British Upper Jurassic Stratigraphy (Oxfordian to Kimmeridgian)

J.K. Wright

**Department of Geology, Royal Holloway,
University of London**

and

B.M. Cox

Formerly of the British Geological Survey, Keyworth.

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Chapter 3

Upper Jurassic stratigraphy in the East Midlands

INTRODUCTION

B.M. Cox

The region covered in this chapter extends from Oxfordshire northwards to the East Riding of Yorkshire (Figure 3.1), and broadly coincides with the Late Jurassic depositional area and structural feature known as the 'East Midlands Shelf' (see Chapter 1). For the purposes of this chapter, the southern limit is taken at where the limestones and sandstones of the Corallian Group in the area covered by Chapter 2 pass into clay facies to the east of Oxford (Horton *et al.*, 1995). The northern limit is defined by the Market Weighton High, which, periodically in Jurassic times, acted as a hinge between the rapidly subsiding Cleveland Basin to the north (Chapter 4) and the more gently subsiding East Midlands Shelf to the south. Major uplift, centred on this structure during the Early Cretaceous, led to the erosion of much of the Jurassic succession that had been deposited over and adjacent to it. For this reason, Upper Jurassic strata are discontinuous and largely absent in the Market Weighton area (Kent, 1980a).

The Oxfordian–Kimmeridgian succession in the East Midlands is almost exclusively argillaceous and therefore differs from that elsewhere in England where significant carbonate sediments occur in the Oxfordian (see chapters 2 and 4, this volume). The strata, largely obscured by Quaternary (Drift) deposits, are almost exclusively marine mudstones and calcareous mudstones that weather easily and give rise to a broad belt of low-lying ground. Silty mudstones, siltstones and concretions or thin tabular beds of muddy limestone (cementstone) occur at some levels, and the Kimmeridgian succession also includes kerogen-rich mudstones (oil-shales). In Buckinghamshire, two main arenaceous horizons interrupt the otherwise argillaceous Upper Kimmeridgian succession. These silty units, which, further west and south-west (see Chapter 2), become increasingly coarse and sandy, may indicate the proximity of land during Late Kimmeridgian times (Horton *et al.*, 1995). In Cambridgeshire, coralline and ooidal limestones are locally developed in the Oxfordian at Upware, and mudstones with limestones rich in reef debris occur at a similar stratigraphical level at Elsworth. These were probably deposited in shallow, current-agitated water close to the London Landmass, which was fringed by patch reefs. At Elsham, in north Lincolnshire, the lower part of the otherwise argillaceous Kimmeridgian succession is interrupted locally by a wedge of medium- to coarse-grained sandstone. It is uncertain whether this deposit was transported by a flush of fast-flowing water (Swinnerton and Kent,1976), or whether it represents a migrating sublittoral sand bar but, clearly, local shallowing of the sea occurred here during the Early Kimmeridgian (Gaunt *et al.*, 1992).

There are no significant natural exposures of this predominantly mudstone succession, which has never been completely exposed. However, in the past, the region was peppered with small brickpits, some of which, together with other local details, were reported in memoirs and papers of the Geological Survey (Jukes-Browne, 1885, 1887; Ussher *et al.*, 1888; Ussher, 1890; Whitaker *et al.*, 1893; Woodward, 1895; Wedd, 1898, 1901), and by geologists from Cambridge (Seeley, 1861a, b, 1862, 1869; Roberts, 1889, 1892), as well as Blake (1875) and Blake and Hudleston (1877), both of whom had been students at Cambridge. The seat of learning at Cambridge continued to be associated with the Upper Jurassic stratigraphy of the region as field parties and individuals from there explored the local geology (Hancock, 1954; Forbes, 1960); the Sedgwick Museum contains important collections of fossils from the region. W. J. Arkell worked there from 1947 and continued to reside in Cambridge until his death. His major monograph on Corallian ammonites (Arkell, 1935–1948) covers the Oxfordian of much of the region. He also contributed some shorter papers (Arkell, 1937a, b, 1938a; Arkell and Callomon, 1963) as well as his earlier regional synthesis (Arkell, 1933). The Oxfordian–Kimmeridgian stratigraphy of the region is covered by the review chapters of Callomon (1968) and Torrens and Callomon (1968), and that of the Huntingdon and Biggleswade, and Cambridge districts by the Survey memoirs published at about this time (Edmonds and Dinham, 1965; Worssam and Taylor, 1969).

Although a few cored boreholes had been drilled in the region in the past (Woodward, 1904; Strahan, 1920; Pringle, 1923), a major advance in knowledge of the detailed stratigraphy came from those drilled in the 1970s in Norfolk (Gallois, 1979b). These became standard reference sections for the Oxfordian–

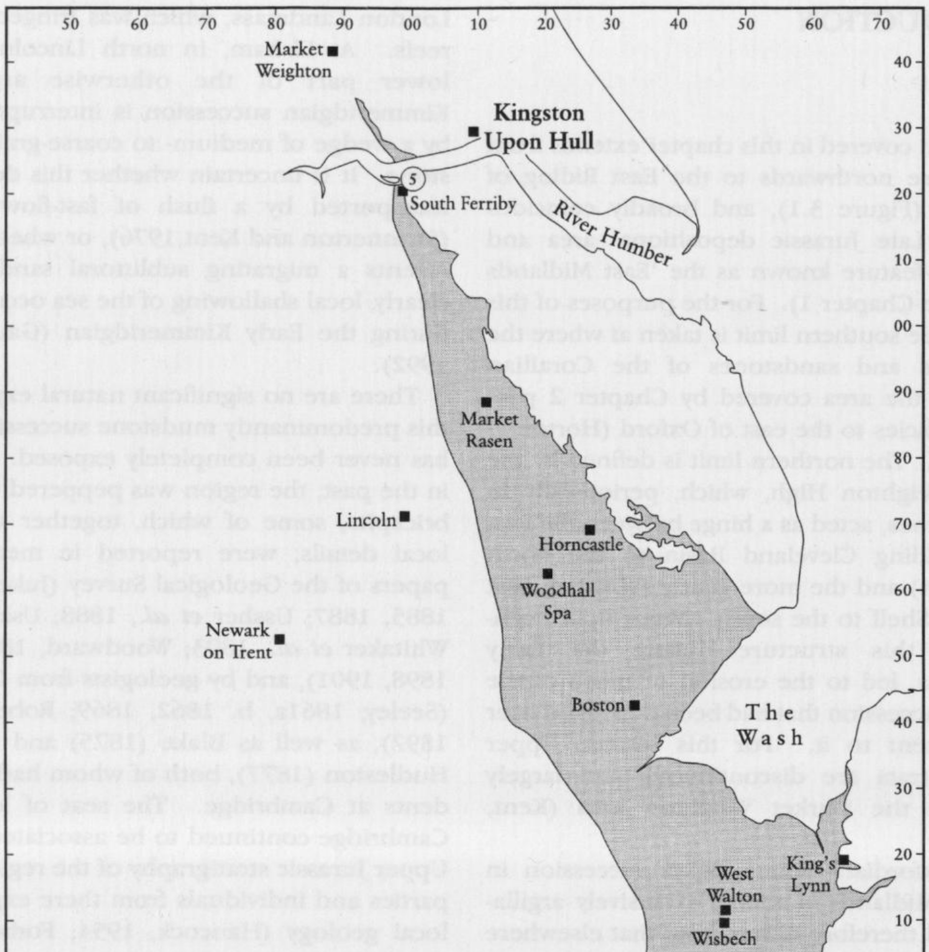
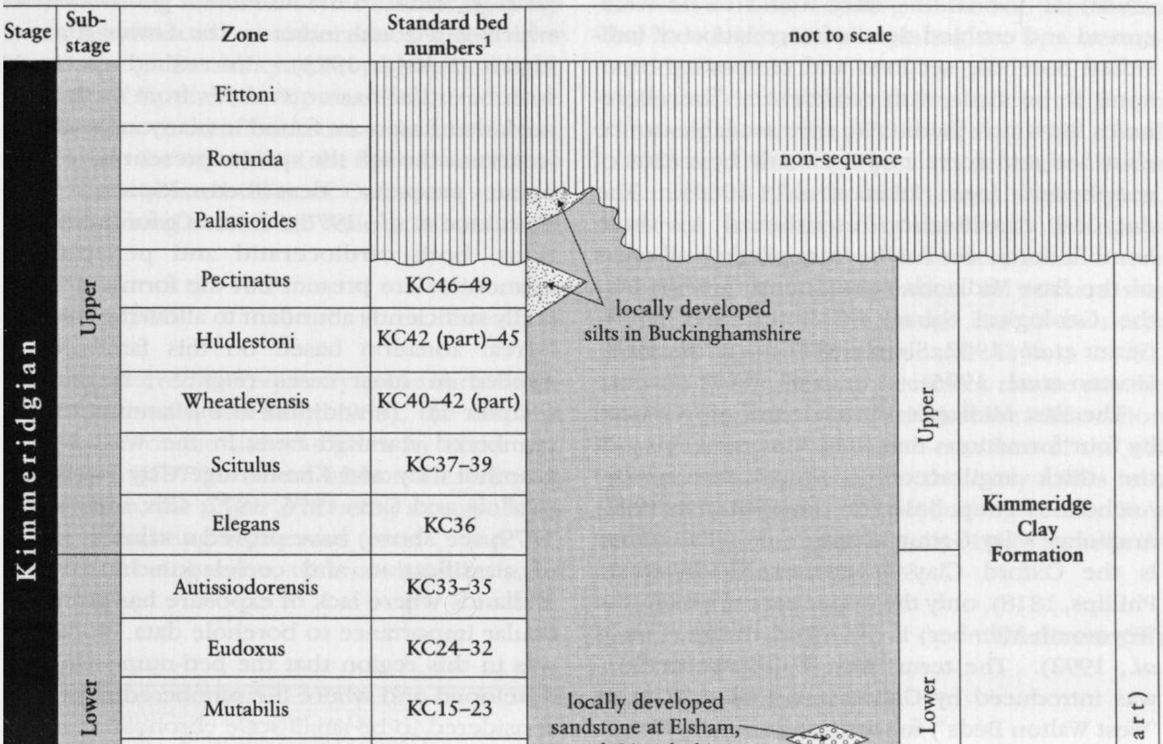


Figure 3.1 **Geological sketch map showing the location of the GCR sites described in Chapter 3. Extensive drift deposits are omitted for clarity. 1, Upware South Pit; 2, Upware; 3, Warboys Clay Pit; 4, Roslyn Hole, Ely; 5, South Ferriby.**



[1]Gallois and Cox, 1976; Cox and Gallois, 1979, 1981.
[2]Base Glosense Zone lowered from base AmC15 to base AmC12 following Wright (1996).

Figure 3.2 Lithostratigraphical classification of Oxfordian–Kimmeridgian strata in the East Midlands.

Kimmeridgian of eastern England and further afield (Gallois and Cox, 1976, 1977; Gallois, 1979b). The internal subdivisions of the various mudstone formations were found to be widespread and enabled detailed correlation of individual borehole sections and temporary exposures to be made with confidence. Even boreholes for which there is no core available can be classified and correlated indirectly by means of geophysical logs (Penn *et al.*, 1986). The detailed classification established in these Norfolk boreholes has been applied to all areas of the East Midlands subsequently mapped by the Geological Survey (Gallois, 1988, 1994; Gaunt *et al.*, 1992; Shephard-Thorn *et al.*, 1994; Horton *et al.*, 1995).

The East Midlands succession is represented by four formations that form the greater part of the thick argillaceous unit known as the Ancholme Group, based on Gaunt *et al.*'s (1992) Ancholme Clay Group (Figure 3.2). The oldest is the Oxford Clay Formation (Buckland in Phillips, 1818), only the upper part of which (the Weymouth Member) is of Oxfordian age (Cox *et al.*, 1992). The term 'West Walton Formation' was introduced by Gallois and Cox (1977) (as 'West Walton Beds') for the overlying unit of generally more silty mudstones, with locally developed more variable silty and calcareous lithologies, between the Oxford Clay and Ampthill Clay. Based on a cored borehole at West Walton, Norfolk, the formation is typically developed in the area of the East Midlands Shelf. Following Gallois and Cox (1977), the locally developed limestones at Upware and Elsworth are recognized as members within it. In the Humber area, beds of this age are slightly more sandy than in areas further south and were differentiated as the Brantingham Formation by Gaunt *et al.* (1992). The Ampthill Clay was named by Seeley (1869), who described its occurrence in Buckinghamshire, Bedfordshire and Cambridgeshire, citing a section on the Bedford–Luton railway near Ampthill, Bedfordshire. The youngest formation is the more widespread Kimmeridge Clay named by Webster (1816) but first recognized as a discrete division (the 'Oaktree Soil') by William Smith on his map of 1815. In the south of the region (Buckinghamshire), silty beds help to divide the Upper Kimmeridge Clay into five members (see Figure 2.52) (Oates, 1991; Horton *et al.*, 1995).

Ammonites are well represented amongst the fossil faunas of all four formations, which can therefore be placed within the ammonite-based chronostratigraphical framework with relative ease. Indeed, Market Rasen in Lincolnshire gives its name to the ammonite genus *Rasenia,* which is a zonal index in the Lower Kimmeridgian (Salfeld, 1913). Uncrushed specimens with beautiful nacreous shells from former pits at Market Rasen are found in many museum collections although the species present have never been properly described (Spath, 1935; Birkelund *et al.*, 1978). In the Oxfordian formations, both cardioceratid and perisphinctid ammonites are present but the former are generally sufficiently abundant to allow the so-called Boreal zonation based on this family to be applied in most cases (Figure 3.2; see also Chapter 1). In addition to the ammonites, the numbered standard beds in the West Walton, Ampthill Clay and Kimmeridge Clay formations (Gallois and Cox, 1976, 1977; Cox and Gallois, 1979; see above) have proved a valuable means of classification and correlation in the East Midlands where lack of exposure has given particular importance to borehole data. Indeed, it was in this region that the bed-numbering was developed and where the numbered beds, now considered to be small-scale chronostratigraphical units, have been most extensively applied.

Further details of the lithologies, thicknesses and depositional environments are included in the site descriptions that follow. In the following list of sites (arranged south to north), (O) indicates that the site belongs to the Oxfordian GCR Block and (K) indicates the site belongs to the Kimmeridgian GCR Block. The location of sites is shown in Figure 3.1.

Upware South Pit (O)
Dimmock's Cote Quarry (O)
Warboys Clay Pit (O)
Roslyn Hole (K)
South Ferriby (O) and (K)

UPWARE SOUTH PIT (TL 539 709)

J.K. Wright

Introduction

Upware South Pit, known as the 'Southern Quarry' in older literature, and as 'Commissioners' Pit' in more recent literature, has been in existence for some two centuries. It was the custom to include the pit in geological excursions as far back as the 1830s (Kelly, 1985), and this occurrence of coralliferous Oxfordian limestones within the area of the Cambridgeshire fens has attracted considerable interest ever since. The pit lies on a small topographical high, the 'Isle of Upware' or 'Upware Ridge', which is nowhere more than 7 m above ordnance datum, and lies on the east side of the River Cam (Figure 3.3). This isolated inlier of Oxfordian strata is only 3 km long and 1.5 km wide at its maximum extent.

Description

Though referred to frequently in the early literature (for details, see Kelly, 1985), the first full description of the site was given by Blake and Hudleston (1877). These authors described a 6 m section, the upper 3 m being a tough limestone containing numerous corals, and the lower 3 m being softer, with ooids and pisoids

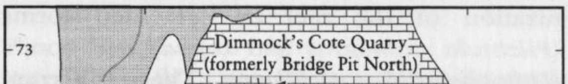


Figure 3.3 Locality map of quarries in the Upware inlier. Outcrop of the Upware Limestone (mapped as 'West Walton Beds'), Ampthill and Kimmeridge clays from BGS Sheet 188 (Cambridge) (1981) and Wright *et al.* (2000).

and an extensive bivalve–echinoid fauna. Though the matrix of the coralliferous beds was not precisely the same as that of the Coral Rag elsewhere in the country, Blake and Hudleston had little hesitation in equating the Upware strata with this unit.

Further detailed decriptions of Upware South Pit were given by Woodward (1895), Reed (1897) and Wedd (1898). Little improvement was made on Blake and Hudleston's description, however, excepting that the fossil lists grew longer. Subsequently, the section became very overgrown, and the attention of workers was drawn primarily to the Bridge Pits to the north (Forbes, 1960; Worssam and Taylor, 1969). Upware South Pit then became a nature reserve owned by the Cambridgeshire Education Department, and the north-east face of the old quarry was cleaned up in the early 1980s as a geological reserve. The following section is a revised version of that of Kelly (1985), as seen by the present author in 1998.

	Thickness (m)
West Walton Formation	
Upware Limestone Member	
(Rubbly weathered limestone and soil	seen to 1.50)
7. Micritic limestone with tabular corals	0.25
6. Seam of brown clay	0.04
5. Tough limestone composed of tabular or foliaceous colonies of *Microsolena* with fine, pelletal, micritic limestone in between the coral colonies. Also seen by Kelly (1985) was a large calcite-replaced coral head of *Isastraea*. Moulds of *Montlivaltia* in life position are common	0.25
4. Flaggy, thin-bedded, largely micritic limestone with *Microsolena* at the base, bored by *Lithophaga*, also with *Plagiostoma* sp. and thin foliae of *Thamnasteria concinna* (Goldfuss)	0.40
3. Seam of brown clay	0.04
2. Tough, coralliferous limestone containing tabular corals in a fine, micritic matrix. *Isastraea* and *Microsolena* are both present, bored by *Lithophaga*, and with	

Plicatula, Opis, pectinids and
Paracidaris 0.30

1. Porous, poorly cemented, bioclastic limestone. The clasts comprise coral, oyster and serpulid fragments, cemented with only a minimum of sparry calcite. Occasional ooidal patches are present. Poorly fossiliferous seen to 1.00

The hard, shelly limestone at the top of Bed 1 forms a ledge upon which rest many fallen blocks from beds 2 to 5. Bed 7 was not recognizable in 1998. Beds 2, 4 and 5 are basically biomicrites. Layers and lenses of *Microsolena* and *Thecosmilia* form a reef framework, with fine, micritic mud in the interstices and in *Gastrochaenolites* borings, which are sometimes still occupied by the boring bivalves *Lithophaga* and *Gastrochaena*. A cemented epifauna includes *Liostrea* and *Nanogyra*. The layers containing coral in living position alternate with layers of shelly, partly decalcified biomicrite, with the fine, micritic matrix full of fragments of *Thecosmilia, Thamnasteria, Microsolena, Nanogyra* and *Trichites*. Most of the larger bivalves are dissolved out and present as moulds. Ammonites are rare, one specimen of *Cardioceras (Miticardioceras)* aff. *tenuiserratum* (Oppel) being known (K.N. Page collection).

Interpretation

The presence of Ampthill Clay to the north, a little above the section (?Upper Oxfordian; Worssam and Taylor, 1969, fig. 2), and the Lower Elsworth Member (Lower Oxfordian; Page, 1986) below are stratigraphically important in constraining the age of these limestones, which, from this information and from the single recorded ammonite, can be dated as Middle Oxfordian, Tenuiserratum Zone.

Bed 1 represents high-energy, shallow-water conditions, with shell and coral fragments and ooids in a sparry matrix with no lime mud, winnowed away by currents. A shallow coral reef, probably situated to the north (see site report for Dimmock's Cote Quarry, this volume), was being eroded, providing coral fragments. Much of the overlying sequence consists of a coral–micrite association, a bioclastic wackestone, which accumulated in a more protected part of the Upware reef complex where micrite was not winnowed away. Interdigitation of clay may indicate fore-reef conditions, and this was the conclusion of Insalaco (1996) in his study of coral morphology at Upware. The colonial corals do not form the rounded, dome-shaped masses normally associated with Corallian reefs. The interlocking framework of platy, foliaceous corals found here, especially with the presence of *Microsolena*, is typical of deep-water biostromes. The coralliferous beds at Upware South Pit accumulated in a moderately deep area below the fairweather wave base in a region with minimal sediment input. Coral growth was very slow – less than 1 mm per year in *Thamnasteria concinna*.

The bivalve fauna of the coralliferous beds is characterized by surface- and near-surface dwelling forms. Shallow burrowers such as *Trigonia*, *Neocrassina* and *Sowerbya* are accompanied by nestling bivalves, especially *Barbatia*, and *Opis*. Byssate forms such as *Mytilus*, *Isognomon*, *Plagiostoma* and *Chlamys*, the shells now dissolved out and represented by moulds, are common. There was plenty of scope for colonization of the reef by cemented forms (*Plicatula*, *Nanogyra* and *Lopha*) and borers (*Lithophaga*, *Gastrochaena*). There is a common vagile epifauna, mainly comprising neritid gastropods and *Paracidaris*. The clays are largely smectite (Kelly, 1985), probably derived by the breakdown of contemporary volcanic material (Ali, 1977).

Several authors have commented on the Tethyan aspect of the Upware South Pit faunal assemblage. *Microsolena* is a common coral in continental Kimmeridgian reefs, but in England it is only known from the Corallian of Yorkshire and Upware. *Isoarca* is particularly unusual elsewhere in the English Corallian, as also are some species of *Opis*. Both these genera are very typical Tethyan forms (Arkell, 1929–1937). In life, many of these bivalves were attached under overhangs and in crevices around the calcareous skeletons of the living and dead coral, and it is the broken fragments of the skeletons of this assemblage that make up the bulk of the surrounding bioclastic debris. The fauna of the Upware reef, though contemporaneous with that of the Oxford reef (Wright, 1980), clearly has its own, unique elements. This suggests the transport of larval corals and bivalves from the margins of Tethys to the south, rather than from the Oxford area to the south-west.

Conclusions

Upware South Pit contains one of the more remarkable exposures of coralliferous strata in the British Oxfordian. This deep-water facies of the coralliferous beds, with their folicaeous colonies set in fine micrite, is unique in the British Oxfordian. Only the Ringstead Coral Bed of Dorset approaches this type of preservation. Upware South Pit also contains one of the most varied coral faunas in the British Oxfordian, only exceeded by that at Steeple Ashton (see Steeple Ashton site report, this volume). The presence of bivalves and corals normally found only well to the south, on the Continent, makes this a key site for our understanding of Oxfordian palaeobiogeography.

DIMMOCK'S COTE QUARRY (TL 543 723)

J.K. Wright

Introduction

This extensive quarry lying north of the A1123 near Dimmock's Cote, Wicken, and 2 km north of Upware (Figure 3.3) is of much more recent origin than Upware South Pit. It has been known for many years as 'Bridge Pit North', to distinguish it from a now-infilled quarry (Bridge Pit South) that lay south of the A1123. The first recorded visit by geologists was in 1950 (Worssam and Taylor, 1969). The Geologists' Association visited the pits in 1958 (Forbes, 1960), when Bridge Pit South was already becoming overgrown, but Bridge Pit North offered a good section. Kelly (1985) gave a comprehensive account of the fauna and sediments of the pit, and Wright *et al.* (2000) described the stratigraphy, sedimentology and palaeoecology of the section. Bridge Pit North, known presently as 'Dimmock's Cote Quarry', is now an extensive working quarry operated by the Wicken Lime and Stone Company, although operations here are being scaled down.

Description

The floor of this pit is approximately 200 m², and the principal area of interest is confined to the eastern half where the state of the faces is constantly changing. The following section was seen in 1996 by Wright *et al.* (2000):

	Thickness (m)
West Walton Formation	
Upware Limestone Member	
9. Cream-coloured, fossiliferous, soft, pisolitic oobiomicrite with regular alternations of micritic and shell fragment-rich bands. The fauna is prolific, including a variety of ammonites (***Perisphinctes*** spp., ***Cardioceras*** spp., ***Neoprionoceras*** sp. and ***Aspidoceras*** sp.), an abundance of reef-phase gastropods and bivalves preserved as moulds of originally aragonitic shells, and a large variety of echinoids (passes up from Bed 7 in E of pit)	3.0–5.0
8. ***The Coral Bed***: a bed of coarse, bioclastic, coral-rich limestone seen only on the west side of the pit, and yielding a wide variety of bivalves and gastropods, and a varied coral fauna: ***Fungiastraea arachnoides*** (Parkinson), ***Isastraea explanata*** (Goldfuss), ***Microsolena*** spp., ***Montlivaltia dispar*** (Phillips) and ***Thamnasteria concinna*** (Goldfuss)	0.6
7. Soft, grey, marly pisolite, poorly fossiliferous except in a band 3–4 m above the base, where echinoids (***Collyrites, Nucleolites,*** etc.) are common	*c.* 4.0
6b. ***The Crinoid Bed***: two beds of coarse biomicrite, the upper slightly paler and more sparry than the lower. Crinoid debris and pisoliths are abundant. The fauna is scattered in the main mass of the bed, and includes ***Perisphinctes (Dichotomosphinctes)*** aff. ***antecedens*** Salfeld, ***Cardioceras*** spp. and occasional bivalves and echinoids	0.6
6a. ***The Sponge Bed***: shelly, fossiliferous, argillaceous limestone containing numerous species of ***Cardioceras***, including ***C. (Cardioceras) highmoori*** Arkell, ***C. (Scoticardioceras) excavatum***	

(J. Sowerby), *C. (Maltoniceras) maltonense* (Young and Bird), *C. (Cawtoniceras) cawtonense* (Blake and Hudleston), *C. (Subvertebriceras) densiplicatum* Boden and *C. (S.) zenaidae* Ilovaisky, *Perisphinctes* spp., and a variety of bivalve and echinoid species 0.1–0.2

Dimmock's Cote Marl Member

5. Dark-grey mudrock containing *Cardioceras (Miticardioceras) tenuiserratum* (Oppel), *C. (Cawtoniceras) cawtonense* and *Chlamys* sp. 0.6
4. Grey argillaceous limestone containing *Cardioceras (Miticardioceras) sopotense* (Malinowska), *C. (Subvertebriceras) zenaidae, Perisphinctes (Arisphinctes)* aff. *pickeringius* (Young and Bird), *P. (A.)* aff. *maximus* (Young and Bird) and a variety of bivalves 0.10–0.15
3. Dark-grey mudrock with scattered *Chlamys* sp. and *Gryphaea* sp. in a layer 0.2 m above the base 1.7
2. Grey, argillaceous, spicular, shelly limestone with *Perisphinctes* sp. and *Pleuromya* sp. 0.3–0.4
1. Dark-grey mudrock containing *Perisphinctes (Arisphinctes)* aff. *pickeringius* about the middle, with just above it a band containing common *Gryphaea* seen to 1.5

A log of the section is given in Figure 3.4, and the quarry is illustrated in Figure 3.5. The Dimmock's Cote Marls are only exposed in drainage ditches in the floor of the quarry. In thin section, the marls are seen to be composed of bioclastic mudstone. The calcareous layers consist of variably calcified, shelly spiculite containing spicules of the sponge *Rhaxella perforata* (Hinde). The Sponge Bed (Bed 6a) is heavily bioturbated into the Dimmock's Cote Marls, with infilled burrows. It is a markedly argillaceous, bioclastic limestone with bivalves and ammonites preserved as mud-filled moulds. There is then a sudden change to the coarse-grained limestone of the Crinoid Beds (Bed 6b), in which macrofossils are scarce. In thin section, profuse crinoid ossicles are seen, with many bivalve fragments.

The lower part of Bed 7, seen at the east end of the pit (Figure 3.5), is a grey marly, pisoidal limestone that is so poorly cemented it can be dug by excavators. The clasts are pisoids rather than oncoids, as they are rounded and no algal structures are visible in them. Bed 9, as seen in this exposure, consists of tougher, cream-coloured, fossiliferous limestone. The rock has an abundance of ooids, seen in thin section set with pisoids similar to those occurring below in a fine, micritic matrix.

Much of the Coral Bed, which occurs between beds 7 and 9, and which was formerly visible in the quarry, has been quarried away. Worssam and Taylor (1969) noted 1.2 m of hard 'Coral Rag' containing *Montlivaltia dispar, Thamnasteria concinna* and *Thecosmilia* sp..

Interpretation

Upware lies on the north-western margin of the London Platform, and Palaeozoic rocks are present only a comparatively short distance below the base of the West Walton Formation. The BGS borehole at Soham 5 km to the east (TL 593 745) proved Silurian–Devonian rocks to be 128 m below its base. Situated on the edge of the massif, the Upware sequence marks the outbuilding into deeper water to the north-west of a ramp of shallow-water carbonate sediments formed originally on the shallows of the London Platform as suggested by Gallois and Cox (1977). Within the Upware inlier there is a marked thickening northwards from Upware South Pit to Dimmock's Cote Quarry.

During deposition of the Dimmock's Cote Marls, shallow-water sedimentation took place to the south, near Upware. One and a half metres of 'coral rock and marl' was described at Upware South Pit by Wedd (1898). Similar soft marls with lenses of *Thecosmilia* limestone were described by Wedd at Upware Village. Dimmock's Cote Quarry was some distance from the shallows, and clays and silts were laid down, with the development of *Rhaxella* sponge thickets during periods of clearer water. The fauna covered a variety of ecological niches, including the burrowing *Pinna* and *Pholadomya*, surface-dwelling *Oxytoma, Gryphaea* and *Serpula*, and free-swimming *Chlamys* and *Camptonectes*. However, the fauna is nowhere near as prolific as in parts of the Upware Limestone, suggesting

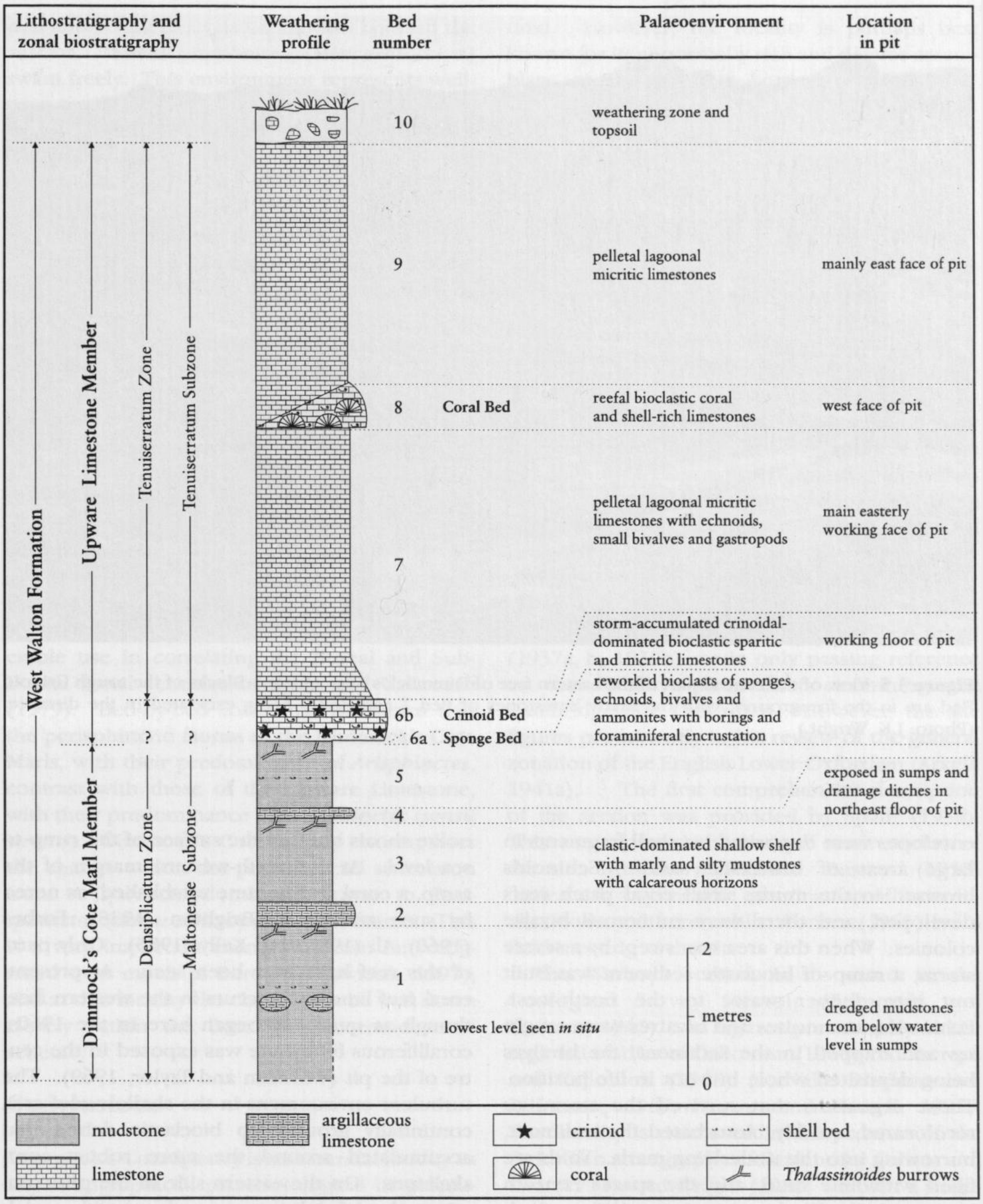


Figure 3.4 Log of the 'Corallian' succession in Dimmock's Cote Quarry (after Wright *et al.*, 2000, fig. 4).

that conditions were not particularly tolerant to life, possibly with a restricted circulation and unstable bottom conditions.

The Sponge Bed (Bed 6a) and Crinoid Beds (Bed 6b) together bear the hallmarks of a tempestite. The constituents of these beds appear to have formed originally in a wide variety of shallow-water carbonate environments. Thickets of *'Pentacrinus'* grew in large lagoonal areas. In the shallows around the lagoons, micritic

Figure 3.5 View of the central part of the eastern face of Dimmock's Cote Quarry. Blocks of the tough Crinoid Bed are in the foreground, with the marly limestones of Bed 7 and Bed 9 being excavated in the distance. (Photo: J.K. Wright.)

envelopes were deposited on shell fragments in large areas of bioclastic sand. Echinoids browsed in the muds, small coral patch reefs developed, and there were numerous bivalve colonies. When this area was swept by a severe storm, a ramp of bioclastic sediment was built out into deeper water to the north-west. Echinoids, ammonites and bivalves were caught up and trapped in the sediment, the bivalves being deposited whole but not in life position. Those organisms that survived the storm, or recolonized, quickly bioturbated the sediment, burrowing into the underlying marls. Voids are filled with lime mud, and the spaces beneath broken shells filled with sparry calcite. Such infiltration fabrics are classic indicators of a tempestite (Kreisa and Bambach, 1982). A similar bed is seen in the Passage Beds sequence at Spikers Hill Quarry (see site report for Spikers Hill, this volume).

Subsequently, there was renewed argillaceous sedimentation, albeit with a much higher bioclastic input (Bed 7). As the ramp stabilized, oolite shoals built up the surface of the ramp to sea level. At the north-western margin of the ramp, a coral reef became established, as noted by such authors as Brighton (1938), Forbes (1960), Ali (1983) and Kelly (1985). Only parts of this reef have ever been seen. At present, coral reef limestone occurs in the western face, though as quarrying began here in the 1960s, coralliferous limestone was exposed in the centre of the pit (Worssam and Taylor, 1969). The turbulent environment in the shallow reef area continually ground up bioclastic debris that accumulated around the more robust coral skeletons. On the eastern side of the pit, comminuted reef debris occurs along with a rich bivalve–gastropod–echinoid fauna (Bed 9). The fauna shows an excellent variety of deep burrowers (*Pleuromya*, *Goniomya*) and shallow burrowers (*Modiolus*, *Gervillella*, *Trigonia*, *Sowerbya*). Epifaunal forms (*Gryphaea*, *Opis*), and byssate forms (*Mytilus*, *Pteroperna*, young pectens), along with small branching corals, colonized the surface, along with a prolific gastropod and echinoid fauna on and just beneath the surface. Small ammonites (*Miticardioceras*) swam freely. This environment represents well-oxygenated, protected shelf conditions, possibly back reef. Southwards (Upware South Pit), conditions became deeper, with folicaeous colonies of *Thamnasteria* and *Microsolena* growing in water depths of 15–20 m only affected by wave action during storms.

The cardioceratid ammonites found at Dimmock's Cote Quarry are mostly long-ranging forms, but the presence of such subgenera as *Cawtoniceras* in the Dimmock's Cote Marl and *Maltoniceras* in the Crinoid Bed establishes that both units probably belong to the upper Maltonense Subzone of the Densiplicatum Zone. However, the presence of two species of *Miticardioceras* in Bed 5 of the Dimmock's Cote Marl, including rare *C. (M.) tenuiserratum*, suggests that this part of the sequence may represent the very lowest Tenuiserratum Zone.

The occurrence in the same beds, along with these Boreal cardioceratids, of Tethyan perisphinctids, means that the section is of considerable use in correlating the Boreal and Sub-Boreal zonal schemes of Sykes and Callomon (1979). Bed-by-bed collecting has shown that the perisphinctid faunas of the Dimmock's Cote Marls, with their predominance of *Arisphinctes*, contrast with those of the Upware Limestone, with their predominance of *Perisphinctes* (*sensu stricto*). Dimmock's Cote Quarry encompasses the change within the perisphinctid succession from *Arisphinctes*-dominant faunas to *Perisphinctes* (*sensu stricto*)-dominant faunas. This is a very important change that can be recognized over much of Europe (Głowniak, 1997), and at this locality the change can be tied down closely within the Boreal cardioceratid zonal scheme.

Conclusions

Dimmock's Cote Quarry is an essential locality in any stratigraphical, palaeontological or palaeogeographical study of the British Oxfordian. The unique abundance of contemporaneous Tenuiserratum zone cardioceratids and Plicatilis Zone and Pumilus Zone perisphinctids confers exceptional value on the ammonite faunas of this site for the purposes of international correlation. Other fossil groups are equally well represented. Nine coral species occur in the Upware Limestone in association with 12 species of echinoid. However, the locality is perhaps best known for its abnormally rich and diverse assemblage of reef-dwelling bivalves, of which 67 species have been recorded.

WARBOYS CLAY PIT (TL 308 818)

J.K. Wright

Introduction

Warboys Clay Pit lies 1.8 km north of Warboys village, and is a large pit currently owned by Fernside Waste Management Ltd and used for waste disposal. It was formerly operated by the London Brick Company, the plastic Weymouth Member (formerly the Upper Oxford Clay) being used extensively to manufacture bricks and extruded hollow clay blocks.

The Warboys exposure was already a 'large working pit (revealing) a fine section' when it was first described by Dixon (1937). Arkell (1937a, b, 1939b) made only passing reference to the locality when first examining the Cambridgeshire Oxfordian. However, the site figures prominently in his review of the general zonation of the English Lower Oxfordian (Arkell, 1941a), . The first comprehensive description of the section was provided by Spath (1939). This work formed the basis of most studies of the site until the mid-1960s. Barnard (1952) undertook a systematic examination of foraminifera collected here, whilst Forbes (1960) led a field meeting at the site.

The Warboys section is discussed in the Geological Survey Memoir (Edmonds and Dinham, 1965), and figures prominently in the regional studies of Callomon (1968) and Torrens and Callomon (1968) (see also Hudson and Palframan, 1969; Horton and Horrell, 1971). The locality is discussed in the account of the Oxfordian stratigraphy of Fenland by Gallois and Cox (1977), and Wright (1980) devoted a single column of the Oxfordian Correlation Chart (Col 012) to the Warboys sequence.

Description

A detailed measured section at the pit was published by Callomon (1968), and this may be summarized, with amendments, as follows.

		Thickness (m)
Ampthill Clay Formation		
12.	Weathered black clay with *Gryphaea*	seen to 1.5
West Walton Formation		
10, 11.	*Warboys Rock*: argillaceous limestone and mudstone with *Perisphinctes* sp.	0.9–1.2
	– non-sequence –	
9.	Black clay with crushed *Cardioceras* spp. and bivalves	0.15
	– major non-sequence –	
Oxford Clay Formation, Weymouth Member		
1–8.	Largely blue-grey calcareous clays with frequent variably persistent marly limestone bands lettered A to H. A prolific fauna of pyritized cardioceratids is present	24.5

A log of the section with lithologies and subzones taken from Callomon (1968) is given in Figure 3.6. Figure 3.7 shows the state of the exposure in 1998. The site has been renowned since the 1930s for the richness of its Weymouth Member ammonite fauna, which provides the zonal standard for much of the East Midlands Oxfordian (Callomon, 1968). The excellent state of preservation of the pyritized ammonites and other macrofauna has held the attention of numerous palaeontologists collecting from the Oxford Clay at this site. At least 23 ammonite species belonging to 12 genera have been recorded here. These include the basal Oxfordian zonal index *Quenstedtoceras (Quenstedtoceras) mariae* (d'Orbigny) and subzonal indices *Cardioceras (Scarburgiceras) scarburgense* (Young and Bird), *C. (S.) praecordatum* Douvillé and *C. (S.) bukowskii* Maire, together with numerous perisphinctids and oppelids, and an important infaunal bivalve assemblage.

The highest level of the Oxford Clay is pale greenish-grey in colour, and clearly was well indurated before being eroded, as fragments of the green clay are incorporated into the basal West Walton Formation (Bed 9). Ammonites collected from Bed 9 include *Cardioceras (Plasmatoceras) popilianense* Boden, *C. (Scoticardioceras) excavatum* (J. Sowerby), *C.*

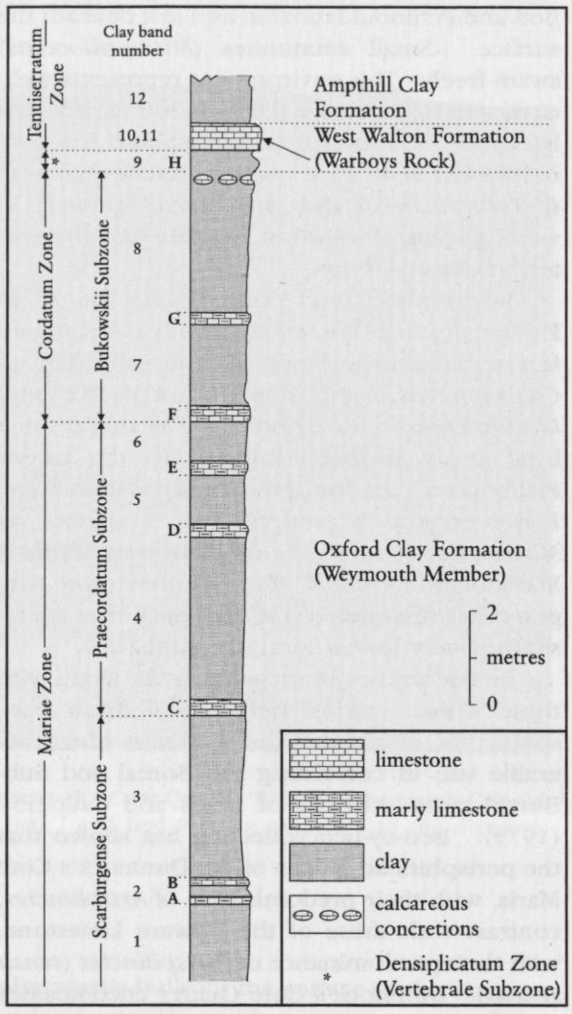


Figure 3.6 Log of the Oxford Clay succession in Warboys Pit (after Callomon, 1968).

(Subvertebriceras) densiplicatum Boden, *C. (S.) sowerbyi* Arkell and *Perisphinctes* sp.. These are found in association with the bivalves *Cercomya* sp., *Chlamys* sp., *Grammatodon* sp., *Myophorella* sp., *Opis* sp., *Oxytoma* sp., *Pinna* sp., and ostreids.

Interpretation

The section in the pit combined with an adjacent Geological Survey boring (Callomon, 1968) indicates that the Weymouth Member here is attenuated when compared with the equivalent sections in southern England. In the early records it is often not possible to separate the Weymouth Member thickness from that of the whole Oxford Clay in southern England. What one can say is

Figure 3.7 View of the upper part of Warboys Pit showing Cordatum Zone Oxford Clay overlain by West Walton Formation, beds 9–12, with the 'Warboys Rock', the distinctive pale band, close to the top of the section. (Photo: J.K. Wright.)

that the Oxford Clay as a whole retains a remarkably constant thickness of 150–160 m from Dorset to north-west Wiltshire (Woodward, 1895; Bristow *et al.*, 1995). Traced northward, the observed thicknesses decrease, and in the Cambridgeshire region, stratal attenuation is attributable not only to reduced sedimentation but also to erosion of the upper beds (Wright, 1980). Evidence for this is clear at Warboys, where the erosive contact of Bed 9 on Oxford Clay represents a pronounced non-sequence. A stratal break of varying significance at this horizon is an important feature of Lower–Middle Oxfordian stratigraphy not only in central and south Cambridgeshire but also in Buckinghamshire and Bedfordshire (Wright, 1980). The relative attenuation of the Cambridgeshire Weymouth Member coincides with an upswell in the underlying Palaeozoic platform on a ridge extending north from the London Platform.

J.H. Callomon assigned the fauna of Bed 9 to the basal Middle Oxfordian (Vertebrale Subzone) (Wright, 1980, p. 73). According to Callomon, the overlying Warboys Rock (beds 10 and 11) (Figure 3.7) has yielded a fauna of the high Parandieri Subzone, possibly equivalent to the Blakei rather than the Tenuiserratum Subzone of the Boreal scheme. A substantial non-sequence below it is thereby clearly indicated. However, Gallois and Cox (1977) believed that beds 10 and 11 belong to the low Tenuiserratum Zone, in which case a non-sequence would not exist at this level. However, evidence of age assignation is not provided by these authors, and herein the age of the Warboys Rock is left open.

The succession therefore has one, and possibly two, substantial non-sequences, the earliest of which omits strata of the Costicardia, Cordatum and lower Vertebrale subzones, while according to Callomon (1968), at least the Maltonense, Tenuiserratum and basal Blakei subzones are cut out at the upper discontinuity. The highest bed of clay at Warboys, Bed 12, is seen in the zone of weathering and has never been well exposed, nor has it yielded stratigraphically useful ammonites.

The widespread stratal breaks below and above Bed 9 point to probable tectonic instability in the basin of deposition. Considering the general irregularity of such features in Cambridgeshire and their localized distribution, it is likely that the principal cause was tectonic uplift rather than eustatic regression. As Torrens and Wright (1980, p. 14) point out, 'A broad, eustatic regression followed by a transgression might well lead to a non-sequence and overlap, but the removal of much of the underlying succession is certainly not an eustatic effect'.

The work of Gallois and Cox (1977) has been of great significance in interpreting the environments of deposition of these beds. During West Walton Formation and Ampthill Clay times, clays, silts and limestones were deposited in near-shore environments in a shallow shelf sea. Southwards along their outcrop, they pass laterally into predominantly arenaceous and calcareous marine sediments (the Corallian Group); to the east, they thin out in East Anglia; and to the north and north-west, into Lincolnshire, beneath much of the North Sea and off the west coast of Scotland, they continue as predominantly argillaceous sediments.

Conclusions

This locality constitutes one of the most important reference sections in the Jurassic of the East Midlands. It offers the opportunity to study at outcrop the Oxford Clay and West Walton formations, the former otherwise known only in Cambridgeshire in boreholes. Beautifully preserved specimens representing 23 ammonite species occur abundantly here in the Oxford Clay Formation, the representative faunas of the Scarburgense, Praecordatum and Bukowskii subzones. The sequence as a whole covers much of Oxfordian time but with significant phases of non-deposition or erosion.

ROSLYN HOLE (TL 555 808)

POTENTIAL GCR SITE

B.M. Cox

Introduction

Roslyn (or Roswell) Hole at Ely, Cambridgeshire, is a large pit complex that has been worked almost continuously since early Victorian times to provide embanking materials for the River Great Ouse drainage system. It provides the most famous section in the Kimmeridge Clay of East Anglia (Gallois, 1988). Many field parties from Cambridge and London visited the pits in the latter part of the 19th century, not only to see the highly fossiliferous Kimmeridge Clay but also to observe the unusually large erratic raft of mainly Cretaceous rocks, first described by Sedgwick (1846), which was exposed in the Quaternary Anglian till (Boulder Clay) there. The controversy and discussion about the relationship of these differently aged strata one to another, and the general interest in the geology of the pit, led to an extensive literature (Seeley, 1865a, b, 1868; Fisher, 1868; Bonney, 1872a, b, 1875; Blake, 1875; Skertchly, 1877; Whitaker, 1883; McKenny Hughes, 1884, 1894; Whitaker *et al.*, 1891; Roberts, 1892; Rastall, 1909). The pits referred to by the 19th century authors, notably Blake (1875), Whitaker *et al.* (1891) and Roberts (1892) all of whom described extensive faunas from the Kimmeridge Clay here, lay on either side of the railway and are now flooded. A new pit was opened by the local river authority in the 1930s immediately south-west of the old pits on the north side of the railway. Gallois (1988) reported that this still exposed a Kimmeridge Clay section (see below) similar to that described by Roberts (1892) (probably at TL 555 810) and a shorter section (probably at TL 555 806) recorded by Skertchly (in Whitaker *et al.*, 1891).

Independent of any stratigraphical significance, the site has been confirmed as a GCR site for its fossil reptiles, in particular, the remains of sauropod dinosaurs and pliosaurs. An account of the reptilian fauna can be found in a companion GCR volume (Benton and Spencer, 1995).

Description

The following description is based on the section (TL 552 807) in the west face of the modern pit, recorded in 1979 by R.W. Gallois and the present author during the geological survey of the Ely district (Gallois, 1988); for ease of reference in the present account, bed numbers (1–27) have been added to their section (Figure 3.9).

Thickness (m)

Kimmeridge Clay Formation

27. Oil shale and pale-grey, calcareous mudstone interbedded in 50–100 mm thick units; very shelly in

Figure 3.8 View of a degraded section of Lower Kimmeridge Clay at Roslyn Hole showing the prominent marker band (arrowed) formed by a line of cementstone nodules in Bed 23 (KC30). Ely Cathedral is seen in the background. (Photo: A13722, reproduced by kind permission of the Director, British Geological Survey ©NERC.)

parts with '*Lucina*', *Protocardia*, abundant *Amoeboceras* *(Nannocardioceras)*, *Aulacostephanus*, *Pseudorhytidopilus*, *Dicroloma*, fish debris and shell dust 2.45

26. Mudstone, pale and medium grey, moderately shelly with fauna as Bed 27; serpulids locally common; *Lingula* and coalified wood fragments common; 80 mm-thick oil shale in middle part of bed 1.33
25. Oil shale, very shelly; fauna as Bed 26 but with *Aulacostephanus* and faecal pellets especially common 0.06
24. Mudstone, pale and very pale grey with bioturbation at several levels picked out by darker infills; sparsely shelly in upper part but with abundant serpulids, *Nanogyra virgula* (Defrance) and other small oysters in lower part 1.40
23. Mudstone, calcareous, with prominent, closely spaced (1.0–1.2 m apart), flattened, spheroidal and ellipsoidal cementstone nodules, mostly 0.35–0.40 m (up to 0.47 m) thick and 1.0–1.2 m in diameter; septarian cracks in cores partially infilled by sparry calcite; 0.15–0.20 m thick band of soft limestone occurs between nodules at level of their horizontal axis; sparsely shelly but with relatively common *N. virgula* and other oysters, and rare *Crussoliceras* 0.40

22.	Mudstone, pale and medium grey; sparsely shelly	0.36
21.	Lumachelle composed almost entirely of *N. virgula*	0.07
20.	Mudstone, dark grey, sparsely shelly to shelly with *Amoeboceras (Amoebites)*, serpulids and rotted bivalves and ammonites; abundant *N. virgula* at base	0.40
19.	Mudstone, thinly interbedded, pale, medium and dark grey; sparsely shelly but with some more shelly bands; fauna as Bed 20	1.75
18.	Mudstone, dark grey with thin seams of muddy oil shale; poorly exposed; passing down into Bed 17	1.10
17.	Mudstone, medium grey, silty, sparsely shelly, passing down into Bed 16	0.15
16.	Siltstone, medium grey, weakly calcite-cemented with widely spaced cementstone nodules (10–15 m apart) of similar size to those in Bed 23; shelly with *Aulacostephanus* ex gr. *eudoxus* (d'Orbigny), *Aspidoceras*, *Laevaptychus*, poorly preserved bivalves and fish debris; inter-burrowed junction with Bed 15	0.17
15.	Mudstone, pale grey becoming darker with depth; shelly in lower part; interburrowed junction with Bed 14	0.40
14.	Oil shale, brownish grey, muddy, deeply weathered	0.10
13.	Siltstone, medium to pale grey, with widely spaced (more than 30 m) cementstone nodules; locally shelly in lower part with common *Aspidoceras* and *Laevaptychus*; interburrowed junction with Bed 12	0.12
12.	Mudstone, pale grey, sparsely shelly	0.20
11.	Mudstone, dark grey, very shelly with *Aspidoceras*, *Laevaptychus* and *N. virgula*	0.09
10.	Mudstone, pale and medium grey, sparsely shelly	0.65
9.	Mudstone, dark grey, shelly with bivalves and ammonites rotted by weathering but *Laevaptychus* occurring in loose spoil	0.45
8.	Mudstone, mostly medium and pale grey; sparsely shelly but with some rotted shelly bands	*c.* 1.5
7.	Mudstone, pale grey, moderately shelly with bivalves and ammonites, including *Aspidoceras*, in rotted pyrite	0.30
6.	Mudstone, medium grey, fissile, shelly; some pyritic bivalves and ammonites; possible phosphatized burrowfills	0.15
5.	Mudstone, pale grey, sparsely shelly, becoming darker in lower part and passing down into Bed 4	0.55
4.	Siltstone, medium grey, pyritic but weathered to form a prominent yellow band with natrojarosite?-coated surfaces; very shelly with fauna concentrated in lower part; *Aspidoceras* and *Aulacostephanus eulepidus* (Schneid) common, *Neocrassina supracorallina* (d'Orbigny), oysters and fish debris also present	0.15
3.	Mudstone, medium grey, sparsely shelly	0.50
2.	Mudstone, faintly brownish grey, fissile; very shelly with abundant *A. eulepidus*; *?A. mutabilis* (J. Sowerby), *N. supracorallina* and faecal pellets	0.15
1.	Mudstone, medium and pale grey, sparsely shelly with concentrations of large, smooth body-chambered ammonites (*?A. mutabilis*) at several levels	seen 0.90

Gallois (1988) reported that part of the sequence described above was also seen below the boathouse in the north-western corner of the old flooded pit (TL 554 810) where the two siltstones (beds 13 and 16) were exposed, the upper one containing cementstone doggers at 2–4 m spacings. The lowest horizon exposed in the modern pit is a pale grey, deeply weathered mudstone that occurs 1–2 m below the lowest beds of the main section. The Kimmeridge Clay is overlain here by the Lower Cretaceous Woburn Sand (Lower Greensand Group), the basal bed of which consists of very pebbly, fer-

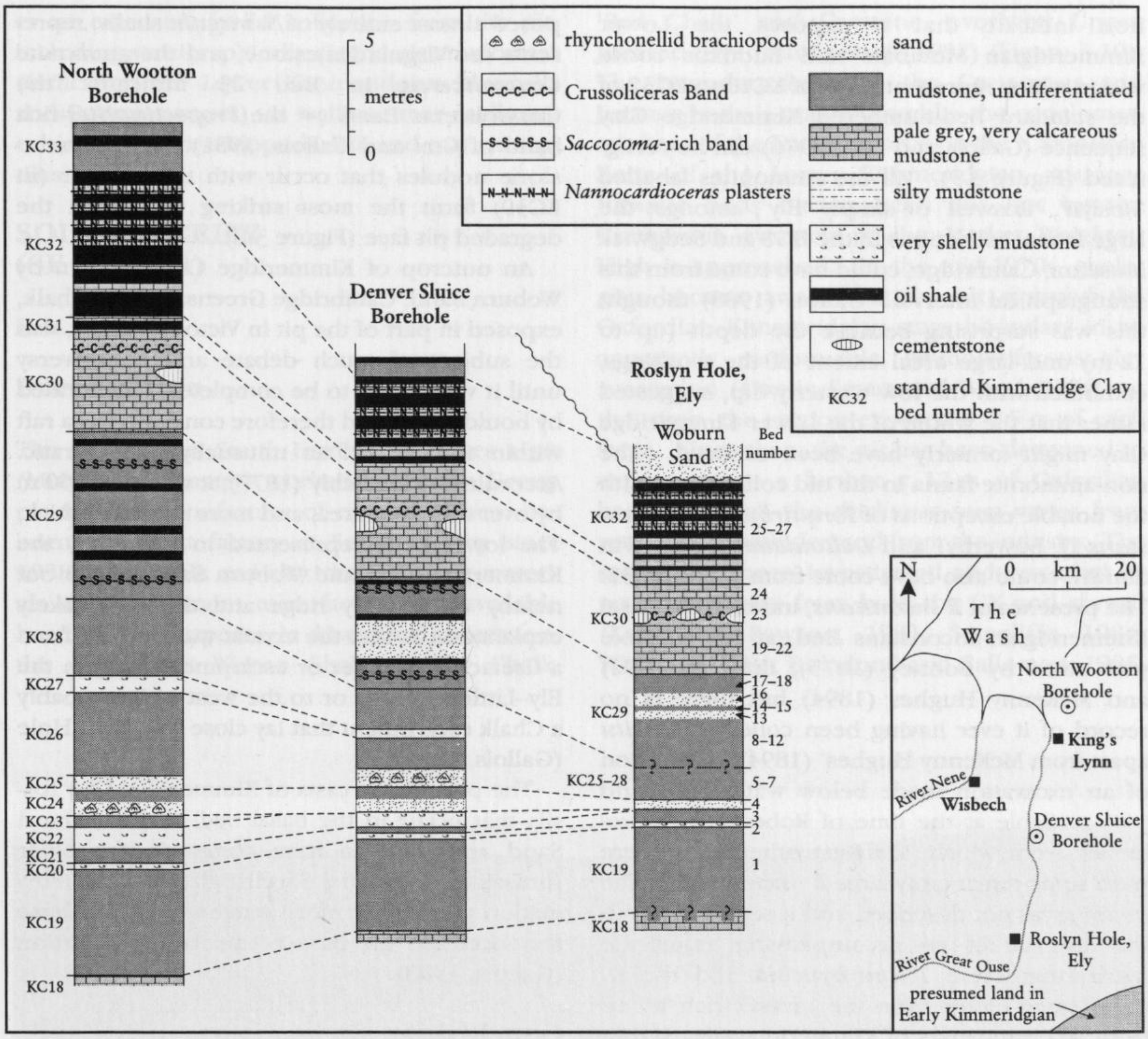


Figure 3.9 Graphic section of the Kimmeridge Clay at Roslyn Hole and borehole sections in Norfolk showing the southwards attenuation towards Ely (after Gallois, 1988, fig. 14).

ruginous sand that rests on an irregular surface cut into the Kimmeridge Clay. The pebbles include phosphatic casts of Kimmeridge Clay fossils. Inevitably, as the pit is worked, the succession of strata exposed may vary somewhat, and a few metres of Kimmeridge Clay, representing higher levels than that recorded herein, have been exposed beneath the Woburn Sand from time to time. The Woburn Sand is itself overlain by Anglian till.

Fauna and flora in old museum collections, additional to that recorded above, includes bivalves (including *Deltoideum delta* (Wm Smith)), belemnites, brachiopods (including *Torquirhynchia inconstans* (J. Sowerby)), echinoid spines, fish (including a well-preserved specimen attributed by Woodward (1890) to *Eurycormus*), plant debris and reptilian remains comprising a mix of terrestrial and marine Kimmeridgian forms including turtles, crocodilians, dinosaurs, plesiosaurs and ichthyosaurs (Tarlo, 1959; Wells, 1964; Benton and Spencer, 1995). As 'Roswell Pits, Ely', the site is included in the companion GCR volume on fossil reptiles; sauropod dinosaurs and pliosaurs are of particular significance here.

Interpretation

The ammonite faunas recorded in the above section indicate that it exposes the Lower Kimmeridgian Mutabilis and Eudoxus zones within which representatives of KC18 to KC32 of the standard bed-numbered Kimmeridge Clay sequence (Gallois and Cox, 1976) can be recognized (Figure 3.9). All the ammonites labelled 'Roslyn', 'Roswell' or simply 'Ely', amongst the large faunal collections in the BGS and Sedgwick Museum, Cambridge, could have come from this stratigraphical interval. Gallois (1988) thought this was surprising because the depth (up to 12 m) and large areal extent of the workings, combined with the low westerly dip, suggested rather that the whole of the Lower Kimmeridge Clay might formerly have been exposed. The non-ammonite fauna in the old collections, with the notable exceptions of *Torquirhynchia inconstans* (J. Sowerby) and *Deltoideum delta* (Wm Smith), could also have come from KC18–KC32. The presence of *T. inconstans*, index of the basal Kimmeridgian Inconstans Bed, at Roslyn Hole was noted by Bonney (1875), Roberts (1892) and McKenny Hughes (1894) but there is no record of it ever having been collected *in situ* apart from McKenny Hughes' (1894) description of an excavation made below water level and 'not available at the time of Roberts' measurements' from which 'amongst other finds there were some remarkably large *R. inconstans*'. The section was not described and it seems likely, in the absence of an accompanying ammonite fauna, that these *Torquirhynchia* and the *D. delta* came either from the Jurassic-rich till or from an erratic mass of Kimmeridge Clay within it (Gallois, 1988).

The formation in the Ely area is thin in comparison with that of adjacent parts of Fenland due to attenuation within the formation, as it approaches the stable high of the London Platform, and pre-Aptian (Early Cretaceous) erosion. Although the lithological and faunal sequences can be matched with those of more northerly parts of Fenland, there are small differences at Ely that reflect the proximity of land in Early Kimmeridgian times. For instance, at Roslyn Hole there is a minor erosion surface at the base of the Eudoxus Zone, such that KC24 rests unconformably on KC21 and the widespread marker known as the Supracorallina Bed (KC22) is missing (Figure 3.9). Also, there are additional thin siltstone horizons notably in KC29, here represented by beds 8–18 (Gallois, 1988). Two well-established marker beds of the Eudoxus Zone can be recognized. Bed 21, composed almost entirely of *N. virgula* shells, represents the Virgula Limestone, and the ammonite *Crussoliceras* in Bed 23 indicates the Crussoliceras Band (= the *Propectinatites*-rich band of Cox and Gallois, 1981). The cementstone nodules that occur with this marker (in KC30) form the most striking feature in the degraded pit face (Figure 3.8).

An outcrop of Kimmeridge Clay overlain by Woburn Sand, Cambridge Greensand and Chalk, exposed in part of the pit in Victorian times, was the subject of much debate and controversy until it was found to be completely surrounded by boulder clay and therefore confirmed as a raft within the till, i.e. an unusually large erratic. According to Skertchly (1877), it was about 50 m by over 400 m in area, and more than 5 m thick. The lower beds represented in the raft – the Kimmeridge Clay and Woburn Sand – crop out nearby on the Ely ridge and the most likely explanation is that the erratic was derived from a Cretaceous outlier or escarpment lying in the Ely–Littleport area or to the west of it, probably a Chalk escarpment that lay close to Roslyn Hole (Gallois, 1988).

The phosphatic casts of Kimmeridge Clay fossils that occur in the basal bed of the Woburn Sand are likely to have come via the older Jurassic–Cretaceous Sandringham Sand Formation as they are more water-worn than those that occur in the base of the latter formation (Gallois, 1988).

Conclusions

The large pit complex at Roslyn Hole has provided an exposure of Kimmeridge Clay since early Victorian times and has had a long history of geological investigation. It provides the only significant exposure of Kimmeridgian strata in East Anglia, where they are otherwise known mainly from cored boreholes. The sections are degraded at the time of writing, but they show fossiliferous shales, mudstones and calcareous mudstones in which a line of cementstone doggers forms a prominent marker. In the late 19th century, the locality became the scene of geological controversy concerning the origin of a large mass of Kimmeridgian and Cretaceous rocks that proved to be a large erratic raft in the Anglian till. This was first described by Professor Adam Sedgwick of Cambridge University in 1846, and the pit has had a long association with this seat of learning. The Sedgwick Museum there houses an extensive faunal collection from the pit, including stratigraphically diagnostic ammonites (indicating the Lower Kimmeridgian Mutabilis and Eudoxus zones), as well as other molluscs, echinoderms, brachiopods, fish and marine reptiles.

SOUTH FERRIBY (SE 993 204)

B.M. Cox

Introduction

The GCR site at South Ferriby comprises a pit (Middlegate Quarry) worked by Rugby Group plc for the manufacture of cement. There has been a cement factory at South Ferriby since 1938; both chalk and clay, the main raw materials used in cement manufacture, are available here. The pit exposes, in downward succession, the Cretaceous Welton Chalk, Ferriby Chalk, 'Red Chalk' and Carstone, overlying Upper Jurassic clays (Gaunt *et al.*, 1992) (Figure 3.10). The boundary between the Cretaceous and Jurassic beds is unconformable; the conglomeratic base of the Carstone rests on the ?Cymodoce Zone of the Lower Kimmeridgian, younger Jurassic beds having been cut out by the Cretaceous overstep as the Market Weighton High is approached. In the mid-1970s, geologists became aware that the pit exposed the Oxfordian–Kimmeridgian stage boundary in an apparently conformable, ammonitiferous clay succession (Cox in Smart and Wood, 1976); at that time, the section exposed *c.* 7.5 m of each stage. Since then, the pit has been deepened to expose up to a further *c.* 12 m of Oxfordian beds, although the thickness seen varies from year to year with demand from the industry. The section has been investigated and recorded by many geologists from both the UK and abroad (Kelly and Rawson, 1983; Stancliffe, 1984; Whitham, 1984; Birkelund and Callomon, 1985;

Figure 3.10 General view of the South Ferriby GCR site in 1987. (Photo: A14379, reproduced by kind permission of the Director, British Geological Survey ©NERC.)

Ahmed, 1987; Wignall, 1990b; Gaunt *et al.*, 1992; Schweigert and Callomon, 1997) and has featured in the search for a Global Stratotype Section and Point (GSSP) for the base of the Kimmeridgian Stage (Page and Cox, 1995). The importance of the site in this respect has led to its inclusion in both the Oxfordian and Kimmeridgian GCR blocks.

Description

The following section of the Jurassic strata at South Ferriby is based mainly on Birkelund and Callomon (1985) and their graphic section published in Ahmed (1987), but with additional data from the more recent papers listed above together with manuscript notes of Professor Callomon and personal observations. Bed notation follows Birkelund and Callomon (1985) (1–12), as extended by Callomon (pers. comm.) (Y–Z), and relates to sections recorded in 1979 and 1982. Although most subsequent authors have used Birkelund and Callomon's section as the basis of their work, there are discrepancies between the factual details recorded by different authors that make compilation of a definitive, composite section problematic. Although Wignall (1990b) was able to recognize all of Birkelund and Callomon's beds and used their bed numbers, he recorded (in the late 1980s) substantial differences in thickness for some beds, notably Bed 9 where he measured 2.0 m compared with Birkelund and Callomon's *c.* 0.75 m; in 1974, the present author recorded 1.5 m. However, for combined beds 8 and 9, the thicknesses recorded by Wignall and Birkelund and Callomon are comparable (c. 6.5 m and 6.9 m respectively). Ammonite determinations have varied with each iteration of the section as work on contemporaneous faunas from elsewhere progresses, and pending a full account of the South Ferriby ammonites. Those named in the section below follow Schweigert and Callomon (1997), who used the name '*Prorasenia anglica*' for the ammonite previously known as *Microbiplices anglicus*. Wignall (1990b) recorded 60 non-ammonite taxa including bivalves, gastropods, scaphopods, brachiopods, crustaceans, echinoids, a crinoid, an asteroid, an ophiuroid, serpulids and bryozoa but, in the following section, only selected records, mainly the more common of the bivalve genera (i.e. those reported by Wignall (pers. comm. 1998) as common or abundant) are listed; Wignall (1990b, fig. 4) showed a bivalve species distribution table down to Bed 3 of the section given below. The most common bivalve is *Thracia depressa* (J. de C. Sowerby), which is present throughout the succession. Ostracod faunas have been reported by Ahmed (1987) and the palynomorph assemblages by Stancliffe (1984). Wignall (1990b) reported that his investigations of the foraminifera indicated that they were very similar to those described by Medd (in Richardson, 1979) from the nearby Worlaby boreholes.

		Thickness (m)
	Kimmeridge Clay Formation	
12.	Mudstone, grey, calcareous; fissile and shaly in top 1 m; lower 2 m very shelly, with lenticular, calcareous or phosphatic concretions including persistent horizon of small septaria near base; ammonites with uncrushed body chambers, with phosphatic infillings particularly in lower part of bed; *Amoeboceras* cf. *cricki* (Salfeld), *Prorasenia* sp., *Rasenia* cf. *cymodoce* (d'Orbigny)/*berryeri* (Dollfus) and *Rasenia* trans. *Pictonia*; bivalves including *Corbulomima*, *Grammatodon*, *Isocyprina*, *Liostrea*, *Nicaniella*, *Palaeonucula* and *Thracia*; the gastropod *Dicroloma*	3.0
11.	Mudstone, sideritic, mottled brown and grey with pale buff-coloured, phosphatic patches; hard, forming prominent marker in pit face; bivalves including *Grammatodon* and *Isocyprina*; sharp boundary at base	0.05–0.1
10d.	Mudstone, grey, massive, calcareous; weakly developed and variable sideritic mudstone at base; very shelly with abundant crushed *Pictonia baylei* Salfeld, *Prorasenia* sp.; bivalves including *Corbulomima*, *Deltoideum delta* (Wm Smith), *Grammatodon*, *Isocyprina*, *Liostrea*, *Modiolus*, *Oxytoma* and abundant *Thracia*; serpulids.	2.0

c. Mudstone, grey, more shaly than Bed 10d; sparsely shelly with *Pictonia* sp. and bivalves including *Liostrea*, *Nanogyra nana* (J. Sowerby), *Oxytoma* and *Palaeonucula* 0.5

b. Mudstone, pale grey, more calcareous and harder than Bed 10c; sparsely shelly with *Pictonia* cf. *normandiana* Tornquist and bivalves including *Liostrea* 0.8

a. Mudstone, pale grey, calcareous, hard, slightly fissile; many pyritized burrows and *Chondrites*; very shelly with *Pictonia densicostata* Salfeld, *Prorasenia* sp.; bivalves including *Corbulomima*, *Grammatodon*, *Pleuromya* in growth position, *Protocardia* and *Thracia*; *Dicroloma*; nest of the brachiopod *Torquirhynchia inconstans* (J. Sowerby) with *Lopha gregarea* (J. Sowerby); uneven base with shell bed including *Amoeboceras bauhini* (Oppel) *c.* 0.5

9. Mudstone, grey, passing into marl and soft limestone in middle part; layer of prominent, large (*c.* 1 m diameter), weakly septarian cementstone concretions at top; small phosphatic concretions and lenses, especially in lower part; very shelly with fossils commonly partially phosphatized and only partially crushed; *Amoeboceras* aff. *cricki*, *A.* cf. *lorioli* (Oppenheimer), *Pictonia densicostata*, *Prorasenia* sp.; bivalves including phosphatic steinkerns of *Pleuromya* in growth position, lumachelles of disarticulated *D. delta* valves, *Corbulomima*, *Grammatodon*, *Isocyprina*, *Liostrea* and *Thracia*; *Dicroloma* and cidarid echinoids; sharp base marked by Oxytoma Cementstone, a patchily cemented, 0.03–0.20 m thick shell-bed with many broken shells, particularly serpulids and *Oxytoma inequivalve* (J. Sowerby), and phosphatic nodules *c.* 0.75

Ampthill Clay Formation

8e. Mudstone, grey, calcareous; very shelly in upper part with ammonites (*Amoeboceras* sp., *Prorasenia* sp., *Ringsteadia*/*Pictonia* sp.), bivalves including *Grammatodon*, *Liostrea*, nuculaceans and *Oxytoma*; *Dicroloma* 2.10

d. Mudstone, grey, hard and tenacious, forming rib in pit face; crowded with serpulids; *Amoeboceras* sp. 0.05

c. Mudstone, grey, calcareous; small limestone concretions; *Prorasenia* sp. and *Ringsteadia evoluta* Salfeld 1.8

b. Mudstone, grey, highly calcareous with layer of scattered limestone concretions or lenses; very shelly with *Prorasenia* sp., *Ringsteadia evoluta* and bivalves including *Corbulomima*, *Liostrea* and *Oxytoma*; *Dicroloma* 0.2

a. Mudstone, grey, moderately calcareous and shelly with *Prorasenia* sp., *Ringsteadia evoluta* and bivalves including *Corbulomima*, *Oxytoma*, *Pinna* and *Thracia* 2.0

7. Mudstone, grey, highly calcareous; layer of reniform concretions at top; many small, uncrushed pyritized ammonites; *Ringsteadia evoluta*; bivalves including *Liostrea* and *Oxytoma*; strongly interburrowed base 0.3

6. Mudstone, grey, very shelly with *Amoeboceras* cf. *marstonense* Spath and *Ringsteadia pseudocordata* (Blake and Hudleston); *Corbulomima*, *Deltoideum*, *Liostrea*, *Oxytoma*, *Placunopsis* and *Thracia* 2.3

5d. Mudstone, grey, highly calcareous, prominent in pit face; very shelly with *Amoeboceras rosenkrantzi* Spath, *Prorasenia anglica* (Arkell), *Ringsteadia pseudocordata* and bivalves including *Corbulomima*, *Oxytoma*, *Protocardia* and *Thracia* 0.3

c.	Mudstone, grey; *Ringsteadia* cf. *evoluta*; clusters of *Pinna* in growth position	0.4
b.	Mudstone, grey, more calcareous than Bed 5c; *Prorasenia* sp.	0.3
a.	Mudstone, grey, calcareous, rather fissile, less massive than Bed 5b; very shelly with partially crushed fossils preserved in pyrite; *Ringsteadia pseudocordata*, wood fragments and lignite	0.4
4.	Mudstone, grey, highly calcareous, locally hardened into soft, marly limestone; layer of large, flat, septarian concretions forming prominent marker; numerous large distinct burrows; sparsely shelly with *Prorasenia* and *Ringsteadia* fragments, occasional bivalves, including *Corbulomima*, *Modiolus* and *Thracia*, and serpulids	0.25
3.	Mudstone, grey, calcareous, very shelly with *Prorasenia* sp. and *Ringsteadia pseudocordata*; belemnites (*Cylindroteuthis*, *Pachyteuthis*), bivalves including *Corbulomima*, *Isocyprina*, *Modiolus*, *Oxytoma*, *Protocardia* and *Thracia*, and serpulids	2.2
2.	Mudstone, very dark grey, forming marker in pit face; blocky, listric fracture; sparsely shelly	0.3
1d.	Mudstone, dark grey, massive; phosphatic lenses in lower part; sparsely shelly with *Prorasenia* sp. and *Ringsteadia pseudoyo* Salfeld/*pseudocordata*; layer of *D. delta* 1 m below top; *Thracia*	2.45
c.	Mudstone, grey, less massive than Bed 1d, with lenticular, partially pyritized and phosphatized, locally cemented lenses of shell debris, particularly *Oxytoma*; *Ringsteadia pseudoyo*, *Pachyteuthis*, *D. delta* and *Thracia*; persistent, 10–30 mm thick, shell-debris-rich bed at base forming marker	1.0
b.	Mudstone, grey, calcareous becoming less so below; scattered small concretions; *Prorasenia* sp., *Ringsteadia pseudoyo*, *Pachyteuthis*, *Pinna* in growth position, *Thracia*	1.2
a.	Mudstone, grey, paler than Bed 1b, moderately calcareous, very shelly with partially crushed fossils preserved in buff-coloured phosphate; *Pachyteuthis*, *Pinna* in growth position and *Thracia*	0.4
Z.	Mudstone, grey, highly calcareous with layer of strongly septarian concretions up to 0.6 m diameter at 1 m spacing, forming marker in pit face; *Prorasenia* sp. and *Ringsteadia pseudoyo*; basal 0.1 m intensely bioturbated with *Chondrites*	0.3
Y.	Mudstone, dark grey, well bedded; moderately shelly with *Prorasenia* sp., *Ringsteadia pseudoyo* and abundant *Thracia*	seen to 1.0

The most obvious marker beds in the pit face are the brownish rib formed by the sideritic mudstone of Bed 11, and the concretions in beds 4 and 9.

Interpretation

The phosphatic nodules/concretions that occur throughout the succession above Bed 6 indicate periods of prolonged residence close to the muddy sea-bottom sediment surface (i.e. relatively slow sedimentation), with localized, anoxic, semi-enclosed environments forming nucleation sites in otherwise oxygenated sediments. Similar depositional conditions are indicated by the occurrence of pyrite, which is restricted to specific sites such as the internal cavities of shells, particularly articulated bivalves and the innermost whorls of ammonites (Wignall, 1990b). According to the latter author, the onset of anoxic bottom-water conditions is indicated in the upper part of Bed 12 by the rapid disappearance of a previously diverse benthos, which is replaced by a highly impoverished fauna consisting almost solely of shallow infaunal filter-feeding bivalves. This assemblage is similar to several others in the Kimmeridge Clay of southern England where high environmental stresses, caused by fluctuating but generally low bottom-water oxygen levels, reduced the fauna to only a few opportunistic bivalve species. Relatively slow sedimentation rates are also indicated at South Ferriby by the ratio of fragmented to complete specimens of benthos in the mudstones. The longer the residence time near the sediment surface (i.e. the slower the sedimentation), the greater will be the fragmentation of the shelly fauna. Overall, the Ampthill Clay shows lower shell fragmentation values (less than 15%) than the Kimmeridge Clay where values are generally over 20% and nearly 50% in the basal bed (Wignall, 1990b).

Wignall (1990b) identified a number of faunal associations within the benthos that enabled further insights into the depositional environments; these included bottom-water conditions in which the substrate was probably quite firm, substrates with soft surface sediments caused by the activities of deposit feeders, and stable conditions with niche partitioning. He also recognized a number of Boreal forms which appeared to occupy similar ecological niches to more southern species, notably the bivalve *Grammatodon schourovskii* (Rouillier and Vossinsky), replacing *G. longipunctata* of southern England, and the gastropod *Dicroloma trifida* (Phillips), replacing *Quadrinervus ornatus* of southern England, as well as species that had no direct ecological equivalent in southern England, such as the bivalves *Parainoceramus subtilis* (Blake) and *Mesosaccella choroschowensis* (Borissjak). The cause of these differences is uncertain, but it can have had nothing to do with the Market Weighton High, which has been invoked to explain variations in species distribution between the Cleveland Basin and southern England (see site report for Green Lane and Golden Hill Pits, this volume), as this lay well to the north of South Ferriby.

The ammonite faunas in the Ampthill Clay indicate that it belongs entirely to the Upper Oxfordian Pseudocordata Zone. Although both the cardioceratid genus *Amoeboceras* and the perisphinctid genus *Ringsteadia* occur, species of the latter are more recognizable here so that the perisphinctid-based Sub-Boreal zonation (see Chapter 1, Figure 1.4) is more readily applied at this level. Successive species of the genus *Ringsteadia* divide the succession into three subzones: Pseudoyo, Pseudocordata and Evoluta (Figure 3.11). The boundary with the overlying Lower Kimmeridgian Baylei Zone is marked at the base of Bed 9 by the Oxytoma Cementstone. When originally recorded by the present author in 1974, this important marker bed was well developed in the pit face but it is only patchily developed and has not always been as obvious elsewhere in the pit; indeed, Birkelund and Callomon (1985) and Callomon (pers. comm.) have never explicitly recorded it. Birkelund and Callomon (1985) suggested that the abundance of shells in this bed was the result of current-winnowing but Wignall (1990b) thought that this was not necessarily so because there was the same ratio (almost twice as many) of the larger, heavily ribbed left valves of *Oxytoma* to the thinner-shelled smaller right valves in both the cementstone and adjacent mudstones; this suggested to him that the conditions leading to the formation of the cementstone were not unique to that bed, and he presumed that the shelly nature of the sediments was controlled by the original abundance of the bivalve itself. The bed has been recognized at a number of localities in north Lincolnshire, including a water-pipeline trench and railway cutting near Elsham and former brickpits at North Kelsey and Moortown Hill (Cox in Gaunt *et al.*, 1992). In the Worlaby G Borehole (Richardson, 1979), *c.* 5 km south-east of South Ferriby, the Oxytoma Cementstone includes a form of *Amoeboceras* comparable with *A. bauhini*. The key ammonite for marking the basal Kimmeridgian Baylei Zone is *Pictonia densicostata* but the presence also of *A. bauhini* enables correlations with other European sections (Schweigert and Callomon, 1997) (see also site report for Kildorais, this volume). Although small in size (25 mm maximum), Birkelund and Callomon (1985) regarded *A. bauhini* as a macroconch, with the even smaller *A. cricki* as the associated microconch. In southern England, the base of the Baylei Zone is marked by the Inconstans Bed characterized by the asymmetrical rhynchonellid brachiopod *Torquirhynchia inconstans* (J. Sowerby). A single cluster of this taxon, together with the bivalve *Lopha gregarea* (J. Sowerby) was reported by Wignall (1990b) in Bed 10a, which he therefore called the Inconstans Bed, implying its correlation with that bed in southern England. However, no other occurrence of this brachiopod has since been reported at South Ferriby, and the validity of this correlation must remain uncertain bearing in mind that asymmetrical rhynchonellids similar to *inconstans* have been reported in Dorset from the younger Black Head Siltstone and Abbotsbury Ironstone (S. Etches, pers. comm. 1995; Blake and Hudleston, 1877; Brookfield, 1973b). If the correlation is correct, a major hiatus must occur beneath the Inconstans Bed in Dorset (Figure 3.11). The section at South Ferriby is considerably more complete although there may still be a break beneath the Oxytoma Cementstone. The phosphatic nodules in that bed show evidence of reworking, which, according to Wignall (1990b), implies that several metres of mudstone have been removed before deposition of Bed 9.

Ammonites in the highest beds include forms transitional between *Pictonia* and *Rasenia*, the latter genus indicating the Cymodoce Zone. Bed 12 is tentatively assigned to that zone, with the sideritic mudstone (Bed 11) marking its basal boundary.

Conclusions

The pit at South Ferriby shows one of the best exposures across the Oxfordian–Kimmeridgian stage boundary in the UK. The structurally uncomplicated mudstone succession there yields a rich ammonite fauna, including an evolutionary succession of *Ringsteadia* species, enabling the subzonation of the youngest beds of the Oxfordian to be documented accurately within the Sub-Boreal zonation. The presence of *Amoeboceras bauhini* allows correlation of the stage boundary sequence with other areas of Europe (see also site reports for Kildorais and Staffin, this volume). The site is thus a most important one for stratigraphical studies and both national and international classification and correlation.

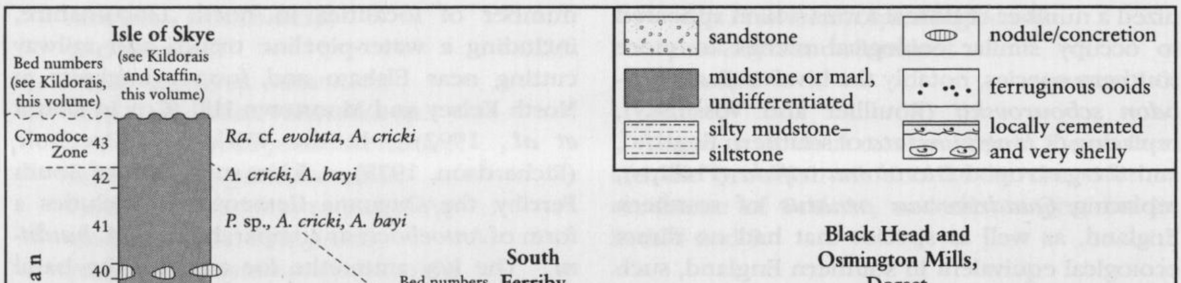


Figure 3.11 Correlation between the Oxfordian–Kimmeridgian boundary beds at South Ferriby and those in Dorset and Skye (after Page and Cox, 1995, fig. 2). *A.* = *Amoeboceras*, *P.* = *Pictonia*, *Ra.* = *Rasenia*, *Ri.* = *Ringsteadia*.