British Tertiary Stratigraphy

Brian Daley

School of Earth, Environmental and Physical Sciences
University of Portsmouth
Portsmouth, UK

and

Peter Balson

British Geological Survey,
Keyworth, Nottingham, UK

GCR Editor: **L.P. Thomas**

JOINT NATURE CONSERVATION COMMITTEE

Chapter 10

The Coralline Crag

P. Balson

THE CRAGS OF EAST ANGLIA

In 1703 Samuel Dale described fossiliferous sand and gravel overlying 'blueish clay' at Harwich in Essex (Dale, 1704). This appears to be the first record of the East Anglian Crag deposits in the scientific literature. The fossiliferous sand referred to would now be called the Red Crag, overlying the London Clay. The section at Harwich is now lost due to coastal erosion, but Dale also recorded exposures at Walton-on-the-Naze and Bawdsey which are described in detail later in the section on the Red Crag.

The term 'crag' as applied to deposits in East Anglia first appears in 1764 (Kirby, 1764) when it was used to describe shelly deposits (Red Crag) near Woodbridge in Suffolk which had been found to improve crop yields when applied as a field dressing (Pickering, 1745). In the classic monograph, *The Mineral Conchology of Great Britain*, Sowerby (1812) described fossils from the 'Crag Marl' of Essex and Suffolk. William Smith (1816) described 'crag' as 'a local term for shells mixed with sand ... in the counties of Norfolk and Suffolk'. His stratigraphical table (Smith, 1817) shows the Crag lying beneath the London Clay, an error probably caused by misidentification of the clay-rich Pleistocene Lowestoft Till which overlies the Crag in parts of East Anglia. The Crag was described in more detail by Sir Charles Lyell in his *Principles of Geology* (1830–1833) but it was not until 1835 that Charlesworth realized that several distinct formations, based on their fossil content, could be recognized within the 'crag-formation' and that these represented distinct time intervals. From exposures at Ramsholt on the bank of the River Deben (see later) he recognized two formations, which he termed the Coralline Crag and the Red Crag (Charlesworth, 1835). In 1837, a third division of the crag-formation was recognized, the Mammiferous Crag (Charlesworth, 1837a), which later became known as the Norwich Crag (Lyell, 1839). This proved to be the foundation for the stratigraphy still in use today (Figure 10.1) and was followed by an explosion of interest in the fossil faunas of the crag formations which yielded many hundreds of species to Victorian collectors. Fossil collection in the Red Crag in particular was greatly aided by the opening of many pits in the mid-19th century to exploit the conglomeratic phosphate deposits, the so-called 'coprolite bed', 'nodule bed' or 'Suffolk Bone-Bed', at the base of that formation. Other economic uses of the Red Crag, which persist to the present day, are its use for making farm tracks and as a bulk fill material for which it continues to be excavated at Waldringfield Heath, for example. The Coralline Crag is similarly used for farm tracks and in the past has been used as a rough walling stone, as for instance in farm buildings around Pettistree Hall, Sutton, and in church towers at Chillesford and Wantisden.

Since the mid-19th century there have been reports of human artefacts and remains from both the Coralline and Red Crags of Suffolk and Essex. These have included bone spear heads (Mortimer, 1863) from the coprolite bed, a carved shell from the Red Crag of Walton-on-the Naze (see later) (Stopes, 1882), flint implements from several localities in the Red Crag including Buckanay Farm (see later) (Moir, 1911) and Coralline Crag at Rockhall Wood, Sutton (see later) (Lankester, 1912; Moir, 1915), and a human mandible from the Red Crag at Foxhall near Ipswich (Newton, 1899; Osborn, 1922).

With respect to the artefacts, considerable doubts over these discoveries centre on:

1. the evidence for human working as against natural formation; for instance, perforations in Crag fossil shark teeth believed at one time to have been human-made are almost certainly due to marine boring organisms (Hughes, 1872); flaked flints claimed to have been worked by humans may be due to natural shattering (e.g. Warren,1948);
2. the stratigraphical location of finds and whether they are *in situ* or not;
3. the possibility of hoax at a time similar to that in which the Piltdown fraud was perpetrated.

The claimed find of a human mandible from the Red Crag at Foxhall appears to have attracted early scepticism (Newton, 1899). The specimen was apparently lost around 1867 (Osborn, 1922).

Given the probable age of the crag deposits, it is unlikely that any of the evidence for human presence at the time of, or before, deposition of the Coralline or Red Crags can be substantiated but nevertheless these deposits have played an interesting role in the arguments over the antiquity of humans in this country.

Inferences of palaeoclimate from the East Anglian crag deposits have played an important

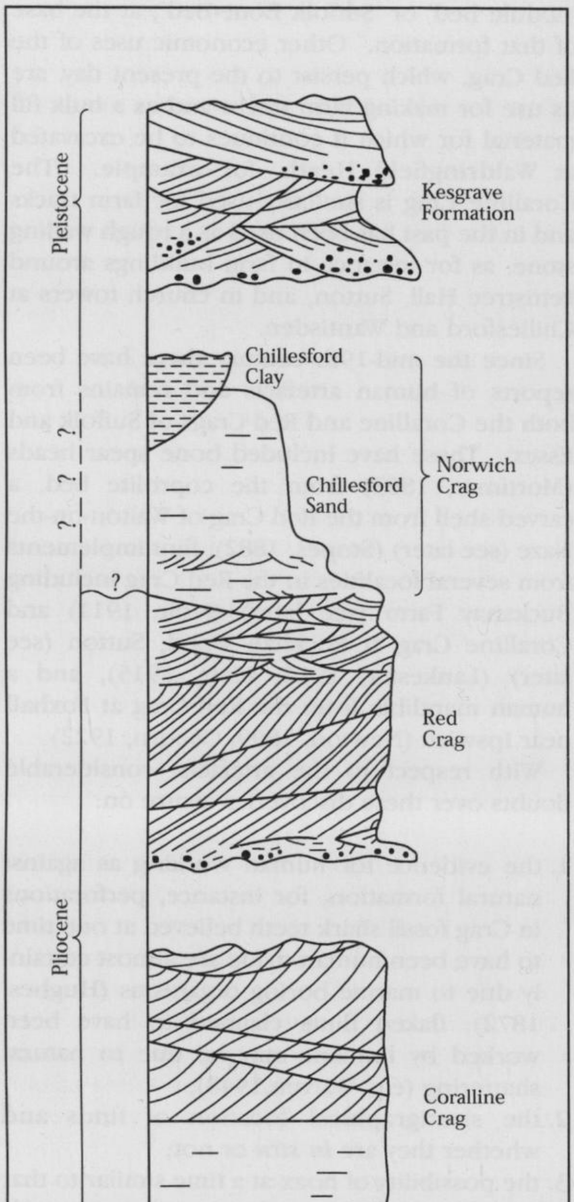


Figure 10.1 Schematic sequence (not to scale) of the Crag formations in Suffolk and north Essex (modified after Mathers and Zalasiewicz, 1985).

part in the establishment of the stratigraphical terminology and sequence in the British Neogene. The position of the Pliocene–Pleistocene boundary in north-west Europe, for instance, has traditionally had a climatic definition. After the division of the Crag into separate formations by Charlesworth, it was Forbes (1846) who, through the study of the crag molluscs and comparison with the distribution of living species, seems to have been the first to show a progressive cooling of the environment in the crag sequence. The climatic deterioration can be traced from the Coralline Crag, whose fauna Wood (1842) had already compared with that of the Mediterranean or the coast of Portugal, through Red Crag, Norwich Crag and finally to the onset of glaciation in the British Isles (Forbes, 1846).

The possibility of a period of glaciation before or even during Crag deposition has often been considered. Evidence has included the report of a large boulder of porphyry 'weighing about a quarter of a ton' in the basal sediments of the Coralline Crag at Rockhall Wood, Sutton, which Prestwich (1871a) believed could only be explained by ice transport. The presence of other exotic pebbles and striated and patinated flints within the basal sediments of the Red Crag has been used as evidence of a 'pre-Red Crag ice age', i.e. between the times of deposition of the Coralline and Red Crags by Spencer (1964, 1971a). At best this evidence is equivocal as such material originally could have been transported into the area at any time since deposition of the Eocene London Clay upon which the Crags rest unconformably over most of their outcrop.

INTRODUCTION

Until 1835, the 'crag-formation' of East Anglia had been thought to be a single deposit of uniform age. Charlesworth observed that in a section on the bank of the River Deben at Ramsholt Cliff a previously unrecognized division of the 'crag-formation' could be seen. This lower division was found to be recognizable elsewhere in the area so Charlesworth proposed a bipartite division of the formation (Charlesworth, 1835). The lower division he termed the 'Coralline Crag' after the abundance of 'corals', later realized to be the skeletal remains of bryozoans (Milne Edwards and Haime, 1850), which characterized the sediment. This distinctive charac-

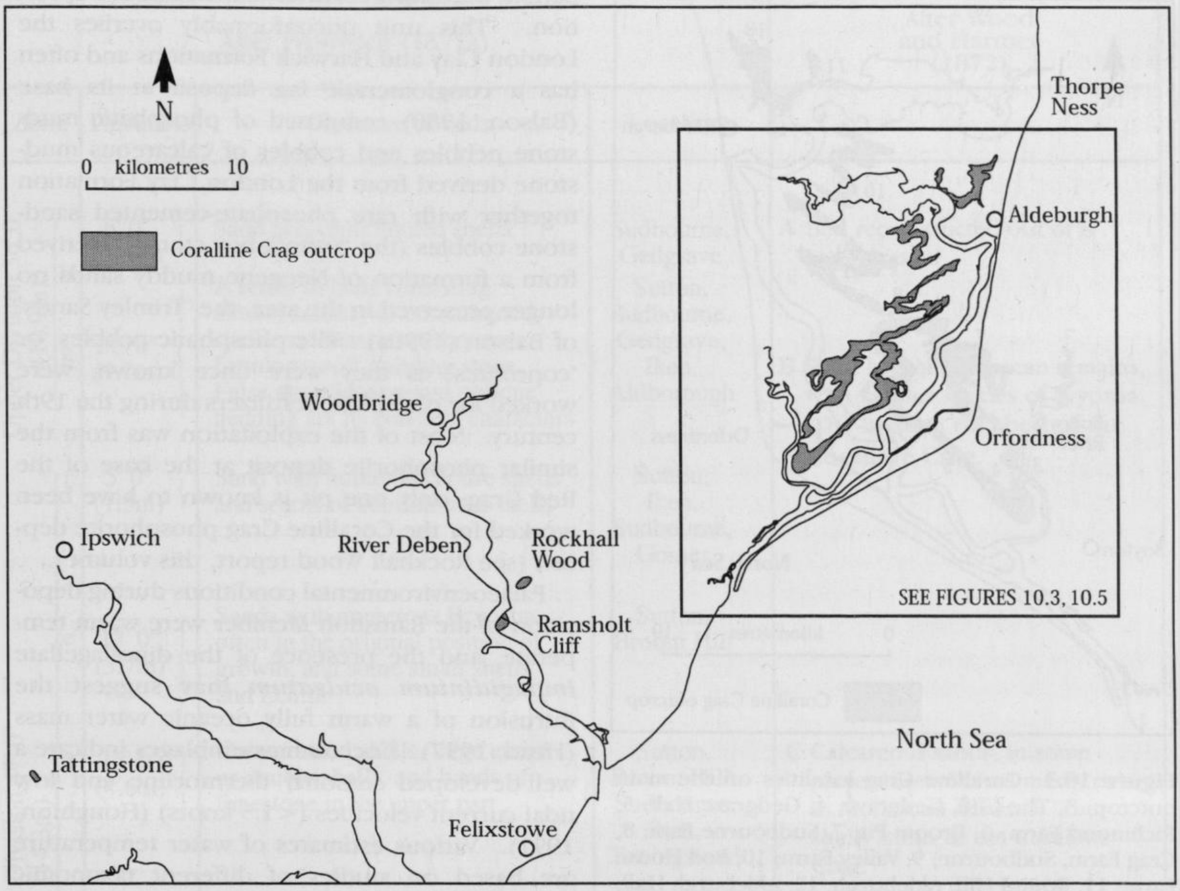


Figure 10.2 Map showing the onshore surface outcrop of the Coralline Crag.

teristic had already been noticed by Taylor (1827) who described 'interesting varieties of coral and sponges forming a soft porous rock' in the Crag around Orford. Charlesworth termed the upper division the 'Red Crag' after its characteristic ferruginous coloration. There followed an intense controversy as to whether the upper division was merely an altered condition of the lower division. Woodward (1835) was particularly antagonistic towards Charlesworth's divisions and went so far as to say that 'corallines' were in fact absent from the Coralline Crag at Charlesworth's key section at Ramsholt. If by 'coralline' Woodward meant bryozoans, he was certainly mistaken as bryozoans are particularly abundant at that locality (see later). Despite this early controversy and attempts to change the name of the Coralline Crag to Lower, Lowest, Suffolk, White, Polyzoan or Bryozoan Crag later in the 19th century (e.g. Jones and Parker,1864; Jones *et al.*, 1866), Charlesworth's original terms have remained in usage up to the present day.

The Coralline Crag is a formation of marine skeletal carbonate sands and silty sands with an outcrop restricted to south-east Suffolk and an adjacent area of the southern North Sea (Balson, 1989, 1992a). The outcrop consists of an elongate NE–SW trending main body and three small outlying bodies to the south-west of the main outcrop (Figures 10.2 and 10.3). Erosion, probably during the late Pliocene, has removed much of the former extent of this deposit. The formation exceeds 20 m thick in places and everywhere rests unconformably on the London Clay or Harwich Formations (Palaeocene–Eocene) which had already been deeply eroded into an undulose surface prior to the Pliocene transgression.

Prestwich (1871a) believed that the Coralline Crag could be divided into a number of units which he referred to as 'zones' (Figure 10.4) which he believed were laterally continuous and traceable throughout the outcrop. His sequence was based largely on the sections then observable at Rockhall Wood, Sutton. Wood and

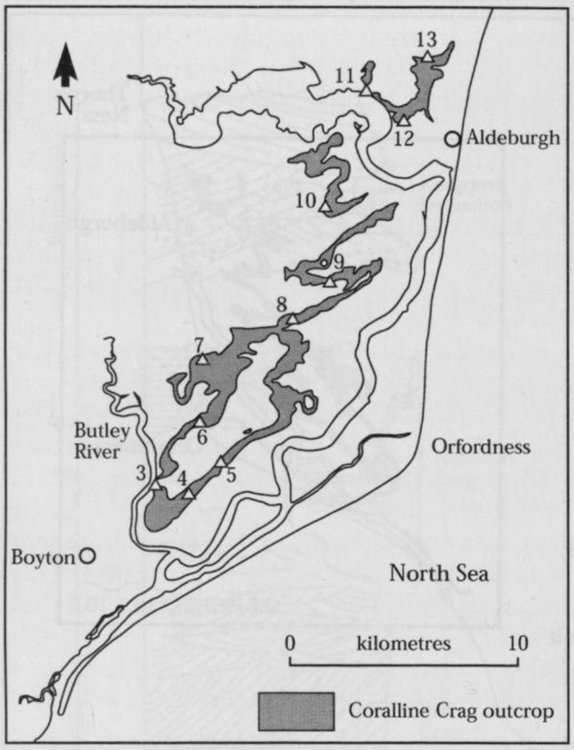


Figure 10.3 Coralline Crag localities on the main outcrop: 3, The Cliff, Gedgrave; 4, Gedgrave Hall; 5, Richmond Farm; 6, Broom Pit; 7, Sudbourne Park; 8, Crag Farm, Sudbourne; 9, Valley Farm; 10, Red House Farm; 11, Round Hill, Aldeburgh; 12, Aldeburgh Hall; 13, Crag Pit Nursery.

Harmer (1872) and later Harmer (1898, 1902, 1910) refuted Prestwich's zonation and believed that the Coralline Crag was essentially similar throughout.

While Prestwich's interpretation is not wholly compatible with modern sedimentological ideas, the Coralline Crag can indeed be seen to exhibit a series of facies on the basis of sedimentary and faunal characteristics. These facies have distinct geographical and vertical distributions although exposures at the present time do not allow all of the relationships between the facies to be seen. Additional evidence from boreholes has recently allowed these facies to be defined as members of the Coralline Crag Formation (Balson *et al.*, 1993).

The Coralline Crag can be subdivided into at least three distinct members. The lowest of these, the Ramsholt Member (Balson *et al.*, 1993), comprises a 7.5 m thick unit of silty carbonate sands with abundant well-preserved molluscan and bryozoan fossils. Few sedimentary structures are preserved due to extensive bioturbation, indicating relatively slow rates of deposition. This unit unconformably overlies the London Clay and Harwich Formations and often has a conglomeratic lag deposit at its base (Balson, 1980) composed of phosphatic mudstone pebbles and cobbles of calcareous mudstone derived from the London Clay Formation together with rare phosphate-cemented sandstone cobbles (the 'Suffolk box-stones') derived from a formation of Neogene muddy sands no longer preserved in the area, the 'Trimley Sands' of Balson (1990a). The phosphatic pebbles, or 'coprolites' as they were once known, were worked for phosphate fertilizers during the 19th century. Most of the exploitation was from the similar phosphorite deposit at the base of the Red Crag; only one pit is known to have been worked for the Coralline Crag phosphorite deposit (see Rockhall Wood report, this volume).

Palaeoenvironmental conditions during deposition of the Ramsholt Member were warm temperate, and the presence of the dinoflagellate *Impagidinium aculeatum* may suggest the intrusion of a warm fully oceanic water mass (Head, 1997). Coccolith assemblages indicate a well-developed seasonal thermocline and low tidal current velocities (<1.5 knots) (Houghton, 1991). Various estimates of water temperature are based on studies of different taxonomic groups. A study of the bivalve *Hiatella arctica* yielded an annual temperature range of 13.5–24°C (Strauch, 1968) although the summer temperature was acknowledged as perhaps being an over estimate. Planktonic foraminifera indicate a range of 10–18°C (Jenkins and Houghton, 1987) with a mean surface water temperature of 14–15°C based on the average width of *Globigerina bulloides* (Wilkinson, 1980). Lagaaij (1963) estimated a minimum temperature of 14°C based on the bryozoan *Cupuladria canariensis*, whilst Cheetham (1967) thought that the presence of the bryozoan *Metrarabdotos* indicated a much higher minimum temperature of 21°C. Raffi *et al.* (1985) suggest temperatures of 20°C for at least three or four months of the year based on the mollusc fauna. These temperatures can be compared with the present-day values in the southern North Sea of 5–9°C in February and 12–17°C in August (Lee and Ramster, 1981). The temperatures during deposition of the Ramsholt Member would thus appear to have been at least 5°C warmer than at present.

The rare occurrence of brackish water ostra-

After Prestwich (1871a)					After Wood and Harmer (1872)
Division	Zone	Thickness	Character of beds	Localities	
Upper Division 36' 0" (10.9m)	h	6' 0" (1.8m)	Sand and comminuted shells	Sudbourne, Gedgrave	**A** Bed reconstructed out of **B** comminuted
	g	30' 0" (9.1m)	A series of beds consisting almost entirely of comminuted shells and remains of bryozoa, forming a soft building stone. False stratification and oblique bedding are its constant characters	Sutton, Sudbourne, Gedgrave, Iken, Aldborough	**B** Solid bed of Molluscan remains, with various species of Bryozoa. 'The Bryozoa rockbed of the Coralline Crag.'
Lower Division 47' 0" (14.3m)	f	5' 0" (1.5m)	Sand with numerous entire shells and seams of comminuted shells	Sutton, Iken, Sudbourne, Gomer	
	e	12' 0" (3.7m)	Sands with numerous Bryozoa, often in the original position of growth, and some small shells and Echini	Sutton, Broom Hill	
	d	15' 0" (4.6m)	Comminuted shells, large entire or double shells, and bands of limestone in the upper part	Sutton, Broom Hill, Sudbourne, Iken, Tattingstone	**C** Calcareous sands, in some places more or less marly, rich in Molluscan remains. 'The shelly sands of the Coralline Crag.'
	c	10' 0" (3.1m)	Marly beds with numerous well-preserved and double shells, often in the position in which they lived	Sutton, Ramsholt	
	b	4' 0" (1.2m)	Comminuted shells, Cetacean remains, Bryozoa	Sutton	
	a	1' 0" (0.3m)	Phosphatic nodules and Mammalian remains	Sutton	
Total		83' 0" (25.3m)			Total Thickness 60 feet (18.3m)

Figure 10.4 Comparison of Coralline Crag stratigraphy between Prestwich (1871a) and Wood and Harmer (1872) (after Burrows, 1895a).

cods may indicate nearby estuarine environments and water depths no greater than 20 m (Wilkinson, 1980). This water depth is supported by evidence from foraminifera. The abundance of *Cibicides lobatulus* and *Planorbulina mediterranensis*, which Carter (1951,1957) demonstrated to be associated with algae, indicates depths no greater than 30 m (Funnell, 1967).

The Ramsholt Member is unconformably overlain by the Sudbourne Member, a unit of conspicuously cross-bedded, well-sorted carbonate sands up to approximately 12 m thick. Exposures in this facies characteristically show large-scale cross-bedding with a set thickness of between 1 and 2.5 m. This unit was deposited by the migration of large submarine sandwaves, up to 3–4 m in height, in a relatively high-energy tidal environment. The constancy of the palaeocurrent directions to the south-west and the elongate ridge form of the outcrop of this unit suggest that it may represent a fossil tidal sand ridge or sandbank aligned parallel to the palaeo-coastline (Balson, 1983) as first suggested by Wood in 1863 (in Jones *et al.*, 1866) and subsequently developed by Harmer (1898). Foreset dips taken from the cross-bedding indicate net sand transport to the south-west, slightly oblique to the long axis of the outcrop (Figure 10.5). The fauna of the Sudbourne Member varies from fairly well-preserved, unbroken skeletal material in the north of the outcrop, to finely comminuted bioclastic debris at the southern end around Gedgrave. Thus sediment derived from the north was transported towards the south-west with consequent breakage and abrasion rounding the skeletal fragments so that in southern exposures of the facies almost none of the larger skeletal debris can be readily identified. There is, however, some evidence of an in-situ fauna but this is of low diversity. At Crag Farm, for instance, large well-preserved colonies of the eschariform bryozoan '*Eschara*' *pertusa* are fairly common. These colonies would have been too fragile to withstand transportation and yet they are present here as well-preserved, in some cases almost complete, colonies, in marked contrast to the comminuted skeletal debris which constitutes the bulk of the sediment. Evidence of other in-situ fauna comes from a variety of unwalled vertical and sinuous burrow structures.

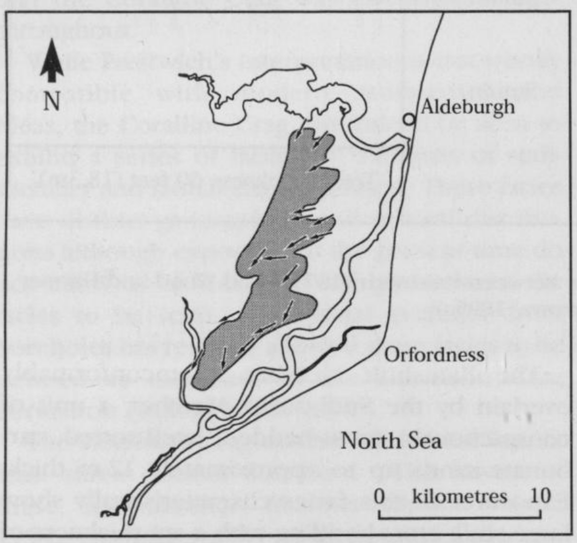


Figure 10.5 Sketch map of the outcrop of the Sudbourne Member showing sand transport directions inferred from foreset dip directions.

Dinoflagellates indicate a similar warm temperate assemblage to the Ramsholt Member but either slightly cooler or with an increase in open-water influence (Head, 1997).

The Sudbourne Member overlies the Ramsholt Member in exposures at Rockhall Wood, 'The Cliff', Gedgrave, and Broom Hill. An erosional and burrowed contact is clearly visible at Rockhall Wood, but the contact is more subtle at the other localities. The Sudbourne Member is well exposed at Richmond Farm, Crag Farm, Valley Farm and Red House Farm.

In the northern part of the Coralline Crag outcrop a unit of bryozoan-rich skeletal sands is found. This unit, the Aldeburgh Member, is up to 13 m thick and differs from the Sudbourne Member in containing markedly less fine-grained sediment, a higher carbonate content, and a much more diverse bryozoan fauna. This unit often shows crude horizontal or slightly inclined bedding. The sediments are characterized by a high (generally greater than 85%) proportion of carbonate skeletal material. The fauna is generally abundant and well preserved and includes a diverse encrusting epifauna as evidence of relatively reduced rates of sedimentation (Balson, 1981b). Evidence of tidal current activity is found in small-scale cross-bedding as seen at Round Hill and Aldeburgh Hall. Evidence of the relatively tranquil conditions has been noted from fine-grained sediment infills of large gastropods such as *Scaphella lamberti* (Dalton, 1900). The relationship between this facies, and the sandwave facies represented by the Sudbourne Member, cannot be seen in the field, but borehole records suggest that the Sudbourne Member overlies the Aldeburgh Member in the northern part of the outcrop (Balson *et al.*, 1993). Exposures of the Sudbourne Member at the northern end of its outcrop, for example at Red House Farm, which are geographically close to the outcrop of the Aldeburgh Member, show the sandwave facies to be rich in coarse skeletal material. It is believed that the two facies were laterally adjacent contemporaneously during deposition of the Coralline Crag and that skeletal grains were transported southwards within the sandwave facies. These coarse skeletal grains show a progressive increase in abrasion and reduction in size southwards within the Sudbourne Member. Study of the morphology of the London Clay surface shows that this model of deposition is compatible with increasing depth of the Coralline Crag basin in a north-easterly direction.

The Sudbourne and Aldeburgh Members are almost everywhere devoid of aragonitic skeletal material, this having been diagenetically leached, leaving behind only the more stable calcitic debris. Consequently mollusc shells, except as moulds, are relatively uncommon in these units when compared to the Ramsholt Member which has only locally been affected by aragonite dissolution. Bryozoans and other calcitic fossils are found throughout the formation. The dissolved aragonite has been reprecipitated as a calcite cement forming a soft, porous limestone. The leached, cemented Coralline Crag has been referred to as the 'Bryozoan Rock Bed' (e.g. Wood and Harmer, 1872; Boswell, 1928), but the use of the term in the literature as a stratigraphical division referring to the Upper Coralline Crag is misleading as the lower limit of dissolution has no stratigraphical significance. However, it can be shown that this selective dissolution has occurred mostly in sediments which were primarily coarse and therefore porous. This was the case for deposits of the Sudbourne and Aldeburgh Members. The Ramsholt Member is much richer in fine-grained sediment, which has prevented extensive percolation of acidic groundwater and thus inhibited aragonite dissolution. The majority of molluscan species secrete aragonitic shells and for this reason localities in the Ramsholt Member were favoured by early collectors for the abundant and diverse molluscan faunas which they yielded. Localities with leached Crag sediments received much less attention.

Correlation between the Coralline Crag and deposits elsewhere has long been a source of controversy. Harmer (1900a) created a new stage, the 'Gedgravian', to be synonymous with the Coralline Crag in Britain. The name Gedgravian was taken from the occurrence of Coralline Crag in the parish of Gedgrave. On the basis of the molluscan fauna he correlated the Gedgravian with the Belgian Sables à *Isocardia cor* and the Casterlien stage (Harmer, 1902, 1910). More recently the Coralline Crag has been correlated with Luchtbal Sand Member of the Lillo Formation in Belgium and the Lower Oosterhout Formation of the Netherlands (Funnell, 1996).

A further stratigraphical division, the 'Boytonian zone', was proposed by Bell (1911) to include deposits formerly worked for phosphatic nodules on the marshes at Boyton which lies just south, and on the other side of Butley River (Figure 10.3), from the section at The Cliff, Gedgrave (see later). He believed that the mollusc fauna of the Boyton site showed intermediate characteristics between the faunas of the Coralline and Red Crags although it had previously been supposed that two separate assemblages were being mixed by the excavators (Wood, 1879; Harmer, 1898). Harmer appears later to have changed his mind and accepted Bell's division (Harmer, 1914–1925). Baden-Powell (1960) dismissed the possibility of a 'Boytonian fauna', believing it to represent an impossible mixture of species derived from separate beds of the two formations at Boyton Marshes. Nevertheless the concept of an intermediate 'Boytonian fauna' seems not to have died (Cambridge, 1977). Bell (1911) also recognized Boytonian deposits at the base of the Red Crag at Bawdsey and Walton-on-the-Naze and at Ramsholt.

The Coralline Crag was thus considered to be attributable to two stages: a lower Gedgravian Stage and an upper Boytonian Stage. An implication of the rather casual usage of lithostratigraphical and chronostratigraphical terms in the early 20th century, where the two were used interchangeably, was that parts of the Red Crag were equated with the Boytonian on faunal evidence and thus became considered as equivalent to part of the Coralline Crag. Despite the controversy over the validity of the Boytonian, the term remained in usage and became significant in the debate over the placement of the Pliocene–Pleistocene boundary in the British sequence, with Glibert and de Heinzelin (1957) placing the boundary between the Gedgravian and Boytonian stages and van Voorthuysen (1957) placing it between the Boytonian and the Walton Red Crag.

More recently Jenkins *et al.* (1988) examined planktonic foraminifera in samples from the Ramsholt Member which indicated a possible age range of 4.2–2.3 Ma (see Figure 8.1), whilst the presence of the nannofossil *Sphenolithus* sp. recorded by Jenkins and Houghton (1987) may indicate a much narrower range of age between 3.6 and 3.4 Ma. This latter age is in agreement with the record of Hodgson and Funnell (1987) of the planktonic algal cyst *Bolboforma costata* in samples from the Ramsholt Member. Andrew and West (1977), in a study of pollen from a borehole which penetrated probable Ramsholt Member near Orford, proposed a correlation with the Brunssumian pollen stage (Figure 8.1). Dinoflagellate assemblages indicate an age no younger than 3.3 Ma based on the presence of *Batiacasphaera minuta* (Head, 1997).

A sample from a silt drape within the overlying Sudbourne Member at Rockhall Wood has been found to contain a pollen assemblage of a slightly different aspect which indicated a possible Reuverian age (Gibbard and Peglar, 1988) (Figure 8.1). Dinoflagellate assemblages, also from Rockhall Wood, indicate an age no younger than 3.3 Ma (Head, 1997).

The available evidence would therefore appear to indicate that the silty sediments of the Ramsholt Member are probably of latest Early Pliocene age. The hiatus at the top of the Ramsholt Member is of unknown, but probably brief, duration, with the Sudbourne Member possibly of early Late Pliocene age.

The stratigraphical relationship of the Aldeburgh Member to the other members has been determined only in boreholes and there is, as yet, little evidence from microfauna or flora on its stratigraphical position in a wider sense. On available evidence the Aldeburgh Member is younger than the Ramsholt Member and probably roughly equivalent in age to the Sudbourne Member (Balson *et al.*, 1993).

The environment of deposition of the Coralline Crag is of great sedimentological interest. The formation consists dominantly of carbonate skeletal grains indicating that terrigenous sediment input was limited. At the present time, modern marine sediments on the floor of the southern North Sea are dominated by clastic terrigenous sediments (Balson, 1992b) and extensive carbonate-rich sediments are found only to the north and west of Scotland, west of Ireland and in the western English Channel and Celtic Sea (Wilson, 1982, fig. 6.2). The Coralline Crag contrasts similarly with other southern North Sea Neogene deposits which are dominantly of terrigenous or glauconitic sediments.

RAMSHOLT CLIFF, RAMSHOLT, SUFFOLK (TM 298429–TM 297427)

Highlights

The section at Ramsholt Cliff is of great historical, palaeontological and stratigraphical significance. It can be considered to be a type section for both the Coralline and Red Crags and is the type locality for the Ramsholt Member of the Coralline Crag Formation. It exhibits an abundant and interesting fauna that has figured strongly in many of the classic monographs of Crag fossils. It is the only locality where the basal contact with the London Clay can be examined at the present time. It also represents the most southerly exposure of the Coralline Crag now accessible.

Introduction

This locality was first described in detail by Charlesworth (1835) although fossils were recorded from 'Ramsholt, near Woodbridge, out of a newly discovered bed of clay' as early as 1821 by Sowerby. Until 1835, the 'crag-formation' had been considered as a single geological formation. Charlesworth recognized that at Ramsholt Cliff two lithologically and palaeontologically distinct formations were present. The upper was termed the 'Red Crag' after its distinctive ferruginous colour. The lower of these two formations he termed the 'Coralline' Crag after the great abundance of 'corals' later recognized to be the skeletal remains of bryozoans, within the sediment. The observation led to a good deal of controversy with Woodward who believed in the uniformity of the crag deposits and held that 'corallines' were in fact absent from Charlesworth's lower division (Woodward, 1835). In fact, 'corallines' or bryozoans are a conspicuous and abundant component of the fauna of the Coralline Crag at this locality. Ramsholt is one of four identifiable localities used by Charlesworth in his description of the Coralline Crag and can therefore be considered as a parastratotype for the formation. More recently the section was designated as the type locality for the Ramsholt Member of the Coralline Crag by Balson *et al.* (1993).

Ramsholt Cliff was well known among early crag geologists, including Sowerby, Lyell and Prestwich. The fauna was known for the abundance of certain species such as *Balanus concavus* and *Culicia woodii* which are rare elsewhere in the Coralline Crag. The section here was described in detail in Prestwich's early definitive works on the East Anglian Crags in 1871 (Prestwich, 1871a). Authors since that time have been content to quote his work, the section having become much less accessible and overgrown

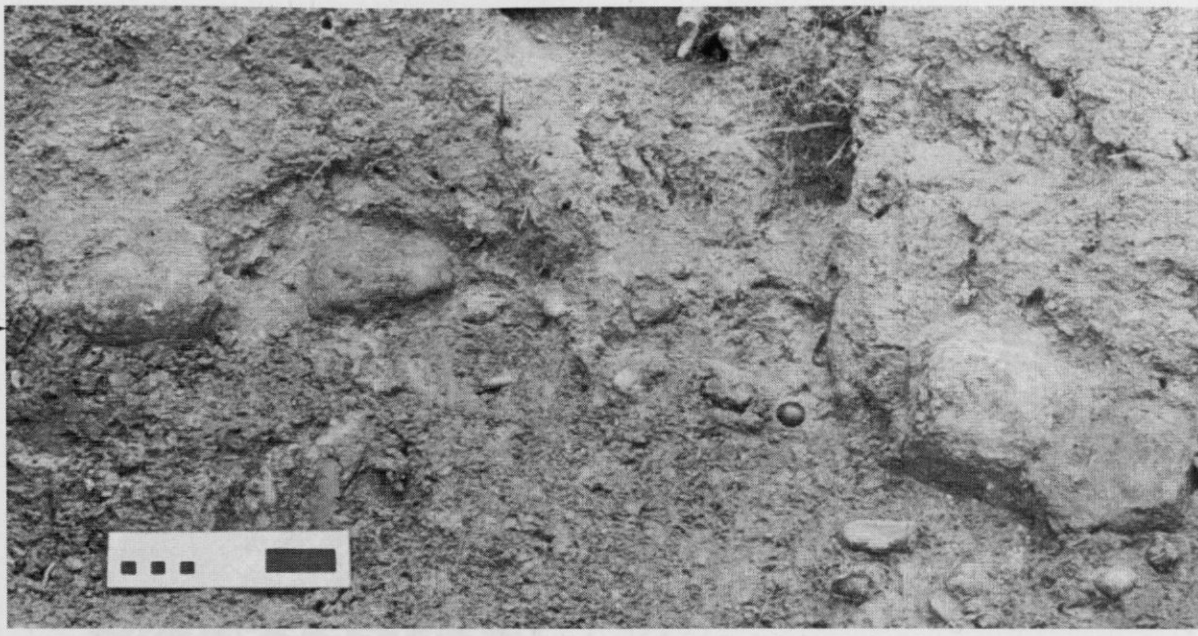


Figure 10.6 Basal contact between the Coralline Crag and the London Clay (arrowed) showing a conglomeratic lag deposit containing phosphatic mudstone pebbles, 'boxstones' and cobbles of calcareous mudstone exposed in a temporary excavation in 1978 (scale is 15 cm long). (Photograph: P. Balson.)

in more recent years.

Description

Ramsholt 'Cliff' is in fact a densely overgrown slope on the north bank of the River Deben. Usually the Coralline Crag is not exposed but erosion along the toe of the much-slipped river bank may intermittently expose small sections of disturbed Coralline Crag. In recent years most of the information regarding the Coralline Crag at this locality has come from temporary excavations either in the river bank or in the field above.

The section at Ramsholt Cliff shows a maximum of about 2.9 m of Coralline Crag, unaffected by aragonite dissolution, resting with marked unconformity on an undulose, erosional surface of London Clay and in turn overlain unconformably by the Red Crag. At the base of the Coralline Crag, resting on the plane of unconformity, is a conglomeratic deposit known in the past as the 'coprolite bed', 'nodule bed' or 'Suffolk Bone-Bed' (Figure 10.6). The thickness of the Coralline Crag varies laterally between the upper and lower planes of unconformity.

The conglomeratic material includes abundant phosphatic nodules, occasional fragments of phosphatized bone, irregular cobbles of a phosphate-cemented sandstone ('boxstones') and large irregular fragments of calcareous mudstone. The origins of the diverse elements of this phosphorite remanié (reworked) deposit and their context in the regional stratigraphy of East Anglia is discussed in detail in Balson (1980).

Much of the material, such as the phosphatic nodules and calcareous mudstone blocks, is derived from the underlying London Clay. Elsewhere the phosphatized bone and cobbles of phosphate-rich sandstone (the 'boxstones' of authors) were derived from a formation of Miocene to Pliocene sands which once covered part of this area of Suffolk, informally termed the 'Trimley Sands' by Balson (1990a). Winnowing of this deposit left the relatively dense bones and sandstone cobbles as a remanié deposit on the surface of the London Clay.

A similar phosphorite deposit is also found at the base of the overlying Red Crag. Elsewhere the Red Crag phosphorite deposit was formerly worked for phosphate in the mid-19th century, the extraction reaching a peak in 1857 when *c.* 12 000 tons of phosphate was obtained (Reid, 1890). The deposit below the Coralline Crag at Ramsholt was never worked commercially but at Rockhall Wood nearby, commercial exploitation of the Coralline Crag phosphate deposit occurred for a few years in the 1860's (Prestwich, 1871a).

The Coralline Crag fauna at Ramsholt Cliff is an interesting and important one. As mentioned above, many species that are common here are rare or absent elsewhere. The species include the large cyclostome bryozoan *Multifascigera debenensis* (Balson and Taylor, 1982) for which Ramsholt Cliff is the type locality and the large barnacle *Balanus concavus* for which the locality was in the past renowned (e.g. Charlesworth, 1835). Large irregularly branching colonies of the bryozoan *Turbicellepora coronopus* are abundant. The colonies are often found to be enclosing the corallites of the coral *Culicia woodii* figured in the monograph of British Tertiary corals by Milne Edwards and Haime (1850). Although *C. woodii* is rare elsewhere in the Coralline Crag this is due in part to the infrequency of large *Turbicellepora* colonies elsewhere to act as hosts, and also to the lack of preservation of aragonitic skeletal material, of which the coral is composed, which is characteristic of many other localities. Associated with the coral is a commensal barnacle *Pyrgomina anglicum* that has a similar limited distribution. These interesting faunal relationships are described in greater detail by Cadée and McKinney (1994) and Tilbrook (1997). The large *Turbicellepora* colonies also form the substrate for encrusting bryozoan species. The molluscan fauna is abundant and well-preserved and figured strongly in the monograph of Wood (1848–1882). Of particular interest is the occurrence of large aragonitic bivalve species such as *Glycymeris glycymeris,* which are occasionally found with both valves articulated. Other common species include *Dosina casina*, *Arctica islandica*, *Venericardia aculeata scaldensis* (Figure 10.7) and *Astarte omalii*.

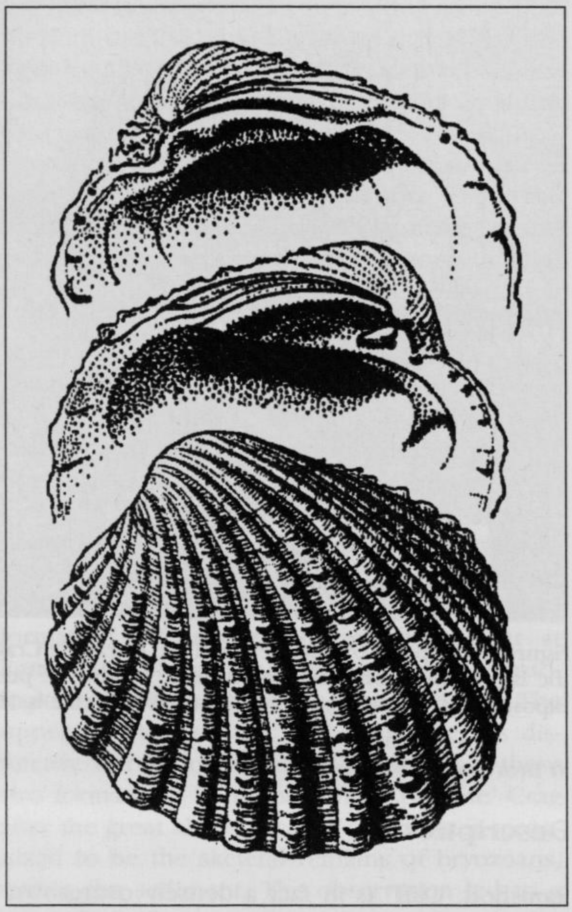


Figure 10.7 *Venericardia* (*Glans*) *aculeata scaldensis* (formerly *Cardita senilis*). Shell is 35 mm across. (Illustration after British Caenozoic Fossils, Plate 35:1 BM(NH), reproduced courtesy of The Natural History Museum, London.)

The Red Crag at Ramsholt Cliff is similarly poorly exposed. It consists of reddish brown shell-rich sands that overlie the Coralline Crag or rest directly upon the London Clay. Its thickness is laterally variable but probably exceeds 2 m in places. The basal sediments contain abundant phosphatic pebbles and boxstones. A list of the fauna of the Red Crag at this locality was given by Holcombe (1966) and includes the molluscs *Aequipecten opercularis*, *Mytilus*, *Glycymeris*, *Cerastoderma*, *Astarte* and *Neptunea contraria*.

Interpretation and evaluation

The section at Ramsholt Cliff is important because it is the only Coralline Crag locality where the basal contact showing its sharp unconformity with the London Clay Formation or Harwich Formation can be exposed. The unconformity represents a gap of around 50 Ma between the two formations. Derivative material in the lowermost sediments of the Coralline Crag represents formations eroded during this long time-span. In fact the only evidence of marine conditions between the mid-Eocene and mid-Pliocene in the area comes from this derivative material. It is, however, likely that for much of this period the area was subaerially exposed. The bulk of the derivative material is derived from the London Clay Formation itself, which at Ramsholt Cliff has been eroded away to rest upon the underlying Harwich Formation. Argillized ash bands, typical of the Harwich Formation, are occasionally exposed on the beach at this location at low tide. The London

Clay-derived material includes phosphatic pebbles, shark teeth and cobbles of the carbonate-cemented Harwich Stone Band. The provenance of some of the other exotic components, which include fossiliferous Jurassic limestone and quartzite cobbles, is less clear. Large, worn cobbles of the phosphatic 'Trimley Sands' (Balson, 1990a) and phosphatized bones represent the remnants of sediments from one or more, earlier Neogene transgressions.

The Coralline Crag sediments at Ramsholt Cliff are unaffected by the aragonite dissolution seen at most other sites, which allows a more complete interpretation of the fauna. The subsequent Red Crag transgression removed or reworked much of the Coralline Crag deposit, particularly the unlithified sediments of the Ramsholt Member, such that the Coralline Crag at Ramsholt Cliff is only an erosional remnant separated from the nearby small isolated outcrop at Rockhall Wood approximately 1 km to the north. It is also the only location where the Ramsholt Member is directly overlain by the Red Crag. Elsewhere it is overlain by younger units of the Coralline Crag.

Conclusions

Ramsholt Cliff is an important site as it is the only locality where the base of the Coralline Crag formation can be exposed easily at the present time. The Coralline Crag section at Ramsholt Cliff is the type locality for the Ramsholt Member. The fauna is an important one and includes elements rare or absent at other locations.

The section is one of the earliest recorded Coralline Crag localities in the literature and was used in the original definition of the formation.

ROCKHALL WOOD, SUTTON, SUFFOLK (TM 304440)

Highlights

The sequence at Rockhall Wood is the best known and most important vertical sequence of the Coralline Crag available for study. It has formed the major source for type specimens for monographs of many taxonomic groups. It is the only Coralline Crag site ever known to have been commercially exploited for phosphorite. In recent years it has provided material for studies of microfauna and microflora which have attempted to place the Coralline Crag in the context of Neogene standard stratigraphy.

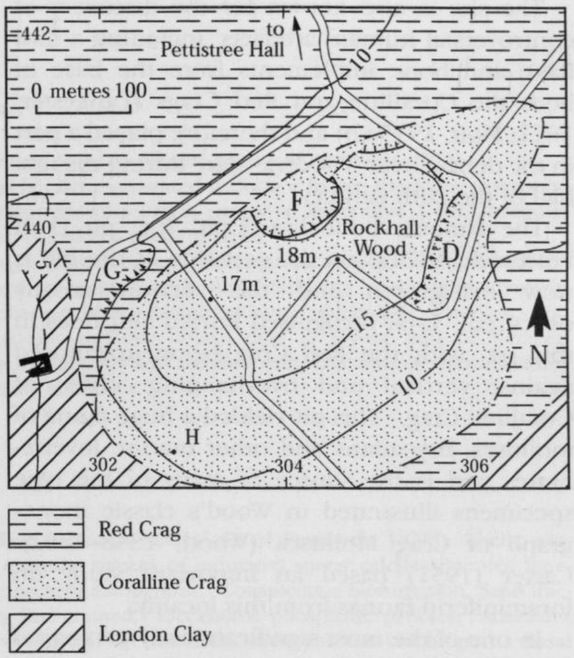


Figure 10.8 Map of Rockhall Wood, Sutton showing the location of sections. D, F, G and H are locality designations used by Prestwich (1871a).

Introduction

The small quarries lying around Rockhall Wood, Sutton (= Sutton Knoll of the literature) which together constitute this site (Figure 10.8) have been studied by geologists since at least 1835. Fossils from the Crag of 'Sutton' are recorded by William Smith (1817).

This outlying body of Coralline Crag, which is responsible for the slight topographical rise, is approximately 12 m thick and was first described by Charles Lyell (1839). These exposures later featured prominently in the subdivision of the Coralline Crag into 'zones' by Prestwich (1871a). Quarries in the uppermost aragonite-leached sediments provided blocks of cemented Crag for use in local building. Farm buildings incorporating Coralline Crag blocks can be seen at nearby Pettistree Hall to the north of the site. The woodland on top of the hill, from which the site takes its name, was largely destroyed by gales in 1987.

The site is also known for the discovery of controversial human 'artefacts' including a flint flake and bone implements from the base of both the Coralline and Red Crags (Lankester, 1912; Moir, 1915a,b) and therefore played a part in the debate over 'Pliocene Man' during the first half of the 20th century.

The famous 'bullockyard pit' (i.e. pit D of Prestwich, 1871a) on the east side of the hill is now overgrown and the section mostly obscured. Lyell recognised buried cliff lines in this pit, with the Red Crag being juxtaposed against vertical and overhanging 'cliffs' of Coralline Crag. This pit yielded a huge fauna of molluscs, bryozoans and other marine invertebrates and is the source of many of the type specimens illustrated in Wood's classic monograph of Crag Mollusca (Wood, 1848–1882). Carter (1951) based an important study on foraminiferid faunas from this locality.

In one of the most significant early geological works, Charles Lyell in his *Principles of Geology* (Lyell, 1830–1833) set out his concept of dividing the Tertiary into Eocene, Miocene and Pliocene periods on the basis of the proportion of living to extinct mollusc species. He had by this time already visited some Crag sites such as Walton-on-the-Naze. In the fourth edition of *Principles of Geology* (1835), Lyell suggested that the Red and Coralline Crags might have been laid down during the same geological period but in different parts of the basin, based on the fact that over 150 species of mollusc were common to both formations. In this suggestion he differed publicly with Charlesworth who had been the first to subdivide the crag formation (Charlesworth, 1835). In 1838, Lyell visited the sections at Rockhall Wood. His observations made him change his mind, as there was clear evidence that the Red Crag was significantly younger than the Coralline Crag. His change of heart cast doubts on the validity of his idea of using quantitative measures of mollusc species to determine geological age and therefore the site at Rockhall Wood was influential in the development of early Tertiary stratigraphical concepts.

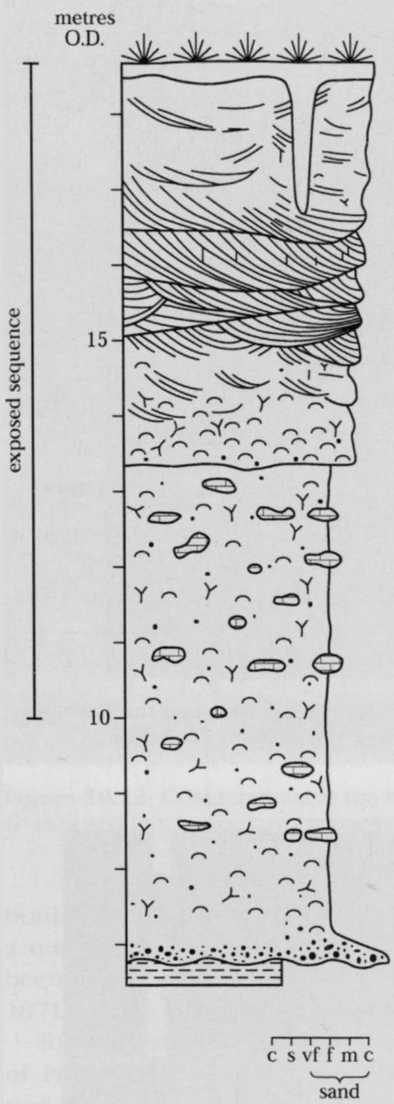
Under the general name of 'Sutton', Rockhall Wood has figured prominently in almost every monograph concerning the Coralline Crag fauna. This locality has remained one of the most important and popular sites for study of the Coralline Crag ever since. The site is also important for former exposures of Red Crag.

Description

A maximum of just under 12 m of Coralline Crag is preserved overlying an undulose surface of London Clay, but only the uppermost 5 m are exposed (Figure 10.9). A borehole at TM 30464396 contained 10.7 m of Coralline Crag, with the top of the London Clay at +7.3 m OD (Hollyer and Allender, 1982). The Red Crag surrounds the hill (Figure 10.8) and rests either directly upon the London Clay or upon, or against, the Coralline Crag.

The best existing exposures of the Coralline Crag are on the north side of the hill. There are presently three exposures (Figure 10.8) but only one of these was shown on the map produced by Prestwich in 1871 (pit F; Figure 10.8). This disused quarry has existed since at least 1836 when it was worked for material for a river wall (Prestwich, 1871a). The surface of the underlying London Clay is approximately 6 m below the quarry floor. Bioturbated bioclastic sands (Ramsholt Member) lacking any well-defined sedimentary structures, are exposed at the base of the pit face and are overlain by trough cross-bedded sediments (Sudbourne Member) (Figures 10.10, 10.11). Carbonate from the dissolution of aragonitic skeletal material in the upper part of the sequence has been redistributed to cement the Crag into a porous limestone sufficiently indurated to be used locally for building. The lower limit of leached sediments is roughly equivalent to the lower limit of well-defined trough cross-bedding and is slightly above the lower boundary of the Sudbourne Member. A second type of sparry calcite cement is found in irregular lithified patches within unleached sediments of the Ramsholt Member. This cement is believed to have formed under subaerial conditions (Balson, 1983).

The famous 'bullockyard pit' (pit D of Prestwich) is now overgrown and obscured. The Coralline Crag in this pit formerly yielded an abundant molluscan fauna to early collectors like Lyell, Wood and Prestwich. This pit yielded almost every known species of Coralline Crag mollusc to the researches of Wood and his son (Wood, 1848–1882). Lyell (1839) recognised the existence of a buried cliff line in this pit, the Red Crag being juxtaposed to vertical and overhanging 'cliffs' of Coralline Crag. He also observed that the Coralline Crag had been bored by pholad bivalves indicating that lithification had occurred before deposition of the Red Crag.



CORALLINE CRAG

Sudbourne Member: 5.4m (= 'zones' f and g of Prestwich, 1871).
Shelly sands, loosely calcite-cemented to form a friable limestone. Aragonite absent due to diagenetic dissolution except in lowermost 1.4m. Irregular upper surface with occasional solution pipes.
Conspicuous trough cross-bedding. Frequent silt drapes and mud pebbles. Sand fraction medium-grained with slight tendency to coarsen upwards. Occasional phosphatic pebbles. Abundant fauna, particularly of molluscs and bryozoans. Aragonitic molluscs found only in lowest part of Member. Bryozoans mostly fragmentary and abraded with fragemnts of *Metrarabdotos monilifera* especially abundant.

Ramsholt Member: 6.5m (= 'zones' a-e of Prestwich, 1871). Shelly, silty sands. Frequent irregular masses of indurated sparry calcite-cemented limestone. Aragonite present throughout. Conspicuous bioturbation. Sand fraction fine- to very fine-grained. Occasional phosphatic pebbles. Abundant fauna including well-preserved molluscs, bryozoans and brachiopods. Basal conglomeratic lag deposit (not exposed) containing phosphatic pebbles and phophatized bone.

LONDON CLAY FORMATION (not exposed)

Figure 10.9 Composite log of Coralline Crag section at Rockhall Wood. Clay = c, silt = s, very fine = vf, fine = f, medium = m, coarse = c. (After Balson *et al.*, 1991.)

After further excavation, Prestwich (1871b) was able to examine a better section of the contact that showed two notches which were interpreted as 'shorelines' separated by an elevation of about 3 m. Boulders of Coralline Crag encrusted with barnacles were found within the Red Crag, indicating that they fell from the cliff during deposition of the Red Crag. Abundant *Mytilus edulis*, many articulated, were found in the Red Crag, confirming shallow littoral conditions and the presence of hard substrates.

The junction between the Coralline Crag and the underlying London Clay was also formerly exposed at Rockhall Wood. The exact location of the former pit is shown by Prestwich (1871a) as pit 'H' a few hundred metres to the south-west of the bullockyard pit (Figure 10.8). This pit was excavated in 1860 and formerly showed over 7 m of Coralline Crag resting unconformably on the London Clay. At the base of the Coralline Crag the phosphorite deposit was exposed and was briefly exploited before the pit was infilled. The basal conglomerate yielded numerous fossil crustaceans derived from the London Clay, phosphatized bones and 'boxstones' (Prestwich, 1871a). Prestwich also recorded 'a rounded

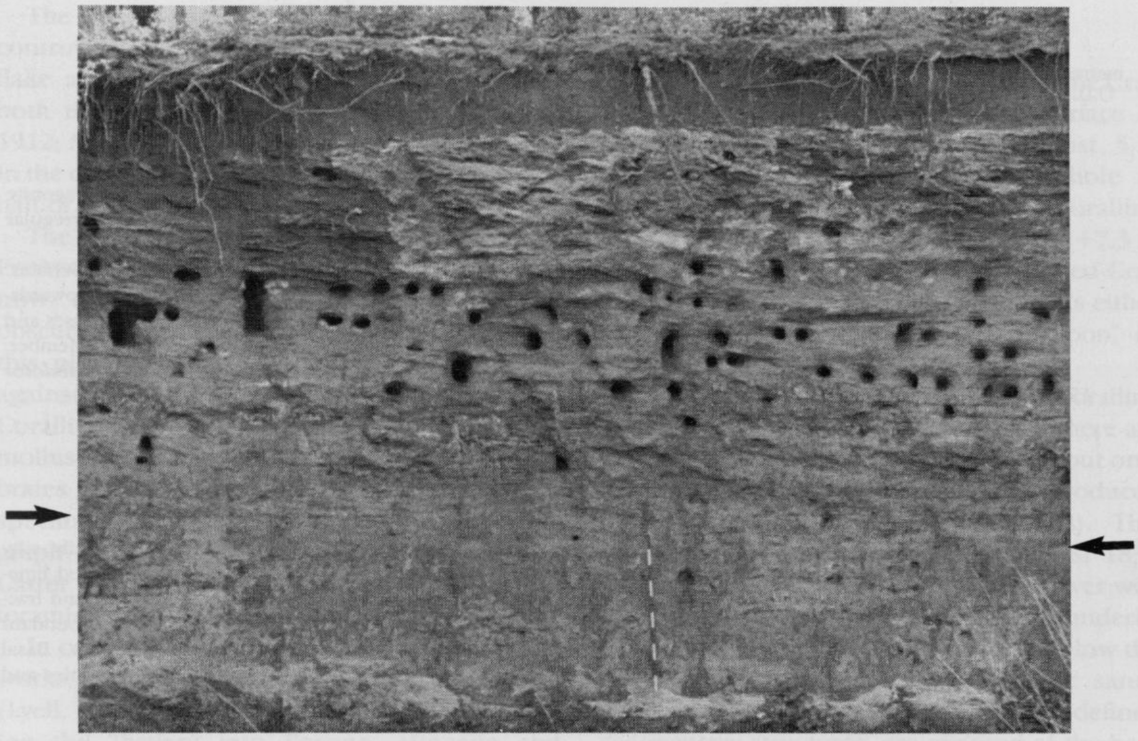


Figure 10.10 Coralline Crag exposed in pit at TM 3050 4408 in 1977. The contact between the Ramsholt Member and the overlying Sudbourne Member is arrowed. Scale is 1 m long. (Photograph: P. Balson.)

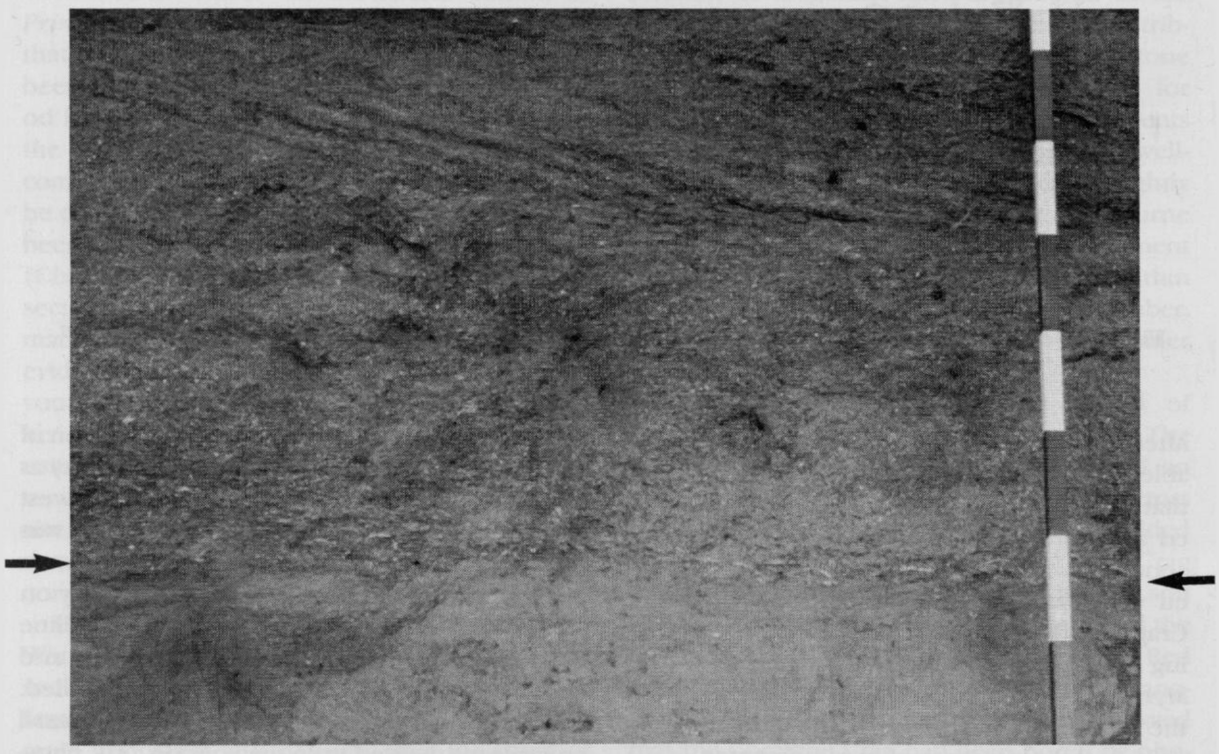


Figure 10.11 The contact between the Ramsholt Member and the overlying Sudbourne Member arrowed. Graduations on scale = 10 cm. Note the cross-bedding in the Sudbourne Member. (Photograph: P. Balson.)

Figure 10.12 Conglomerate at the base of the Red Crag overlying the London Clay in Prestwich's (1871a) 'Pit G' exposed in a temporary excavation in 1989. Graduations on scale = 10 cm. (Photograph: P. Balson.)

boulder of dark-red porphyry ... weighing about a quarter of a ton', which he believed to have been transported into the area by ice (Prestwich, 1871a).

To the west of the hill an overgrown pit (Pit G of Prestwich, 1871a) previously showed a section (Prestwich, 1871b, fig. 23) of Red Crag containing abundant boulders and fragments of lithified Coralline Crag, the largest weighing up to 'more than a ton'. This pit was apparently already obscured by 1890 (Reid, 1890). A temporary excavation into the floor of this pit in 1989 showed the basal contact of the Red Crag with the London Clay, with the basal Red Crag sediments containing abundant phosphatic pebbles (Figure 10.12). Large blocks of cemented Coralline Crag, often encrusted with barnacles, are contained within Red Crag sediments showing that cementation predated deposition of the Red Crag.

The unleached Coralline Crag sediments at this site contain large numbers of well-preserved small aragonitic molluscs (see Balson and Long, 1988) dominated by bivalves (*c.* 82% of all individuals). The most abundant are the infaunal *Spisula subtruncata triangulata*, *Timoclea ovata*, *Corbula gibba*, *Limopsis anomala coxi*, *Pteromeris corbis, Goodallia triangularis*, and the epifaunal *Padodesmus squamula*, and *Modiolus* sp. Gastropods are mainly represented by *Haustator incrassata*, *Epitonium clathratulum minutum*, *Margarites trochoideus*, *Caecum mammillatum*, *Gibbula obconica* and *Emarginula fissura* but are often less well-preserved than the bivalves. The very diverse assemblage represents a size-sorted, transported mixture from a variety of sub-littoral habitats. Bryozoan fragments are common throughout the sections and are least abraded in the lower energy facies of the Ramsholt Member. Large fragments of *Metrarabdotos monilifera* are particularly common. Carter (1951) attempted to distinguish between indigenous and transported assemblages of foraminifera, concluding that *Planorbulina mediterranensis* and *Cibicides lobatulus* were indigenous whilst most other species were transported. Common ostracods include *Aurila convexa*, *Murrayina* *lacunosa* and *Quadracythere macropora*, and this is the type site for *Schizocythere pliocenica* (Wilkinson, 1980).

The Neogene sequence at Rockhall Wood commences with a conglomeratic bed of remanié material containing vertebrates and sandstone concretions ('boxstones') which are derived from a fauna of possible earliest Pliocene age (Balson, 1990a) over which the Coralline Crag Sea transgressed. Deposition of silty carbonate sands with a rich benthic fauna followed. Strong tidal currents later became established which swept quantities of coarse skeletal material into the area. These were deposited by migrating sandwaves which produced the trough cross-stratification seen in the quarry faces. Later erosion, either prior to or during the Red Crag transgression, left a small elliptical remnant of Coralline Crag sitting unconformably on the London Clay.

The Red Crag transgression formed cliffs in the consolidated Coralline Crag which were later buried by Red Crag deposits which incorporated blocks of lithified sediment and fossils from the earlier deposit.

The silty sands of the Ramsholt Member are extensively bioturbated and lack the well-defined cross-bedding of the overlying Sudbourne Member, indicating that the sedimentation rate was relatively slow with relatively weak bottom currents. A minimum water depth of 50 m was suggested by Hodgson and Funnell (1987). Jenkins and Houghton (1987) suggest a well-developed thermocline and a temperature range of 10–18°C. They attribute the low species diversity of planktonic foraminifera as either due to poor preservation in these relatively shallow water deposits or due to a remote connection with the Atlantic Ocean around the north of Scotland. Raffi *et al.* (1985) suggest temperatures of 20°C for at least three or four months of the year during Coralline Crag deposition, based on the mollusc fauna.

The boundary between the Ramsholt Member and the Sudbourne Member of the Coralline Crag appears unconformable with occasional

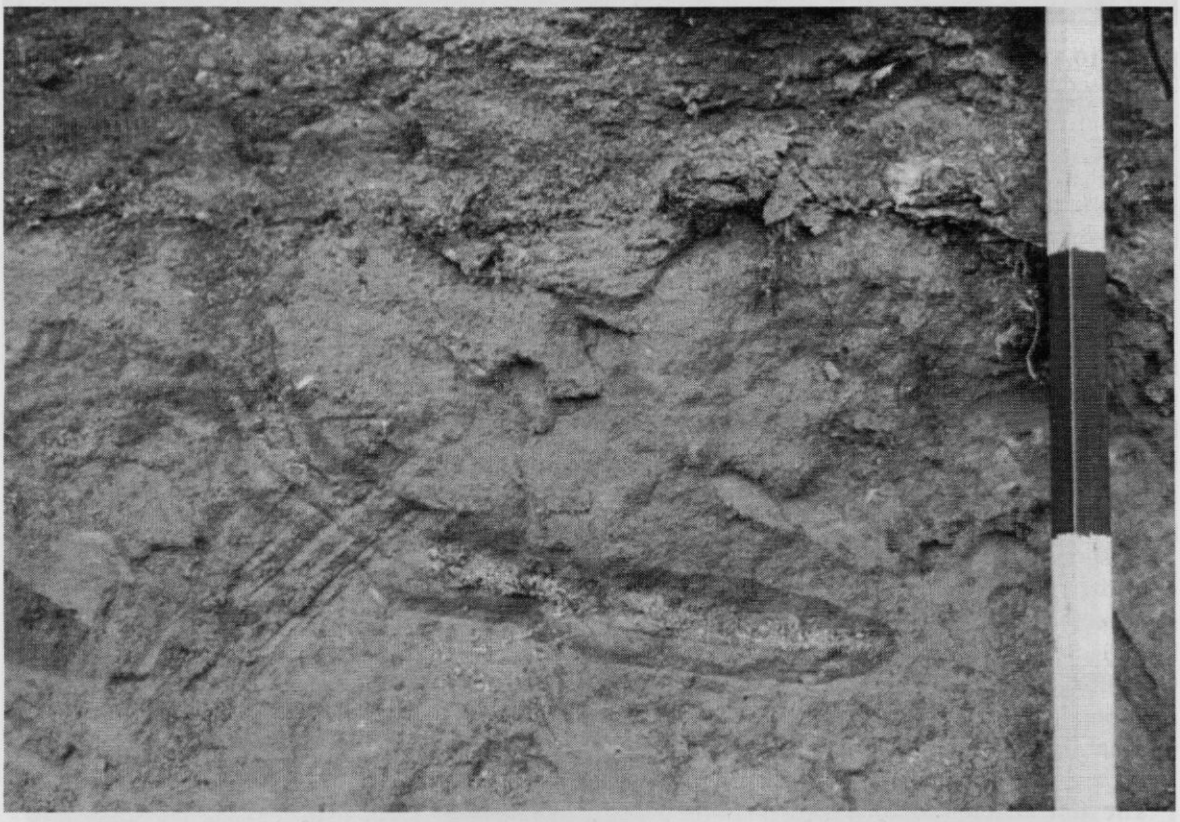


Figure 10.13 Burrow extending downwards from the unconformable contact between the Ramsholt Member and the overlying Sudbourne Member in 'bullockyard pit' (= pit D of Prestwich, 1871a). Graduations on scale = 10 cm. (Photograph: P. Balson.)

vertical burrows penetrating downwards from the plane of unconformity (Figure 10.13). The unconformity corresponds with the boundary between Prestwich's 'zones' 'e' and 'f'. The Sudbourne Member represents a change in the prevailing conditions of deposition. The trough cross-bedding shows almost unidirectional migration of small sandwaves to the west-south-west. Occasional silt drapes lie mostly between cross-bedded sets or on erosion surfaces. This is in contrast to the drapes seen at some Red Crag localities (e.g. Vale Farm, TM 317456), which occur within sequences of sandy cross-beds representing periods of reduced flow or slack water in the tidal cycle. The bryozoan fauna of the Sudbourne Member is largely abraded as a result of transport. Most bryozoan species would have been unable to live on the mobile substrates offered by the migrating sandwaves.

Interpretation and evaluation

Taken together the various exposures around the small hill at Rockhall Wood allow examination of the stratigraphy of the Coralline Crag in this outlying body. The basal contact of the Red Crag which oversteps the London Clay onto and against the Coralline Crag can also be exposed by excavation. The basal contact of the Coralline Crag is not presently exposed but has been exposed in excavations in the past. The exposed section of Coralline Crag shows sediments of the uppermost part of the Ramsholt Member unconformably overlain by sediments laterally equivalent to the Sudbourne Member of the main outcrop. The contact between the two members appears sharper and better defined than at sites on the main outcrop, as for instance at 'The Cliff', Gedgrave and Broom Hill Pit. The lower part of the Ramsholt Member is best seen at Ramsholt Cliff nearby.

This site offers one of the very rare opportunities to see Coralline Crag overlain by Red Crag (*sensu stricto*). The only other locality is at Ramsholt Cliff nearby.

Conclusions

Although the Coralline Crag outcrop here is small and unconnected with the main outcrop to the north, the exposures at Rockhall Wood provide the best opportunity to study the stratigraphy of the Coralline Crag and its stratigraphical relationships to the Red Crag.

Rockhall Wood is the most renowned of all Coralline Crag localities and is a site of national importance. It has provided a prodigious marine fauna, particularly of molluscs, to researchers over the last 150 years and has been the subject of more papers and monographs than any other site in the UK Neogene. This site is without doubt one of the most important sites for the study of the Pliocene in this country.

'THE CLIFF', GEDGRAVE, SUFFOLK (TM 39724863)

Highlights

The locality at 'The Cliff', Gedgrave, provides, in a single section, the opportunity to examine the rich shelly fauna of the Ramsholt Member and to see the cross-bedded Sudbourne Member which overlies it. This is the most southerly exposure of the main Coralline Crag outcrop.

Introduction

The exposure of Coralline Crag on the bank of the Butley River at 'The Cliff' has been known since at least 1890 when it was recorded by Reid in his synopsis of the British Pliocene deposits. It was later recorded by Harmer (1898) and is shown on his map of Coralline Crag localities as 'locality 3'. Baden-Powell (1960) drew attention to the rich fauna from this locality and observed that as a collecting site it had previously always been overshadowed by the famous 'Gomer' pit a short distance to the north which had by then been long infilled.

Description

The exposure at 'The Cliff' is at the extreme southernmost end of the main Coralline Crag outcrop which stretches northwards as far as Aldeburgh where it is cut by the River Alde. To the south of the Butley River only small isolated outliers of Coralline Crag are known to occur, as at Tattingstone, Ramsholt Cliff and Rockhall Wood, although Coralline Crag is alleged to have been present in former workings on Boyton Marshes, just across the Butley River from this locality.

The exposure at the present time shows a section of just over 3 m of Coralline Crag. The uppermost 2.4 m consist of leached bioclastic sands showing large-scale cross-bedding (Figure

Figure 10.14 Cross-bedded calcarenites of the Sudbourne Member overlying the Ramsholt Member at 'The Cliff', Gedgrave. The contact is arrowed. Scale is 1 m long. (Photograph: P. Balson.)

10.14). The largest cross-bedded set is 1.5 m thick. The upper surface of the Coralline Crag here formerly showed an undulose upper contact with solution pipes overlain by dark reddish brown sand. This sand probably represented the insoluble residue after dissolution of the Coralline Crag sediments.

This exposure of the Sudbourne Member is at the extreme southern end of the main outcrop of that member. The sediment is composed of finely comminuted and extremely abraded bioclastic debris with a high percentage (approximately 35%) of terrigenous sediment, mostly quartz. The high terrigenous content is characteristic of the Coralline Crag around Gedgrave and the abraded nature of the bioclastic material is indicative of prolonged transportation of biogenic carbonate derived from the north. Few macrofossils are identifiable in this Member except in its northern part (e.g. at Red House Farm). Most of the Member has suffered from aragonite dissolution but the lowermost part may occasionally still contain aragonitic shell material.

About 0.6 m of silty, unleached Coralline Crag can be seen underlying the Sudbourne Member at this locality. These sediments belong to the Ramsholt Member of the Coralline Crag. The boundary between the two facies here is indistinct but small silty clasts within the basal part of the Sudbourne Member are evidence of

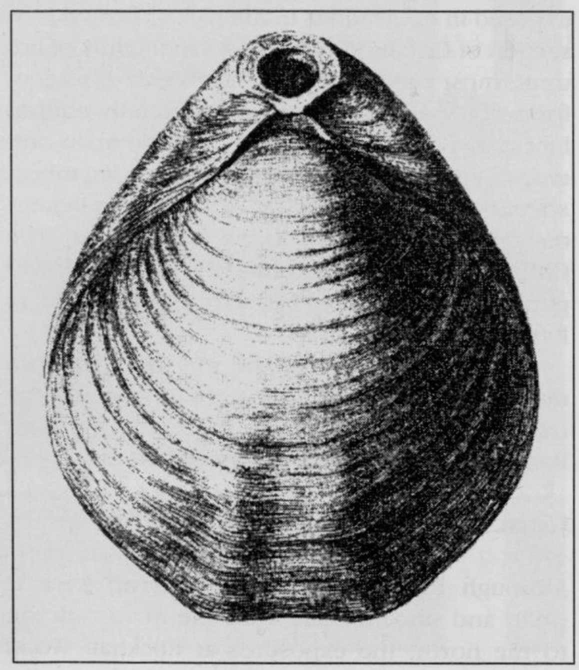


Figure 10.15 *Terebratula maxima* (illustration after Wood, 1848–82). Specimens may exceed 100 mm long.

contemporaneous erosion.

The fauna of the Ramsholt Member is very rich and well preserved at this locality. Well-preserved bivalves, occasionally with both valves articulated, are conspicuous. These include *Lucinoma borealis*, *Aequipecten opercularis*, *Nucula* sp., *Astarte* sp., *Cyclocardia scalaris* and *Arctica islandica*. *Palliolum gerardi*, which is fairly common at this locality, has been used by some authors as evidence of the equivalence between the Coralline Crag and the Belgian 'zone à *Pecten gerardi*' (Cambridge, 1977). This locality is particularly known for the occurrence of specimens, often articulated, of the large brachiopod *Terebratula maxima* (*Terebratula grandis* of early authors) which at lengths of over 100 mm is the world's largest known species of terebratulid (Figure 10.15). Calcareous nannofossils from this locality have been described by Hamilton and Hojjatzadeh (1982).

Interpretation and evaluation

The section at 'The Cliff', Gedgrave, is one of the few localities on the main Coralline Crag outcrop where the relationship between the cross-bedded Sudbourne Member and underlying Ramsholt Member can be examined. The only other locality where this contact is presently exposed is at the Broom Hill Pit approximately 1.5 km to the north. The selective dissolution of aragonitic shell material may be related to primary porosity differences between the two members (Balson, 1983). At this locality the interface between aragonite-bearing and aragonite-free sediments lies a little above the contact so that there is a rare opportunity at this locality to examine the aragonitic fauna of the Sudbourne Member of the Coralline Crag.

A few hundred metres to the north, a small exposure in the Ramsholt Member can be seen which is also very shelly but which includes some species like *Dosina casina* and *Venericardia aculeata scaldensis* which are uncommon in the exposure at the southern end of The Cliff. This indicates the way in which two Coralline Crag localities which may be in the same facies and at the same vertical elevation may differ in fauna despite being separated by only very short distances. This feature of the Crag faunas was first noted by Charlesworth in 1835 who drew comparison with the rapid lateral variations in fauna which are observable on modern sea floors.

Conclusions

The section at 'The Cliff', Gedgrave, is an important section for the study of Coralline Crag facies relationships and post-depositional diagenetic processes. It is important in conjunction with other sites to illustrate lateral differences in fauna within the Coralline Crag outcrop.

GEDGRAVE HALL, GEDGRAVE, SUFFOLK (TM 40534859)

Highlights

The pits at Gedgrave Hall are of great historical importance in that they have been interpreted as the type locality for Harmer's Gedgravian Stage and are also of great importance in work on Coralline Crag facies distributions.

Introduction

The old quarries at Gedgrave Hall have been known since at least 1871 and were described in detail by Burrows (1895a,b). Harmer (1900a), in attempts to correlate the Coralline Crag with Neogene stages on the continent, proposed a new stage, the 'Gedgravian', which was to be synonymous with the Coralline Crag in Suffolk. Harmer took the name from the parish of Gedgrave where the Coralline Crag was well exposed at the time. Later authors interpreted the pits at Gedgrave Hall to represent the type locality for Harmers' Gedgravian Stage (e.g. Boswell, 1938; Ovey and Pitcher, 1948).

Description

Two pits exist at Gedgrave Hall at the present time. The more northern pit showed a section of about 20 feet (6 m) in 1894 (Burrows, 1895a,b). A section of about 5 m of cross-stratified Coralline Crag was still visible in 1978 but since that time the pit has degraded considerably so that now only 2.3 m of Coralline Crag can be seen in an exposure about 10 m wide. The exposure shows cross-bedded sands of the Sudbourne Member with a maximum set thickness of about 1 m. The foresets dip steeply towards the south-south-west, which is comparable to the dip directions observed at other localities in this facies. The Coralline Crag sediment has been selectively leached of aragonitic material and now consists largely of highly comminuted and abraded calcitic shell material.

The second pit, a few metres to the south and slightly downslope, shows only a small exposure about 1.5 m wide of about 40 cm of unleached Crag at the present time. Poorly defined cross-bedding can be seen. Although only a small exposure presently exists, it is notable for the abundance of small species of aragonitic molluscs, particularly fragile valves of *Ensis*. A fairly rich bryozoan fauna is also present consisting mainly of *Turbicellepora* and *Metrarabdotos monilifera*. The fauna is thus in marked contrast to the northern pit which lies at about a 1 m greater elevation. Burrows (1895a,b), in a study of foraminifera from this locality had noted a difference between the two pits and assigned the sediments of the lower pit to zone 'f' of Prestwich (1871a), and the uppermost pit he assigned largely to Prestwich's zone 'g' which is equivalent to the Sudbourne Member. The contact between the two units is not exposed at the present time. The lower pit is the type locality for the foraminiferid *Alliatinella gedgravensis* (Carter, 1957).

A nearby borehole (TM 40364869) a little upslope from the northern pit penetrated 10.6 m of Coralline Crag and reached the London Clay surface at –5.6 m OD (Balson *et al.*, 1993).

Interpretation and evaluation

This is one of the most southerly exposures in the Sudbourne Member and skeletal material derived from the north has therefore suffered longer transportation and abrasion than at other localities. The lack of identifiable macrofauna is thus thought to be mainly due to the effects of prolonged transportation, although occasional abraded bryozoans and *Aequipecten* are found.

Taken together, the two pits at Gedgrave Hall provide an important section in the study of Coralline Crag stratigraphy. The northern pit shows a section in the Sudbourne Member that is near the southern limit of its main outcrop. The shelly sand is more comminuted at this locality than at localities further north and identifiable macrofauna is relatively scarce. The southern pit exposes sediments which probably lie only a little above the underlying Ramsholt Member and contain an aragonitic shell fauna which contrasts with that at The Cliff, Gedgrave, about 1 km to the west.

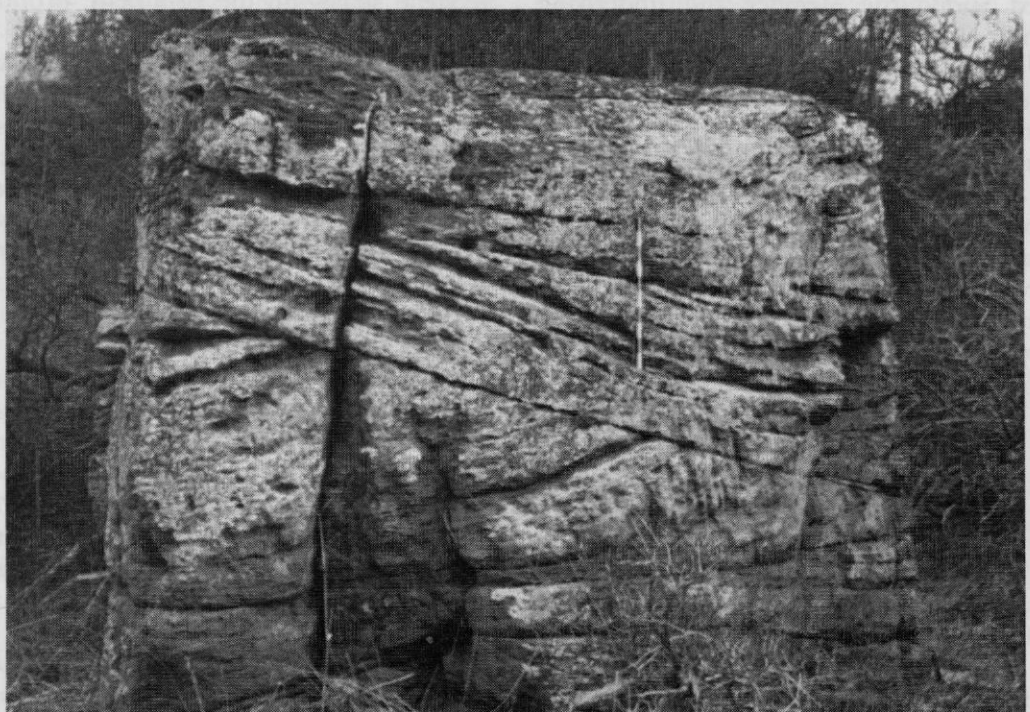


Figure 10.16 Cross-bedded calcarenites of the Sudbourne Member at Richmond Farm. Scale is 1 m long. (Photograph: P. Balson.)

Conclusions

Although Harmer did not specifically identify the pits at Gedgrave Hall as type sections of the Gedgravian Stage, this was the interpretation placed on them by later authors. The site is therefore worthy of preservation as a possible type locality for this stratigraphical interval. If re-excavated, it would provide an excellent section to examine the nature of the contact between the Sudbourne and Ramsholt Members of the Coralline Crag.

RICHMOND FARM, GEDGRAVE, SUFFOLK (TM 41224922)

Highlights

The pit at Richmond Farm shows an excellent exposure in the Sudbourne Member of the Coralline Crag Formation which exhibits well-preserved large-scale cross-bedding. Although rather poor in fossils it is an excellent locality for study of the sedimentary structures associated with marine sandwaves.

Introduction

The large quarry in the Coralline Crag at Richmond Farm was recorded by the Ordnance Survey in 1880 and was included by Reid (1890) in his synopsis of the Pliocene deposits of Great Britain. It was recorded by Harmer (1898) as 'locality 9' and was described by Boswell (1928) in the Geological Survey memoir of the area.

Description

This pit shows a section of about 6 m of the Sudbourne Member of the Coralline Crag. The faces show large-scale cross-bedding (Figure 10.16) with a set thickness of around 1.5 m. The sediments have been selectively leached of all aragonitic material. The remaining sediment has a high content of terrigenous material (approximately 30%) which is mostly quartz. The calcitic bioclastic material is comminuted and very abraded indicating prolonged transportation. Identifiable fossils are uncommon but include occasional calcitic bivalves such as *Aequipecten* and bryozoan fragments. Small vertical and sinuous burrows can be seen in places. Well-developed joints are present in some of the quarry faces.

Carter (1957) proved a total thickness of more than 13 m of Coralline Crag at this location by augering into the floor of the pit. He noted a distinct contact with more silty sediments 11 feet 8 inches (3.55 m) below the floor of the pit. This contact was interpreted as the junction between 'zones' 'e' and 'f' of Prestwich (1871a), which is equivalent to the contact between the silty sediments of the Ramsholt Member and the overlying less silty Sudbourne Member. An abundance of the foraminiferids *Alliatina excentrica* and *Alliatinella gedgravensis* was found in the uppermost part of the Ramsholt Member just below the contact, as was also seen at the section at Rockhall Wood, Sutton (Carter, 1957). This led Carter to the conclusion that this contact had stratigraphical significance.

Interpretation and evaluation

Richmond Farm lies about 2 km NE of the pits at Gedgrave Hall and at a similar elevation. These exposures of the Sudbourne Member together with other exposures at 'The Cliff', Broom Pit, Crag Farm, Valley Farm and Red House Farm allow the geometry of this facies to be reconstructed and allow comparison of lateral variations in grain size, sorting, and carbonate content which indicate sediment transport directions. The sediments at Richmond Farm are relatively fine and very abraded, indicating prolonged transport.

The foraminiferid *Alliatina excentrica* described by Carter (1957) from this locality had previously been recorded only from the late Pliocene 'Astian' stage of Italy.

Conclusions

The site at Richmond Farm is the best exposure of the cross-bedded Sudbourne Member of the Coralline Crag in the Gedgrave area and shows finer, more abraded, carbonate sediment than in localities further north. It has yielded foraminifera that can be correlated with the late Pliocene of continental Europe.

BROOM HILL, GEDGRAVE, SUFFOLK (TM 40634995)

POTENTIAL GCR SITE

Highlights

Broom Hill pit is currently one of the deepest sections of Coralline Crag, and is probably the best section in the main outcrop to show the contact between the silty Ramsholt Member and the overlying cross-bedded Sudbourne Member. In contrast to many other sites, the Sudbourne Member retains an aragonitic shelly fauna throughout much of its thickness.

Introduction

The Broom Hill Pit was a very important collecting locality for mollusc fossils in the latter half of the 19th century and over 400 species are recorded in the monographs of Wood (1848–1882) and Harmer (1914–1925).

This pit was first described in detail by Prestwich (1871a) who described it then as already 'well-known' and listed 65 species of mollusc that had been collected there in 1863. Prestwich identified 7 feet of his 'zone e' overlying 15 feet of 'zone d', a total of 22 feet (approximately 6.7 m) or a little less than the 8 m exposed at the present time. Harmer (1898) identified this pit as 'locality 11' and proved the basal contact with the London Clay to be a further 22 feet (6.7 m) below the floor of the pit at that time. By 1890, Reid had described the pit as 'perhaps the best known of any in the Coralline Crag' (Reid, 1890, p. 29). According to Boswell (1928), large collections of fossils were still being made from this site in 1908, but subsequently the site appears to have become obscured by slips and talus (e.g. Bell and Notcutt, 1925) and by 1928 less than a metre of Coralline Crag was exposed (Boswell, 1928). In the last few years it has been re-excavated to expose one of the deepest sections of Coralline Crag.

Description

The pit is presently about 9 m deep and exposes a section of Coralline Crag about 40 m wide on the west side of the pit. Solution pipes penetrate a metre or more downwards into the upper surface. The uppermost 4.7 m of the Coralline Crag has been affected by selective aragonite dissolution and is dark orange-brown in colour. The sediments below are light grey when freshly exposed and contain abundant aragonitic shell debris. Cross-bedding is clearly seen in parts of the section where the sediments are weakly lithified and the face has been weathered, and can be faintly seen on the more freshly excavated faces. Where seen, the foresets dip approximately to the south-west, in common with other exposures in this area. Faint cross-bedding is also visible in lower parts of the section which are unaffected by aragonite dissolution suggesting that most of the section can be ascribed to the Sudbourne Member of Balson *et al.* (1993). Occasional mud drapes are seen near the top of the section. The presence of small mud clasts in places indicates the erosion of mud drapes by renewed strong currents.

Near the base of the exposed section the sediments become noticeably siltier and contain abundant large and complete mollusc shells, particularly of *Venericardia aculeata scaldensis* and *Astarte* spp.

These sediments can probably be ascribed to the Ramsholt Member of Balson *et al.* (1993). It is interesting to note that Prestwich (1871a) ascribed the entire section of 22 feet (6.7 m) to his 'zones' 'd' and 'e' which are equivalent to the Ramsholt Member and made no mention of the presence of 'zone' 'g' which is equivalent to the Sudbourne Member.

Interpretation and evaluation

The Broom Hill Pit now shows one of the thickest sections of Coralline Crag. Unusually, the cross-bedded Sudbourne Member retains aragonitic skeletal material in its lower part, allowing examination of the aragonitic shelly fauna of this facies. The Sudbourne Member forms an elongate outcrop running from Iken in the north to 'The Cliff' in the south. Most exposures of this member lie along the south-east flank of this outcrop (e.g. Crag Farm, Richmond Farm) but the Broom Hill Pit lies on the north-west flank, allowing a better reconstruction of the lateral variability of sediments and fauna within this facies. The extensive fauna yielded to early collectors from this pit may be a mixture of species from the lower part of the Sudbourne Member and the upper part of the Ramsholt Member, and further work is necessary to separate the two faunas to allow an improved palaeoenvironmental interpretation.

Conclusions

The Broom Hill Pit is of great significance in the reconstruction of the geometry and lateral variation of the Sudbourne Member of the Coralline Crag. It also represents an historically important site in the study of the Coralline Crag mollusc fauna.

SUDBOURNE PARK, SUDBOURNE, SUFFOLK (TM 40705135)

Highlights

This section dates from the early part of the 19th century and was one of the sites used in the original definition of the Coralline Crag in 1835 (Charlesworth, 1835). The abundance of fossils led historically to its renown as a collecting locality and it remains important for the study of Coralline Crag faunas and environmental interpretation.

Introduction

Sudbourne Park has been known as a locality for the Coralline Crag since at least 1835 when Charlesworth described an exposure here as part of his definitive work on the subdivision of the East Anglian Crags, and it therefore represents a parastratotype section for the Coralline Crag Formation. A large exposure was mentioned by Prestwich (1849), Reid (1890), Burrows (1895a,b) and Harmer (1898). The pit remained a popular locality for subsequent studies due mostly to the rich fauna of molluscs obtainable from this locality. This locality represents a section in the Ramsholt Member of the Coralline Crag.

Description

Although Boswell (1928) was able to record an exposure of 12 feet (3.66 m) of shelly sands, the pit is now obscured by a conifer plantation and there is little exposure at present. Harmer was able to auger down to the London Clay at this locality at a depth of 31 feet (9.45 m), or 27 feet (8.23 m) below OD.

In sections shown in temporary excavations, the sediments exhibit few sedimentary structures, probably as the result of intense bioturbation which is characteristic of the Ramsholt Member. Occasionally, large solution pipes filled with dark red-brown sand and clay can be seen penetrating the Coralline Crag. This is the only Coralline Crag locality where solution pipes have been observed in sediments otherwise apparently unaffected by diagenetic solution.

The fauna at Sudbourne Park is abundant and well preserved. Large aragonitic molluscs are particularly notable, including *Venericardia aculeata scaldensis*, *Arctica islandica*, *Glycymeris glycymeris* and *Astarte* sp. This locality is also notable for the occasional occurrence of articulated specimens of the giant brachiopod *Terebratula maxima* and is the type site for *Terebratula orfordensis* (Muir-Wood, 1938). Also notable is the occasional occurrence of very large specimens of the bryozoan *Meandropora aurantium*. Encrusting epifauna on the large shells is much less common than in the coarser-grained Aldeburgh Member (e.g. at Aldeburgh Hall). This may be evidence of a more rapid rate of deposition here or may indicate that the fine sediment was deleterious to the delicate encrusting filter feeders.

Interpretation and evaluation

The importance of the site at Sudbourne Park lies mainly in the rich, well-preserved fauna of the Ramsholt Member. This locality is the furthest north that this facies can be seen and is important in helping to define its geographical extent and geometry.

Conclusions

The pit in Sudbourne Park is one of the localities which formed the basis of the original definition of the Coralline Crag as a distinct formation in 1835. It has been one of the best localities for the collection of fossils from the silty facies now referred to the Ramsholt Member and is important for the study of fauna and facies relationships within the Coralline Crag.

CRAG FARM, SUDBOURNE, SUFFOLK (TM 42805232 AND 42985235)

Highlights

The pits at Crag Farm present the largest and most spectacular exposures of the cross-bedded calcarenites in the Sudbourne Member of the Coralline Crag, for which it is also the type locality.

Introduction

The large quarry just to the west of Crag Farm has long been a popular locality for field parties

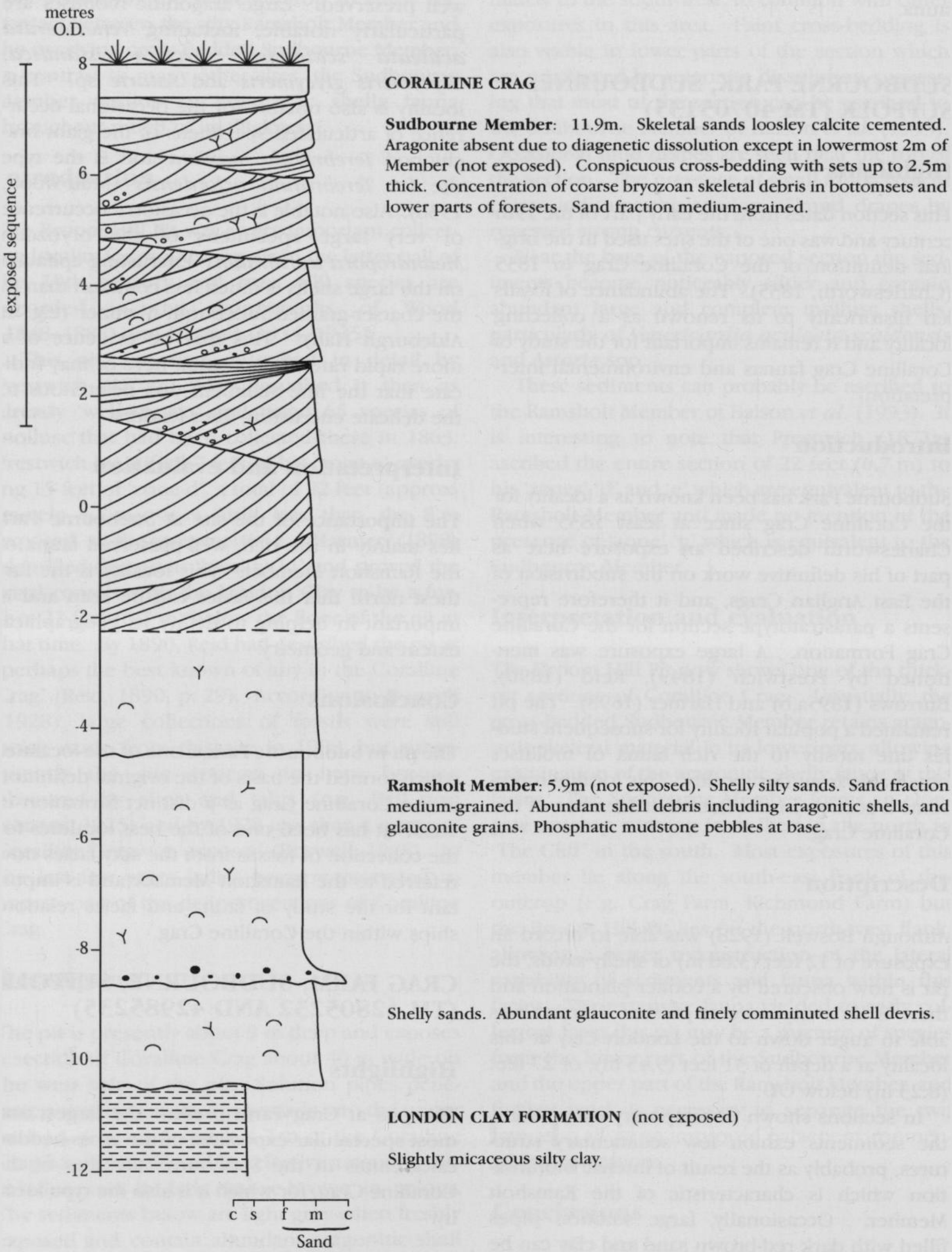


Figure 10.17 Composite log of Coralline Crag section at Crag Farm. Clay =c, silt = s, fine = f, medium = m, coarse = c. (After Balson *et al.* 1991.)

by virtue of its large size, accessibility and the spectacular cross-bedding displayed in its faces; it is one of the most frequently visited of all Coralline Crag sites. A Crag pit only slightly smaller than today was depicted on the tithe map of 1841. It was recorded by Harmer (1898) as 'locality 18'. Spencer (1971b) records that a long section in this pit was reopened in 1953. A second large quarry at Crag Farm occurs 100 m east of the above pit and shows similar geological features. This second quarry was not recorded in Harmer's survey. Recent studies at Crag Farm include Balson (1990b), Balson *et al.* (1991, 1993), Hodgson and Funnell (1987) and Taylor *et al.*, (1981).

Description

In this quarry about 5.6 m of leached Coralline Crag sediments belonging to the Sudbourne Member are very well exposed. A recent borehole at this site (Balson *et al.*, 1993) showed 6.3 m of the Sudbourne Member overlying 5.9 m of the Ramsholt Member beneath the quarry floor, with the surface of the London Clay at approximately 10.4 m below OD (Figure 10.17). The sediments of the Sudbourne Member consist of skeletal calcarenites containing less than 5% mud and are partly lithified by a calcite cement that fringes carbonate grains (Balson, 1983) to form a porous, crumbly limestone. The weathered faces show excellent cross-bedding structures with set thicknesses of between 0.5 and 2.0 m (Figures 10.18). The migration direction implied by the dip direction of the cross-bedding is unidirectional to the south-west. Pit faces at right angles to the direction of migration often show broad troughs indicating some sinuosity of the bedform crests. Reactivation surfaces in the cross-bedded units are rare. Occasional thin silty laminae are seen mostly within the bottomsets. In some cross-bedded units, poorly defined graded cycles are visible, which may be the result of tidal cyclicity (Figure 10.19). In contrast with the Red Crag, the identification of tidal rhythms in the Coralline Crag is difficult. This may be due to a less asymmetric tidal ellipse in the Coralline Crag sea or may be the result of the coarser skeletal nature of the sediments and the effects of post-depositional diagenetic changes, which have obscured fine detail in the structures.

The Coralline Crag here is fissured by an orthogonal joint set which may reflect tectonic subsidence within the southern North Sea area during the late Pliocene or early Pleistocene (Balson and Humphreys, 1986). Some of these fissures are infilled with shelly sediments of

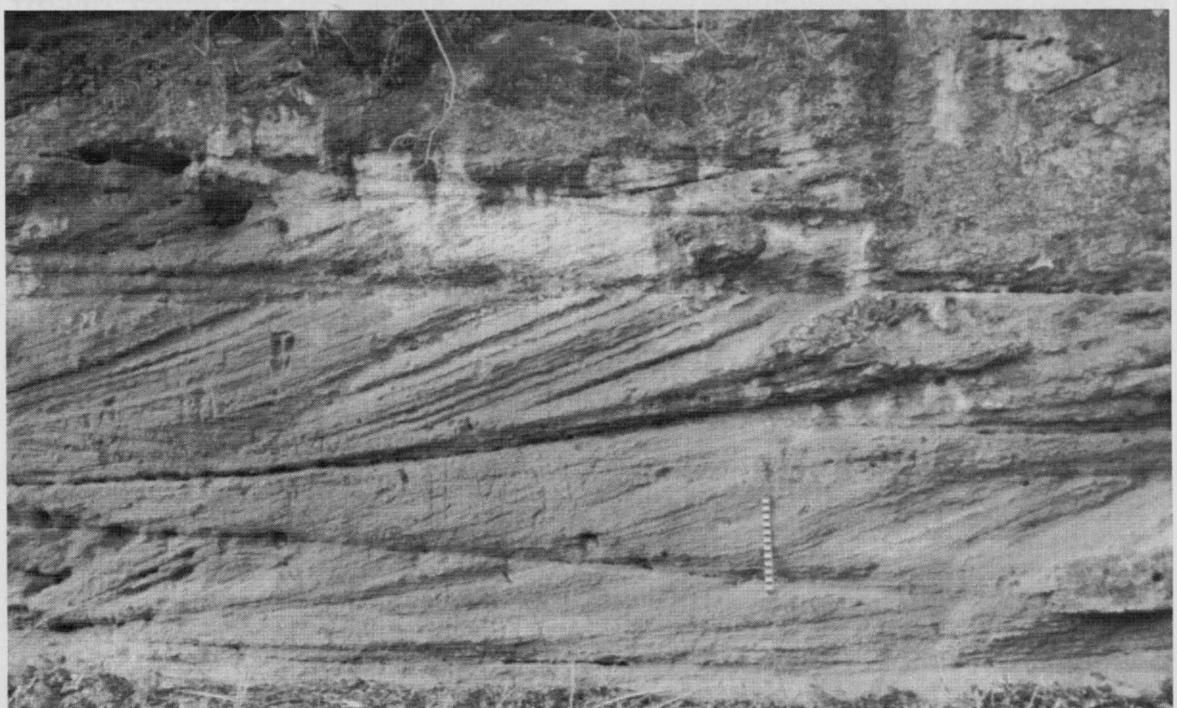


Figure 10.18 Cross-bedded calcarenites of the Sudbourne Member at Crag Farm. Scale is 0.5 m long. (Photograph: P. Balson.)

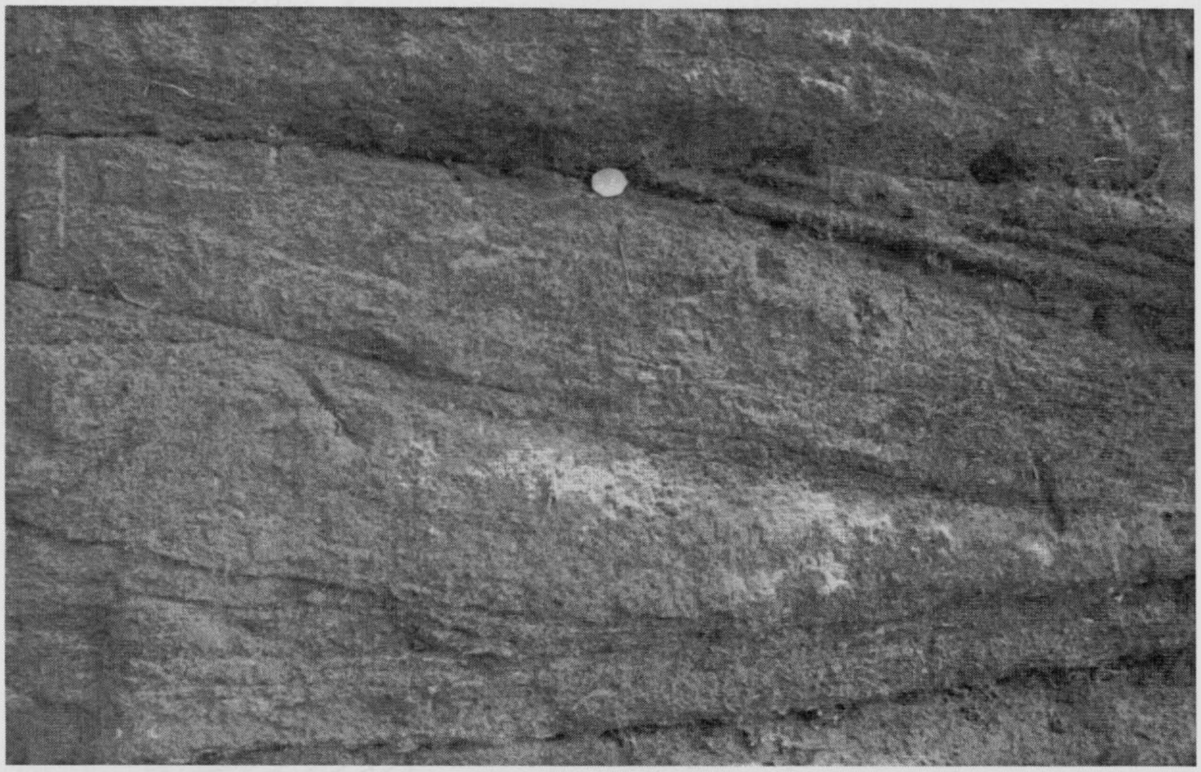


Figure 10.19 Cross-bedded calcarenites showing possible tidal rhythms, Crag Farm GCR site. Coin is 30 mm diameter. (Photograph: P. Balson.)

probable early Pleistocene age. Many of the fissures are partly infilled by white micritic calcite, which often shows rhizocretion structures. The micritic calcite is derived from solution of the upper surface of the Crag and may also be seen along bedding surfaces, particularly towards the top of the pit faces. The timing of the precipitation of the calcite is not precisely known but post-dates both the aragonite dissolution of the Coralline Crag and the infill of the fissures with Pleistocene sediment, and probably occurred during subaerial exposure of the outcrop.

The fauna of the Coralline Crag at this locality is rather sparse and consists dominantly of transported, abraded fragments of calcitic molluscs and bryozoans. The fauna can be subdivided into (a) transported skeletal fossils and (b) demonstrably in-situ fossils which are rather rare. The transported fauna includes occasional abraded fragments of the bryozoans *Meandropora* and *Blumenbachium* as well as other bryozoan debris. The inferred in-situ fauna includes large well-preserved colonies of the eschariform bryozoan '*Eschara*' *pertusa* which are often found in abundance in the foreset sediments.

The most abundant mollusc is the calcitic *Aequipecten opercularis*. Trace fossils include lined vertical burrows (*Skolithos*) and unlined, sinuous, horizontal or subhorizontal burrows (*Planolites*).

Interpretation and evaluation

The size of the exposed sections at Crag Farm, both in terms of length and height, provide the best opportunity to examine the cross-bedded Sudbourne Member of the Coralline Crag. The geometry of the bedforms which produced the cross-bedding can be established through examination of sections at right angles to each other more easily at this locality than any other. The locality is approximately midway along the elongate main outcrop of this member and the deposits show some contrasting characteristics to localities to the north, e.g. at Red House Farm, and to the south, e.g. Richmond Farm. The preservation of fragile bryozoan colonies within cross-bedded calcarenites is particularly notable at this locality.

The calcarenites were deposited by large sandwaves (height approximately 2–3 m) which migrated towards the south-west. Deposition was primarily on the avalanche slopes of the sandwaves which formed an unstable substrate for benthic organisms. However, large and often well-preserved eschariform bryozoan colonies of '*Eschara*' sp. are frequently found in foreset beds. These colonies probably became established during periods of reduced sedimentation and subsequently were broken and rapidly buried by influxes of sediment (Balson, 1981b). Fragments of eschariform and abraded celleporiform bryozoan colonies frequently are seen to have accumulated at the base of the foresets. The bryozoan fauna also includes abundant well-preserved fragments of species with flexible, articulated crisiid, catenicellid and cellariid growth forms which may also have been able to colonize the mobile sediment substrate (Balson, 1981b; Cadée, 1982).

Conclusions

The pits at Crag Farm exhibit the best exposures of the Sudbourne Member of the Coralline Crag to illustrate the nature and facies of a cross-bedded skeletal calcarenite. Many aspects of the sedimentary structures are better seen at this site than at any other.

VALLEY FARM, SUDBOURNE, SUFFOLK (TM 43585306)

Highlights

The pit at Valley Farm is an important section showing an exposure of the Sudbourne Member of the Coralline Crag. It is also important stratigraphically in showing the contact with overlying shelly sediments of probable Pleistocene age.

Introduction

A pit at this locality was marked on a tithe map of 1841 and on subsequent Ordnance Survey maps, so it is perhaps surprising that this large Coralline Crag exposure was not recorded during Harmer's comprehensive study of 1898 and does not appear to have been mentioned in any subsequent study until 1981 (Balson, 1981a). Nevertheless, the quarry at Valley Farm affords an excellent exposure in the Sudbourne Member of the Coralline Crag.

Description

The faces of the pit show a vertical section of about 5.5 m of the Sudbourne Member of the Coralline Crag. On the west face in particular, large-scale cross-bedding with a set thickness of about 1 m is present, and is characteristic of this Member. On the opposite face, a few metres to the east, trough cross-bedding is present (Figure 10.20). A typical trough is 0.50 m deep and 3.50 m long. Some 'veins' of powdery calcite are present which was probably deposited after the diagenetic phase that selectively leached aragonitic material from the sediment here.

On the west face are a pair of weathered joint planes which, in contrast to those at other localities such as Crag Farm where the joints are vertical, are obliquely sloping at dips of 30–40°.

The fauna at Valley Farm is rather sparse but transported fragments of eschariform and celleporiform bryozoan colonies are fairly common. Some moulds of aragonitic bivalves are also present.

Resting on the Coralline Crag with marked unconformity in the southern part of the pit is a section, of reddish brown shelly sands, about 30 m thick and extending laterally for approximately 5 m, which may be stratigraphically equivalent to the Pleistocene Scrobicularia Crag (Dixon, 1979; see Chapter 11). The presence of aragonitic shells in this overlying deposit indicates that the aragonite dissolution which affected the Coralline Crag occurred before deposition of the Scrobicularia Crag.

Interpretation and evaluation

The pit at Valley Farm exposes a large section in the Sudbourne Member about 1 km NE of the sections at Crag Farm and at a similar elevation relative to OD. Despite this there are significant contrasts between the two sites, particularly with respect to the cross-bed set thickness and therefore to the implied size and geometry of the bedforms which produced them. Trough cross-bedding is rather uncommon in the Coralline Crag and is the result of deposition by more active sinuous bedforms. The bedforms represented by the cross-bedding at Valley Farm would therefore appear to have been smaller and more sinuous than at Crag Farm.

Shelly Pleistocene sediments which unconformably overlie the Coralline Crag in this area are preserved only within joint fissures at Crag

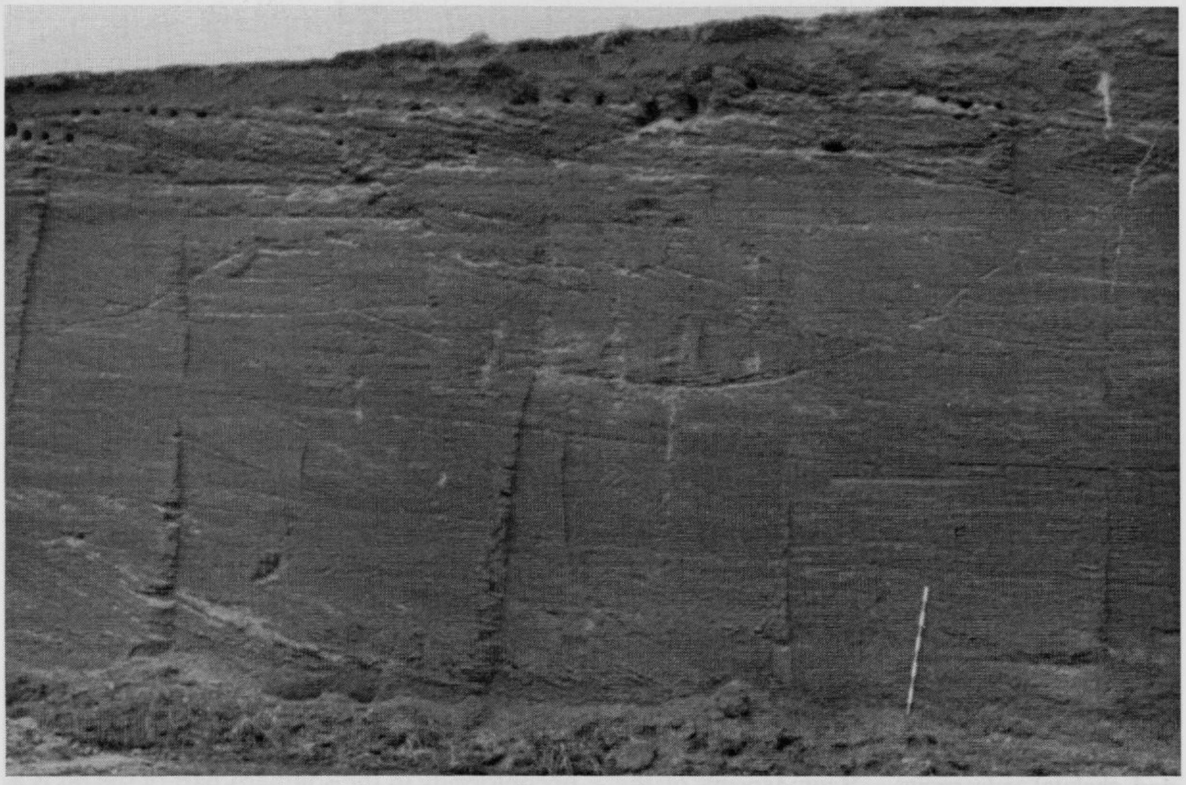


Figure 10.20 Eastern face of the quarry at Valley Farm, showing trough cross-bedding. Scale is 1 m long. (Photograph: P. Balson.)

Farm but can be seen at Valley Farm resting unconformably on leached Coralline Crag sediments.

Conclusions

Taken together with other exposures of the Sudbourne Member of the Coralline Crag, the site at Valley Farm is important to the study of the geometry and lateral sedimentary facies variations within this cross-bedded unit. Valley Farm is one of the very few localities where the contact of the Coralline Crag with overlying marine sediments is exposed. The site yields

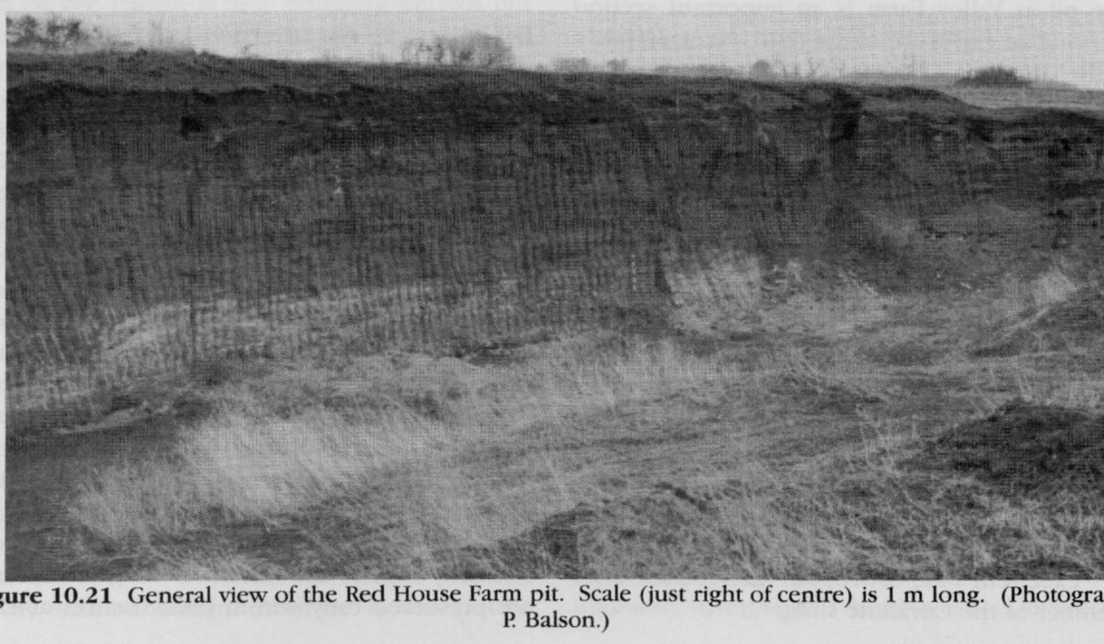


Figure 10.21 General view of the Red House Farm pit. Scale (just right of centre) is 1 m long. (Photograph: P. Balson.)

important information on the timing of aragonite dissolution in the Coralline Crag. The oblique fissures/faults are extremely unusual in the Coralline Crag and may be important to the study of post-depositional deformation of the region.

RED HOUSE FARM, IKEN, SUFFOLK (TM 43525473)

Highlights

This pit is representative of former well-known exposures in the Iken area and is important in reconstruction of facies and palaeoenvironments of the Coralline Crag.

Introduction

This pit, approximately 300 m east of Red House Farm, was recorded by the Ordnance Survey in 1881 but apparently not by Harmer's comprehensive survey of Coralline Crag localities in 1898. It was briefly mentioned by Spencer (1971b) in a survey carried out between 1953 and 1959. The pit is located within 250 m of Harmer's locality No. 25, which was described in detail and figured by Boswell (1928) but is now infilled. Since then the pit appears to have received relatively little attention until examined by Balson (1981a).

Description

The Red House Farm Pit now shows a section of about 5.5 m of the cross-bedded Sudbourne Member of the Coralline Crag in a face approximately 90 m wide (Figure 10.21). It therefore represents one of the largest and most northerly localities to expose the Sudbourne Member. The sediment has been leached of aragonitic material but is rich in calcitic skeletal material, roughly 85% of the sediment being carbonate. Near the base of the section, aragonitic shell debris can be found in places.

The fauna at Red House Farm includes fairly well-preserved specimens of the large bryozoan *Meandropora* as well as abundant fragments of other bryozoan types. *Aequipecten* is fairly common and aragonitic molluscs are represented by moulds of various species.

Interpretation and evaluation

The rich, fairly well-preserved fauna is in marked contrast to the fauna from more southerly exposures of the Sudbourne Member in the Gedgrave area, e.g. at 'The Cliff', Gedgrave, Gedgrave Hall, Broom Hill Pit and Richmond Farm. The deposits at Red House Farm are believed to represent the northern end of a linear sandbank in which sediment was being transported towards the south-west. The sediment at this locality is thus closer to the 'source' which is inferred to be to the north-east. Skeletal material is thus coarser and less abraded than at localities in the down-transport direction. Taken together with the other exposures of the Sudbourne Member, Red House Farm is important for the study of the geometry and lateral facies changes in a cross-bedded deposit interpreted as a fossil tidal sandbank.

Conclusions

The pit at Red House Farm exhibits a large exposure of the cross-bedded Sudbourne Member of the Coralline Crag which is unusually fossiliferous compared to other exposures of this Member.

ALDEBURGH HALL, ALDEBURGH, SUFFOLK (TM 45255665)

Highlights

The shallow pit at Aldeburgh Hall respresents the best locality for collecting the rich bryozoan faunas of the carbonate-rich Aldeburgh Member of the Coralline Crag, including the large cyclostomes *Meandropora* and *Blumenbachium* which are so diagnostic of the Coralline Crag and the Pliocene. The pit is of great importance in the study of Coralline Crag facies and faunas.

Introduction

The quality of the exposure in this shallow pit has varied considerably over recent years as a result of periodic working of the Coralline Crag for material for the construction of farm tracks. Currently about 2 m of section is exposed in a face about 30 m long.

A pit has existed on this site since at least 1881. Harmer (1898) recorded a pit in the vicinity of Aldeburgh Hall pit but the position was omitted from his map (locality 30). Since this time no other mention of the locality appears to have been made in the literature until the 1980s (e.g. Balson, 1981a; Taylor *et al.*, 1981; Cadée, 1982).

Description

The Coralline Crag at this locality consists of weakly cemented calcarenites of the Aldeburgh Member. Rims of calcite cement crystals on carbonate fragments probably formed penecontemporaneously with aragonite dissolution (Balson, 1983). Aragonitic fossils are absent.

Poorly-defined planar beds are present dipping at 6–7° to the SSE (Figure 10.22). Silt drapes up to a centimetre or more in thickness are occasionally seen on the dipping beds and may be exposed on the floor of the pit. Subordinate, poorly defined cross-bedding may be seen in sets up to 20 cm thick dipping to the south-west (Figure 10.23). As at Crag Farm, white micritic calcite has been deposited along some bedding planes towards the top of the section. Abundant calcitic bryozoans are a feature of the Coralline Crag at this locality.

Globose colonies of the large cyclostome bryozoans (Figure 10.24) *Meandropora aurantium*, *M. tubipora* and *Blumenbachium globosum* (syn. *Alveolaria semiovata*) up to 10 cm in diameter, appear to be more common at this locality than anywhere else in the Coralline Crag. These bryozoans lived on the sea floor or occasionally on erect stems of hydroids (Balson and Taylor, 1982). The surfaces of the colonies show relatively little abrasion or colonization by epifauna. Although *M. aurantium* and *B. globosum* are both found in Pliocene deposits on the continent, these species, including *M. tubipora* (apparently restricted to the Coralline Crag), could be said to be characteristic species of the Coralline Crag of Britain. Unfortunately all are extinct and no comparable cyclostome bryozoans exist with which to make palaeoecological comparisons. Other types of bryozoan are also very numerous at Aldeburgh Hall. These include globular colonies of *Turbicellepora*, large eschariform colonies of *'Eschara' pertusa* and *Biflustra savartii*, and most notably, colonies of *Cellaria*. *Cellaria* has a colony consisting of a series of cylindrical calcitic internodes which branch dichotomously at flexible organic nodes. The preservation of colonies in which the original configuration of the internodes is preserved, as in occasional specimens at Aldeburgh Hall, is remarkable considering the coarse bioclastic nature of the enclosing sediment. Bryozoans are also a conspicuous member of the encrusting epifauna together with occasional serpulids and barnacles, which are found encrusting calcitic bivalve shells including *Aequipecten*, *Ostrea* and *Anomia*, and occasionally colonies of the large cyclostomes, particularly *B. globosum*. Aragonitic shells, like *Scaphella lamberti*, *Arctica islandica* and *Glycymeris glycymeris*, are preserved as internal or external moulds, the surfaces of which often show the undersides of the encrusting calcitic epifauna. The presence of an abundant, well-preserved, encrusting epifauna is evidence of a relatively reduced rate of sedimentation and is characteristic of the Aldeburgh Member.

Valves of *Ostrea* often show clionid borings as further evidence of a relatively reduced sedimentation rate that allowed in-situ bioerosion.

Figure 10.22 Gently dipping beds of the Aldeburgh Member at Aldeburgh Hall. Scale is 1 m long. (Photograph: P. Balson.)

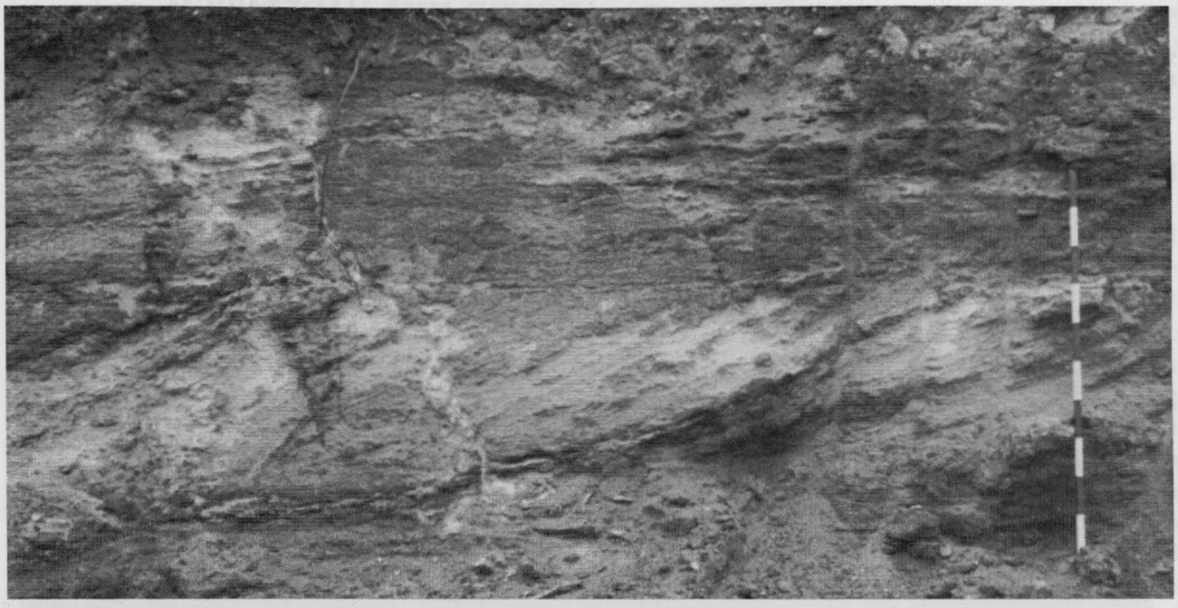


Figure 10.23 Cross-bedding within a gently dipping unit at Aldeburgh Hall. Scale is 1 m long. (Photograph: P. Balson.)

Many of the larger fossils found at this locality are well-preserved indicating that much of the fauna lived at or close to this site. *G. glycymeris* sometimes occurs as moulds of articulated specimens. The sand that formed the substrate for these organisms, however, consists of extremely abraded and comminuted skeletal debris indicating transportation from elsewhere. Many of the molluscan shells were encrusted by bryozoans or barnacles or were bored by marine organisms including *Cliona*. This evidence suggests relatively slow rates of deposition. Conversely, the large bryozoan colonies of *Meandopora* and *Blumenbachium* are generally not encrusted or bored, suggesting rapid burial.

Recently, a thin layer up to 1 cm thick was found composed almost entirely of small (10–12 mm), unribbed pectinids (?juvenile

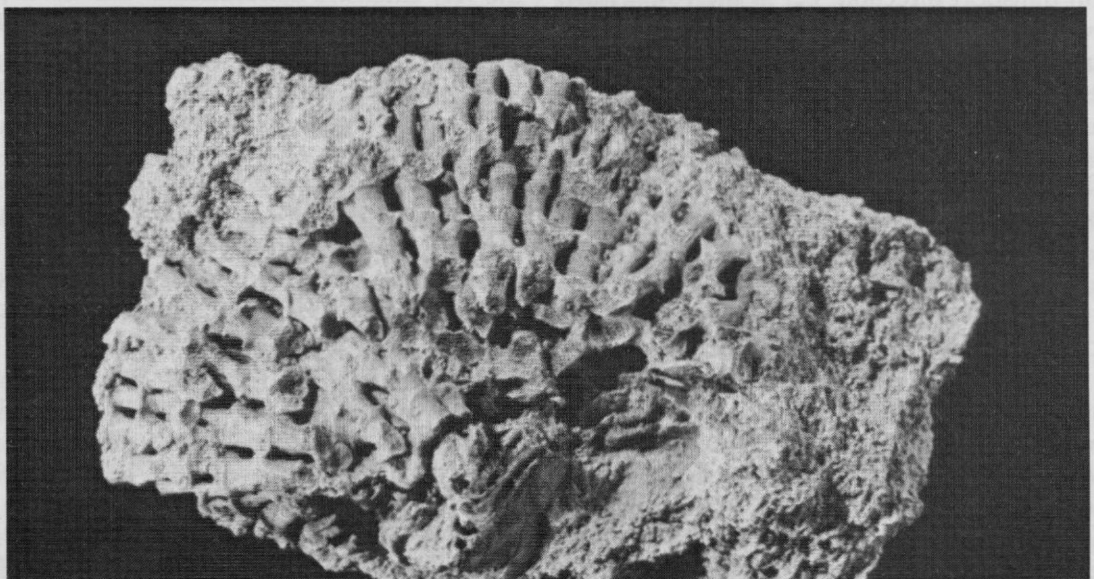


Figure 10.24 *Meandropora tubipora*. Specimen is 60 mm across. (Photograph: P. Balson.)

Palliolum gerardi) compacted together. This layer contains virtually no other sediment grains and probably existed as a thin lens of limited extent.

Interpretation and evaluation

The pit at Aldeburgh Hall provides the best opportunity to examine the fauna of the Aldeburgh Member in its type area. The abundance and quality of preservation at this locality allows reconstruction of palaeoecology and palaeoenvironments. These show interesting apparent contradictions between energy and sediment supply indicated by the presence of migrating bedforms and less vigorous conditions and reduced sediment supply indicated by the in-situ benthic and epibenthic faunas. The explanation of this apparent contradiction may be that the low-relief bedform, which deposited the low-angle dipping beds, was only periodically mobile, possibly related to storm events. These periodic movements rapidly buried the indigenous fauna with sand, allowing preservation of relatively delicate bryozoan colonies like the articulated *Cellaria*. The lack of epifauna or borings on the surfaces of the large bryozoan colonies may also be due to rapid burial. During intervening periods conditions were more tranquil with occasional small bedforms migrating across the low-angle bedform in the regional sand transport direction, i.e. to the south-west. Low-energy conditions also allowed the accumulation of the thin layer of juvenile pectinid valves possibly as a result of a mass mortality event. The superimposition of smaller, perhaps more active bedforms on a larger, lower relief one is a particular feature of this site. Round Hill, only a kilometre to the north-west, shows similar small-scale cross-bedding, and Crag Pit Nursery exhibits low-angle bedding.

Conclusions

This site is an important one, for two main features. Firstly, the fauna at Aldeburgh Hall is both diverse and well-preserved and the remarkable abundance of fist-sized bryozoan colonies, unique to the Neogene, make this one of the most important palaeontological sites in the Coralline Crag. Secondly, the sedimentary structures indicate that periods of slow deposition may have been interspersed with periods of rapid burial.

ROUND HILL, ALDEBURGH, SUFFOLK (TM 44425732)

Highlights

This pit is of great interest in providing a contrast with other exposures of the Aldeburgh Member in the Aldeburgh area. It provides a rare opportunity in the northern part of the Coralline Crag outcrop to see preserved aragonitic skeletal material.

Introduction

The small pit at Round Hill was probably excavated in the 1970s and was first visited by the author in 1977. The section exposes a small section in the Aldeburgh Member of the Coralline Crag.

Description

This small pit lies about 1 km to the north-west of the exposure at Aldeburgh Hall and is roughly at the same elevation. However, the two pits differ considerably in the features they exhibit. The pit at Round Hill shows a section of Coralline Crag of just over 2 m. Some indistinct bedding can be seen which appears to dip gently to the south. The most conspicuous feature of the leached Coralline Crag sediments here is the very extensive bioturbation. The lower part of the face in particular shows almost complete reworking by burrowers. Although nearly all the sediments here have been leached of aragonitic material, at one point at the lowest part of the pit and close to the level of the water table poorly preserved aragonitic shells can be found. In common with other exposures of the Aldeburgh Member there is only a small component of terrigenous sediment (approximately 10%), and occasional silt drapes may indicate episodic events.

A particular feature of this small pit is the undulose and piped uppermost surface which is sharply overlain by reddish-brown silty sand (Figure 10.25). This sand probably represents the insoluble residue left after solution of the carbonate grains in the Coralline Crag.

The fauna of the pit at Round Hill is rather sparse. Some small specimens of *Meandropora aurantium* have been found but they are by no means as common as at Aldeburgh Hall. Calcitic shells of *Aequipecten* are fairly common but

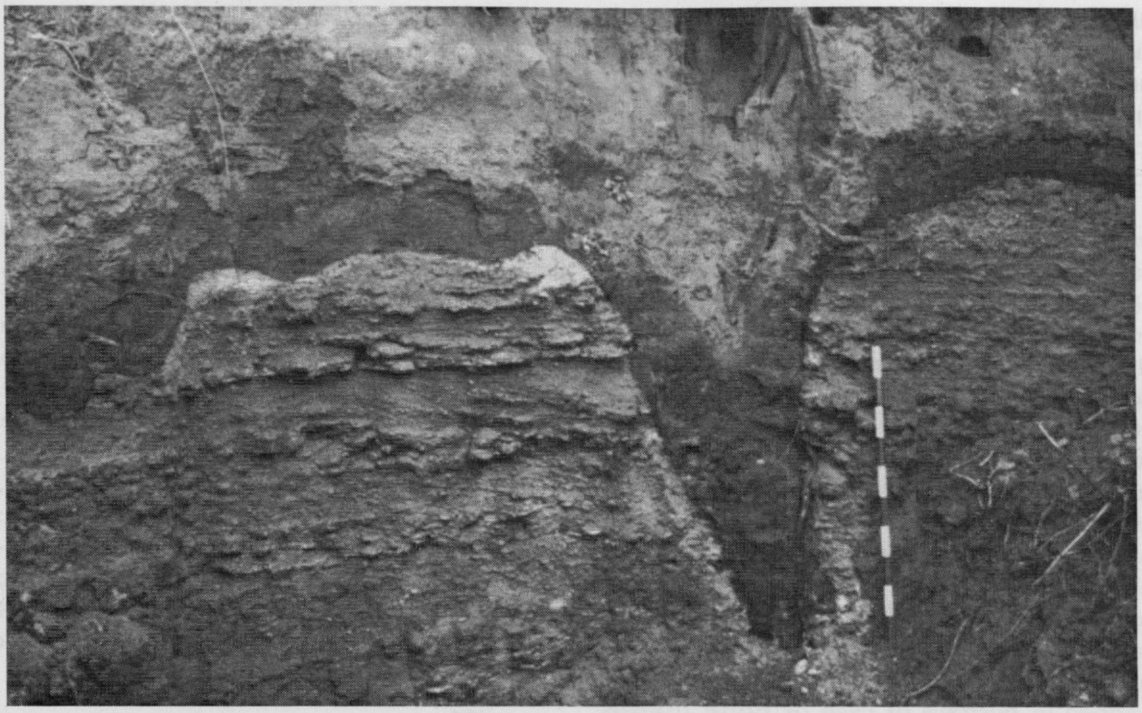


Figure 10.25 Large solution pipe within horizontally bedded calcarenites at Round Hill. Note the cross-bedding within units just to the left of the pipe. Scale is 1 m long. (Photograph: P. Balson.)

most notable of the bivalves are abundant specimens of *Mytilus* which appear to be rather rare elsewhere in the Coralline Crag.

Interpretation and evaluation

The pit at Round Hill provides information on the lateral facies variations within the Aldeburgh Member of the Coralline Crag. This section shows extensive reworking of the sediment by burrowers in a shallow marine environment, together with evidence of carbonate solution of the Coralline Crag.

Conclusions

The site at Round Hill is significant as it exhibits a rare section in the Aldeburgh Member of the Coralline Crag and together with sites at Crag Pit Nursery and Aldeburgh Hall forms a network to illustrate lateral facies variations.

CRAG PIT NURSERY, ALDEBURGH, SUFFOLK (TM 458580)

Highlights

Crag Pit Nursery is an important locality as it is the most northerly exposure of Coralline Crag available for study. It clearly shows the sedimentological and palaeontological features of the Aldeburgh Member of the Coralline Crag.

Introduction

The former Crag Pit Nursery was situated within this shallow pit which has existed since at least 1846 and may be the 'large quarry by the side of the road leading from Aldborough to Leiston' recorded by Charlesworth (1837b, p. 97). It was recorded in the Geological Survey Memoir for the area by Dalton and Whitaker (1886). The pit was also recorded by Harmer (1898) and was a popular collecting site for many years.

Description

At the present time this locality shows a vertical section of just over 2 m of Coralline Crag (Figure 10.26). Solution pipes penetrating downwards from the upper surface of the Crag were conspicuous as noted by Dalton and Whitaker (1886). The Crag shows horizontal or slightly dipping stratification typical of other localities in the Aldeburgh area.

The Crag sediment here has been leached of all aragonitic skeletal material but evidence of the aragonitic fauna is preserved as moulds of large bivalves and occasional internal moulds of the large gastropod *Scaphella lamberti*. The sediment at Crag Pit Nursery consists of over 85% carbonate.

The calcitic fauna is, in general, abundant and well-preserved. Most notable are valves of *Aequipecten* and *Pecten*, which often show a diverse and very well preserved and delicate encrusting epifauna of bryozoans and occasional serpulids on their concave surfaces. The occurrence of these and frequent clionid borings in the molluscan shells is evidence of a relatively slower rate of deposition in this offshore facies. Current winnowing of fine-grained sediment may have been important in maintaining a coarse, clean, carbonate sand which suited development of a diverse epifauna. Some fine sediment is present, however, in the form of small lenses only a few centimetres long. These scattered lenses may represent sediment trapped in burrows or even by ripple troughs. Other notable fauna include large, well-preserved colonies of the bryozoans *Meandropora* and *Blumenbachium globosum* (syn. *Alveolaria semiovata*). Whilst *Meandropora* is also found in localities in the south-western part of the outcrop, e.g. at Ramsholt Cliff, *B. globosum* is apparently only abundant in localities around Aldeburgh.

Interpretation and evaluation

This pit is the most northerly exposure of Coralline Crag on land. Offshore, the Coralline Crag is exposed on the seabed off Sizewell a few kilometres to the north-east (Lees, 1982; Balson, in press). The sediment and fauna exhibit many similarities to that at Aldeburgh Hall. The fauna is diverse and well preserved, occasionally with an abundant epifauna. By contrast the large cyclostome bryozoans, so common at Aldeburgh Hall, appear less common at this locality.

The high carbonate production and diverse, well-preserved encrusting epifauna are evidence of reduced terrigenous input and current winnowing. This locality is representative of the 'source area' for carbonate sand which was swept by tidal currents along a linear sand bank to the south-west.

Conclusions

Crag Pit Nursery is an important site in the Aldeburgh Member as part of a network of sites which illustrate the variations in fauna and facies in the Coralline Crag.

Figure 10.26 Gently dipping calcarenites of the Aldeburgh Member at Crag Pit Nursery. Scale bar is 1 m long. (Photograph: P. Balson.)