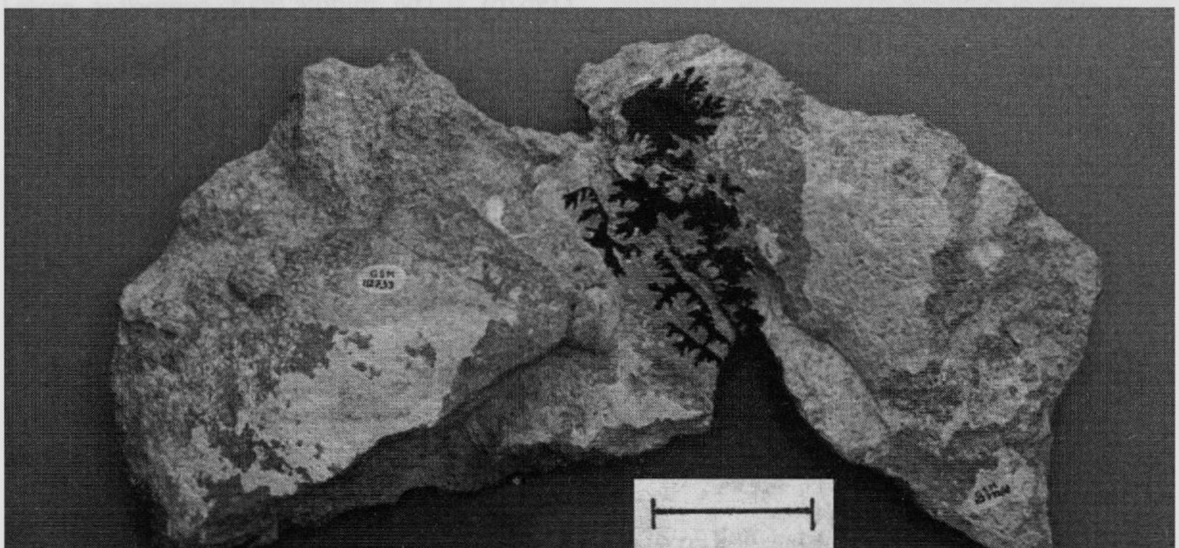


Figure 4.52 Poorly preserved *Hyperlioceras* fragment from the Cave Oolite Member of Eastfield Quarry (BGS specimen number GSM 112733); scale-bar represents 50 mm. (Photo: M.G. Sumbler.)

with the unit known as the 'Millepore Bed' (Wright, 1860) on the Yorkshire coast (Cloughton Formation, Lebberston Member) (see Chapter 5).

The fauna and lithologies are suggestive of deposition in a warm, shallow sea. Dune bedforms suggest strong tidal conditions, the high-energy environment of which did not favour the preservation of ammonites.

Conclusion

The Eastfield Quarry site provides one of the last, and certainly the best, existing exposure of the Cave Oolite Member. It has also yielded the only known ammonite from that unit. It is a key site for establishing the correlation of the Cave Oolite Member with its lateral equivalents – the Lebberston Member of the Cloughton Formation in the Cleveland Basin, and the Kirton Cementstone and Hibaldstow Limestone members of the Lincolnshire Limestone Formation farther south into Lincolnshire.

DREWTON LANE PITS, EAST RIDING (SE 918 333, SE 920 329)

K.N. Page and B.M. Cox

Introduction

The GCR site known as 'Drewton Lane Pits' is located to the east of the A1034 road *c.* 2 km north of South Cave in the East Riding of Yorkshire (formerly Humberside) (Figure 4.49). It comprises two small quarries: Kettlethorpe Quarry (SE 918 333), which has long been disused; and the more famous South Cave Station Quarry (SE 920 329), which is larger and worked periodically (Figure 4.53 and 4.54). The section at Kettlethorpe Quarry has been noted by Walker (1972), Penny and Rawson (1969) and Page (1988), and that at South Cave Station Quarry by De Boer *et al.* (1958), Penny and Rawson (1969), Walker (1972), Brasier and Brasier (1978) and Page (1988). Quarrying at the latter site has now partly destroyed the old Drewton

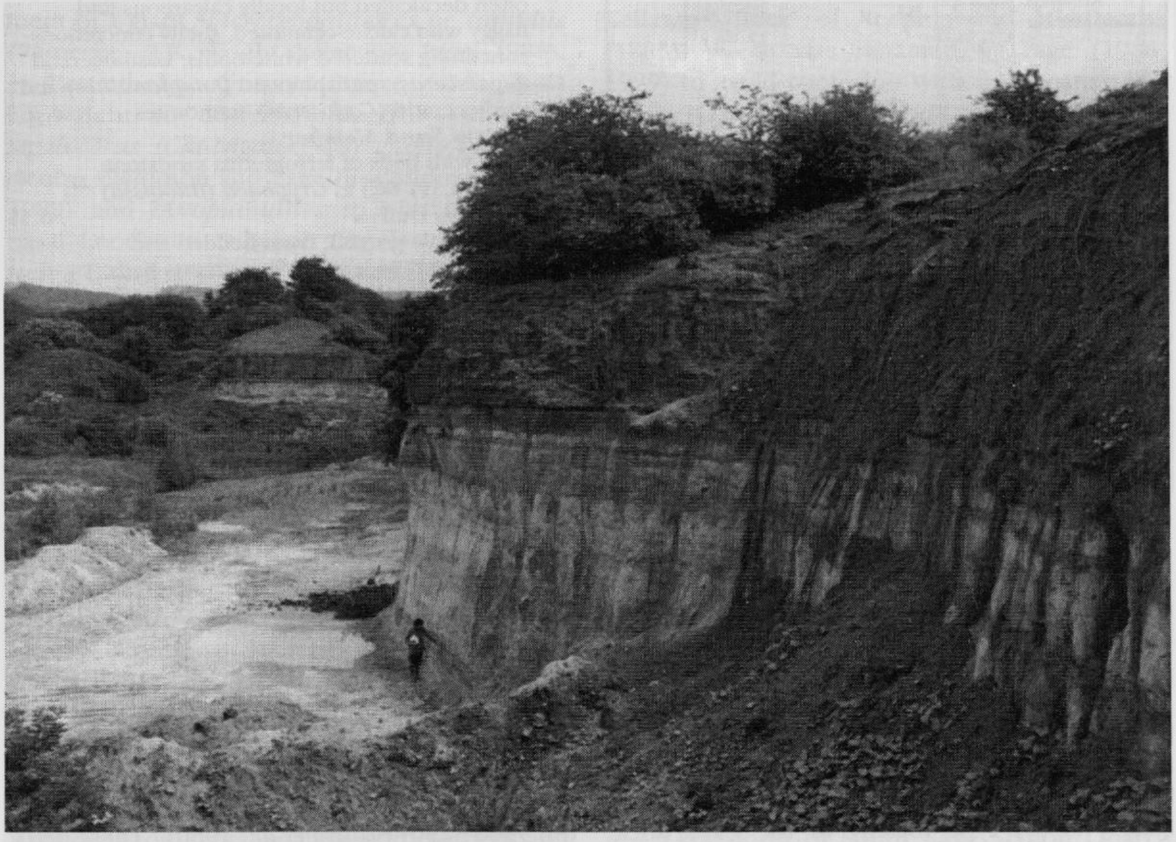


Figure 4.53 South Cave Station Quarry (part of the Drewton Lane Pits GCR site), showing the pale Kellaways Sand Member overlain by the darker Cave Rock Member. (Photo: M.G. Sumbler.)

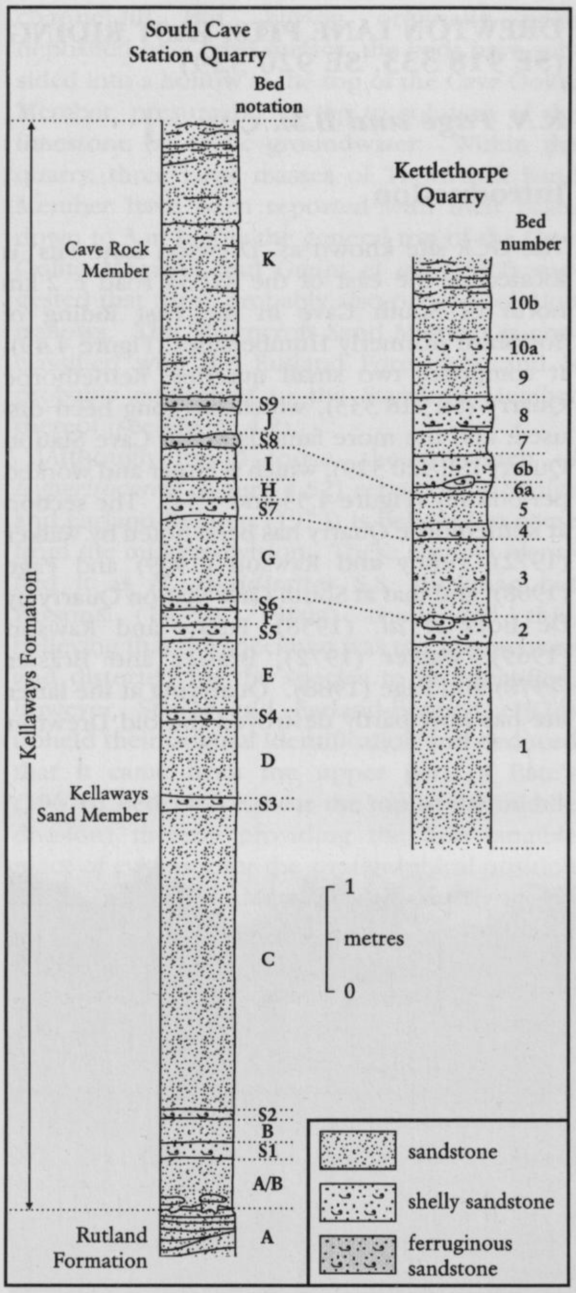


Figure 4.54 Graphic sections showing the correlation between South Cave Station Quarry and Kettlethorpe Quarry. Bed notation follows Brasier and Brasier (1978) and Page (1988) respectively.

Railway Cutting that was referred to by Keeping and Middlemiss (1883), Dakyns *et al.* (1886) and Fox-Strangways (1892). South Cave Station Quarry is the type locality of the Cave Rock Member of the Kellaways Formation (Page, 1989). This member yields a rich molluscan fossil fauna, including ammonites, and the site is a designated reference section for the Enodatum Subzone of the Lower Callovian Calloviense Zone.

Description

The most detailed description of South Cave Station Quarry is that of Brasier and Brasier (1978). Records of Kettlethorpe Quarry vary in detail and the only full description is that of Page (1988). A composite succession for the two sites is given below; details of the Oxford Clay Formation are based on Drewton Railway Cutting (Keeping and Middlemiss, 1883) and bed notation in the Kellaways Sand Member follows Brasier and Brasier's (1978) record of South Cave Station Quarry shown in Figure 4.54.

	Thickness (m)
Oxford Clay Formation	
Clay, dark bluish-grey, becoming sandy near base	*c.* 2.4–3
Kellaways Formation	
Cave Rock Member	
Sandstone, orange-brown to pale-yellowish, often decalcified but locally calcareous and flaggy with calcite-cemented, shelly concretions containing scattered white ooids; kosmoceratid (*Sigaloceras*), perisphinctid (*Anaplanulites*) and cardioceratid (*Cadoceras*) ammonites	*c.* 2.7
Kellaways Sand Member	
J: Sand with beds of ferruginous sandstone (S8 and S9) rich in *Gryphaea* (*Bilobissa*) *dilobotes* Duff	0.55
C–I: Sand, pale-greyish, cross-bedded and bioturbated with some ferruginous beds and occasional large calcareous concretions; shell beds (S3–S7) with *Gryphaea*	*c.* 6.4
B: Sand, grey to brown, bioturbated; belemnite conglomerate at top (S2), bivalve-rich layer below with *Pleuromya* and *Lopha marshii* (J. Sowerby)	*c.* 0.45
A/B: Sand, grey to orange-brown, muddy with belemnites and *Pleuromya*; abundant trace fossils; interburrowed junction at base	up to 0.5
Rutland Formation	
Thorncroft Sand Member	
A: Sand, pale-pink to whitish	*c.* 2.6

Interpretation

The sands at the base of the section are assigned to the Thorncombe Sand Member, following Gaunt *et al.* (1992) who recorded the section proved in the BGS South Cave Borehole (SE 9366 3230) (Gaunt *et al.*, 1980). These beds are believed to represent the lower part of the Rutland Formation of mainly Bathonian age, and there is thus a pronounced non-sequence with the beds above.

The age of the lowest beds of the overlying Kellaways Sand Member is uncertain owing to the absence of age-diagnostic fossils. The presence of belemnites in Bed A/B suggests the Lower Callovian Koenigi, or younger, Zone; the more muddy lithology may indicate a level close to the top of the Kellaways Clay Member (which apparently has been recorded below the Kellaways Sand Member in a well section at nearby Drewton (SE 925 334) (Fox-Strangways, 1892; Page, 1988). The absence of *Gryphaea* in these lowest beds supports a pre-Calloviense Zone age by analogy with sections in eastern and southern England; a corollary of this is that the incoming of *Gryphaea* (with abundant belemnites) in Bed S2 may indicate that the beds above belong to the Calloviense Subzone with the base of the Enodatum Subzone lying at around the level of beds S8–S9. At South Cave Station Quarry, the only ammonites that the latter beds appear to have yielded are a *Homoeoplanulites* (specimen figured by Cox, 1988 (as *Choffatia cardoti* (Petitclerc)) and Page, 1991) and a fragment of a giant *Macrocephalites* ex gr. *tumidus* (Reinecke) (J.K. Wright collection; Page, 1988). At Kettlethorpe Quarry (Figure 4.54), beds equivalent to S8–S9 yield, from Bed 6b, *Sigaloceras* (*Catasigaloceras*) *enodatum* transient α Callomon and Page (in Callomon *et al.*, 1989) and ?*Anaplanulites* sp., indicating the basal Enodatum Subzone (*Sigaloceras enodatum* α Biohorizon) and, from Bed 8, *Sigaloceras enodatum* aff. transient β Callomon and Page (in Callomon *et al.* 1989), *Anaplanulites difficilis* S.S. Buckman and *Cadoceras* cf. *durum* (S.S. Buckman), indicating the Enodatum Subzone (*Sigaloceras enodatum* β Biohorizon). Abundant bivalves (including '*Astarte*', *Chlamys*, *Gryphaea* and *Myophorella*) and rhynchonellid brachiopods are also present. The zonal evidence from the Kellaways Sand Member therefore suggests that the erosive phase and non-sequence below Bed A/B at South Cave Station Quarry represents at least the entire Lower Callovian Herveyi Zone and part of the Koenigi Zone (and probably a significant part of the Bathonian Stage also). This erosion is related to uplift on the Market Weighton High.

Brasier and Brasier (1978) provided a detailed palaeoenvironmental analysis of these beds and concluded that Bed A/B represented a submerged marsh with a typical trace-fossil assemblage (*Ophiomorpha*, *Arenicolites* and *Skolithos*) suggesting intertidal to nearshore subtidal conditions and indicating that, in earliest Callovian times, the Market Weighton High formed a shoal and may even have been emergent. The bulk of the overlying Kellaways Sand Member, a sequence of shell beds alternating with cross-bedded often muddy sands, was interpreted as the point-bar deposits of laterally migrating tidal channels, with the shell beds representing basal lag deposits. The trace-fossil assemblage, with abundant *Arenicolites*, *Skolithos* and *Ophiomorpha*, is also consistent with an intertidal to shallow subtidal environment, as is the presence of 'tidal bedding', mud-cracks, a coarse sediment grain-size and frequent plant-debris and mica. According to Brasier and Brasier (1978), deepening and establishment of subtidal conditions is reflected by the increase in abundance of *Gryphaea* towards the top of the Kellaways Sand Member and the high diversity of epifaunal and infaunal bivalves in beds S8–S9 (and their equivalents at Kettlethorpe Quarry) and the overlying Cave Rock Member.

The Cave Rock Member is the 'Upper Kellaways Rock' of Keeping and Middlemiss (1883), which was renamed by Page (1988, 1989) to avoid confusion with the separate but similarly named development of calcareous sandstone at a lower stratigraphical level in Wiltshire (see **Kellaways–West Tytherton** GCR site report, this volume). The member has yielded a very rich and well-preserved fauna with many ammonites, including macroconch and microconch *Sigaloceras* (*Catasigaloceras*) *enodatum* β (Nikitin) (including the types of *S. planicerclus* S.S. Buckman, *S. curvicerclus* S.S. Buckman and *S. crispatum* S.S. Buckman; specimens figured by Buckman, 1923a,b; Tintant, 1963; Page, 1989, 1991) with macroconch and microconch *Anaplanulites difficilis* Buckman (including the lost holotype; specimens figured by Cox, 1988; Page, 1991) and macroconch and microconch *Cadoceras* (*C.*) *durum* Buckman (including the holotype; specimens figured by Buckman, 1922b; Page, 1991). This fauna was used by Callomon (1955) to establish the Enodatum Subzone (originally as Planicerclus Subzone), with the South Cave Station Quarry as its type locality. Page (1989) subsequently proposed an alternative section at South Newbald, *c.* 2.5 km north of South Cave Station Quarry, because the fauna of the subzone's oldest (*Sigaloceras enodatum* α) biohorizon is exposed there in Cave Rock Member facies and consequently faunal preservation is much better than in areas farther south. The ammonite *Anaplanulites* appears to be a Subboreal genus that is almost unknown where *Homoeplanulites* is common, such as in parts of France (Cariou, 1984; Mangold, 1970a,b). Its morphology and distribution are reminiscent of the Subboreal genus *Proplanulites* from which it may well descend. The remaining fauna of the Cave Rock Member includes the bivalves *Anisocardia*, *Chlamys*, *Entolium*, *Goniomya*, *Grammatodon*, *Gresslya*, *Gryphaea*, *Isodonta*, *Myoconcha*, *Oxytoma*, *Pinna*, *Pleuromya*, *Protocardia*, *Thracia* and *Trautscholdia*, the belemnite *Cylindroteuthis* and the brachiopod *Rhynchonelloidea*; full listings are given by Walker (1972) and Brasier and Brasier (1978).

The Cave Rock Member appears to increase in stratigraphical range northwards, and at South Newbald includes levels equivalent to the top of the Kellaways Sand Member at South Cave Station and Kettlethorpe quarries. This phenomenon is certainly related to the proximity of the Market Weighton High, the unit perhaps representing a shoal of shelly sands fringing the southern side of a then largely submerged positive area. The presence of, presumably allochthonous, ooids may indicate a shallow-water, subtidal lagoonal or platform environment over the High.

Keeping and Middlemiss' (1883) record of '*Ammonites* [*Binatisphinctes*] *comptoni*' and '*Ammonites* [*Kosmoceras*] *elizabethae*' from the Oxford Clay Formation at Drewton Railway Cutting is compatible with Gaunt *et al.*'s (1980) account of the nearby BGS South Cave Borehole where the Upper Callovian Athleta Zone is identified in the basal Oxford Clay Formation. A significant non-sequence is thereby indicated between the Kellaways and Oxford Clay formations.

Conclusions

South Cave Station Quarry and Kettlethorpe Quarry, which together comprise the GCR site known as 'Drewton Lane Pits', include the type section of the Cave Rock Member of the Kellaways Formation. Sedimentary and palaeontological features in the exposed strata allow detailed palaeoecological analysis. The Cave Rock Member yields ammonite faunas of international importance that have facilitated recognition of the Enodatum Subzone of the Lower Callovian Calloviense Zone across Britain and Europe to Russia and beyond. The member here is the stratotype of this subzone that has yielded many specimens of the ammonite *Anaplanulites*, a genus restricted to Subboreal regions, and a single specimen of the ammonite *Macrocephalites*, only one other specimen of which is known from the Enodatum Subzone in Britain. Although the South Cave Station and Kettlethorpe quarries do not yield the well-preserved *Sigaloceras enodatum* α Biohorizon faunas of the now lost South Newbald site, a little farther north, they do provide an important reference section for the next youngest *Sigaloceras enodatum* β Biohorizon, the internationally most widespread and typical development of the Enodatum Subzone in Europe.