# Chapter 10 The Coralline Crag

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## 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 fossilif-erous 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 o1 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 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 characteristic 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 (Figure 10.2) and (Figure 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 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 boxstones') 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 ostracods 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.

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 a *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).

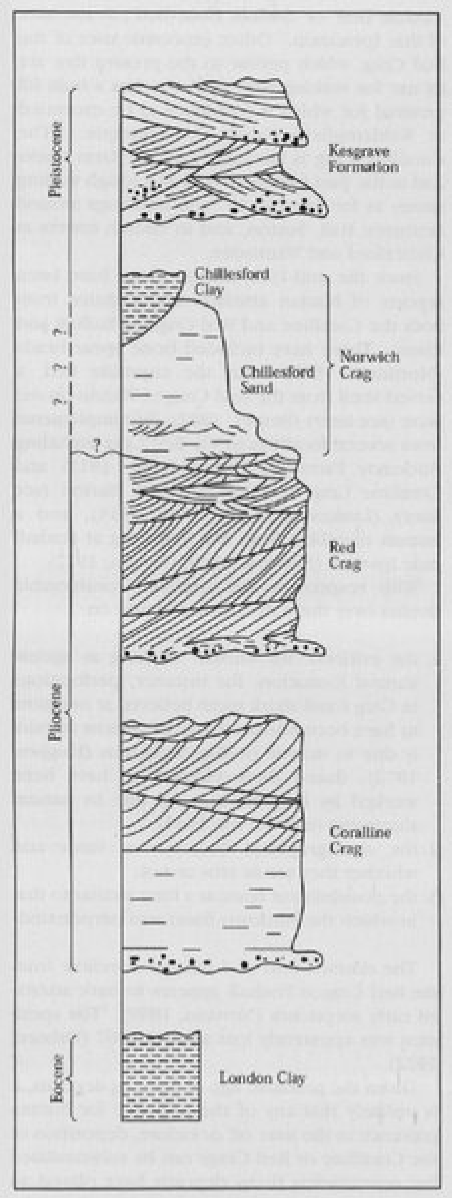
A sample from a silt drape within the overlying Sudbourne Member at Rockhall Wood has been found to contain a pollen assemblage of a slightly different aspect which indicated a possible Reuverian age (Gibbard and Peglar, 1988) (Figure 8.1). Dinoflagellate assemblages, also from Rockhall Wood, indicate 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.

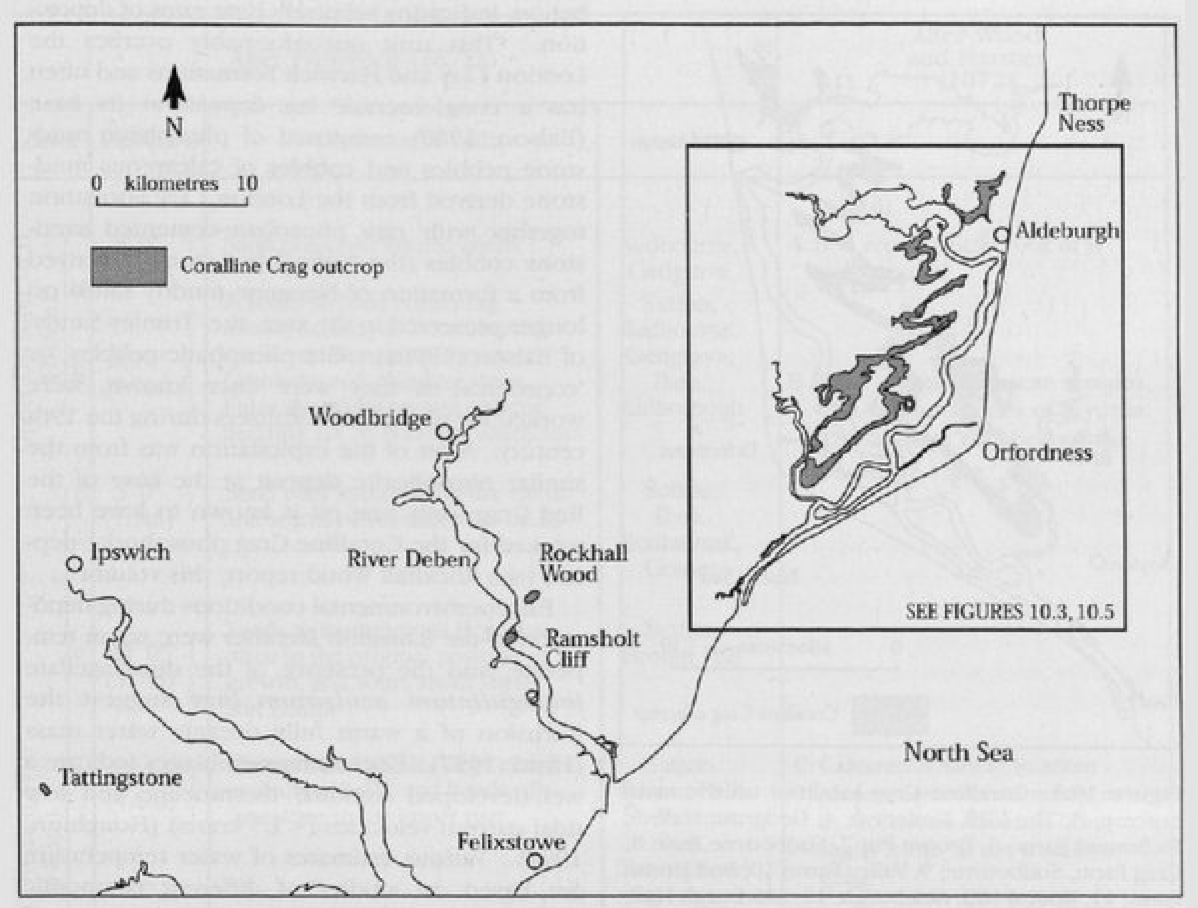
The stratigraphical relationship of the Aldeburgh Member to the other members has been determined only in boreholes and there is, as yet, little evidence from microfauna or flora on its stratigraphical position in a wider sense. On available evidence the Aldeburgh Member is younger than the Ramsholt 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 elastic 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.

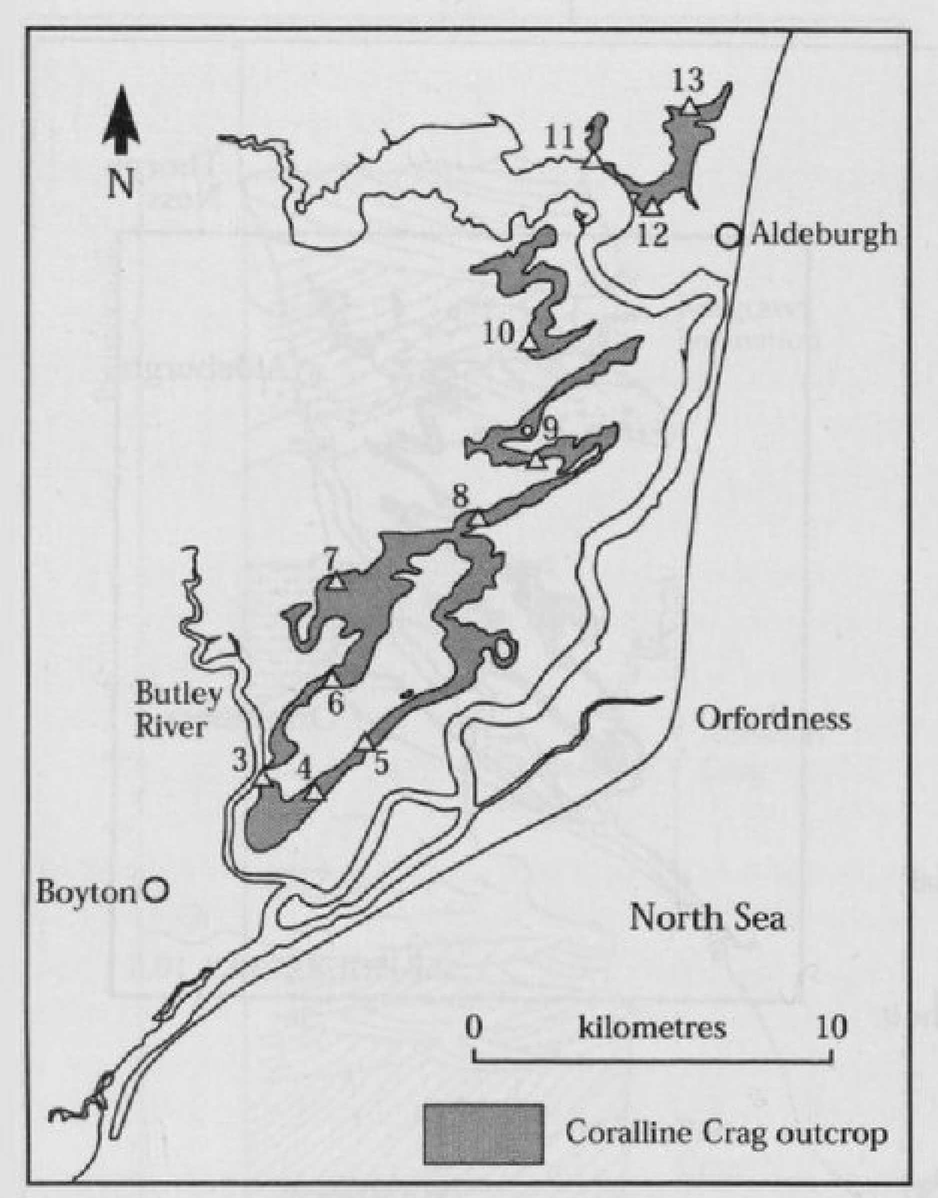
**References**




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



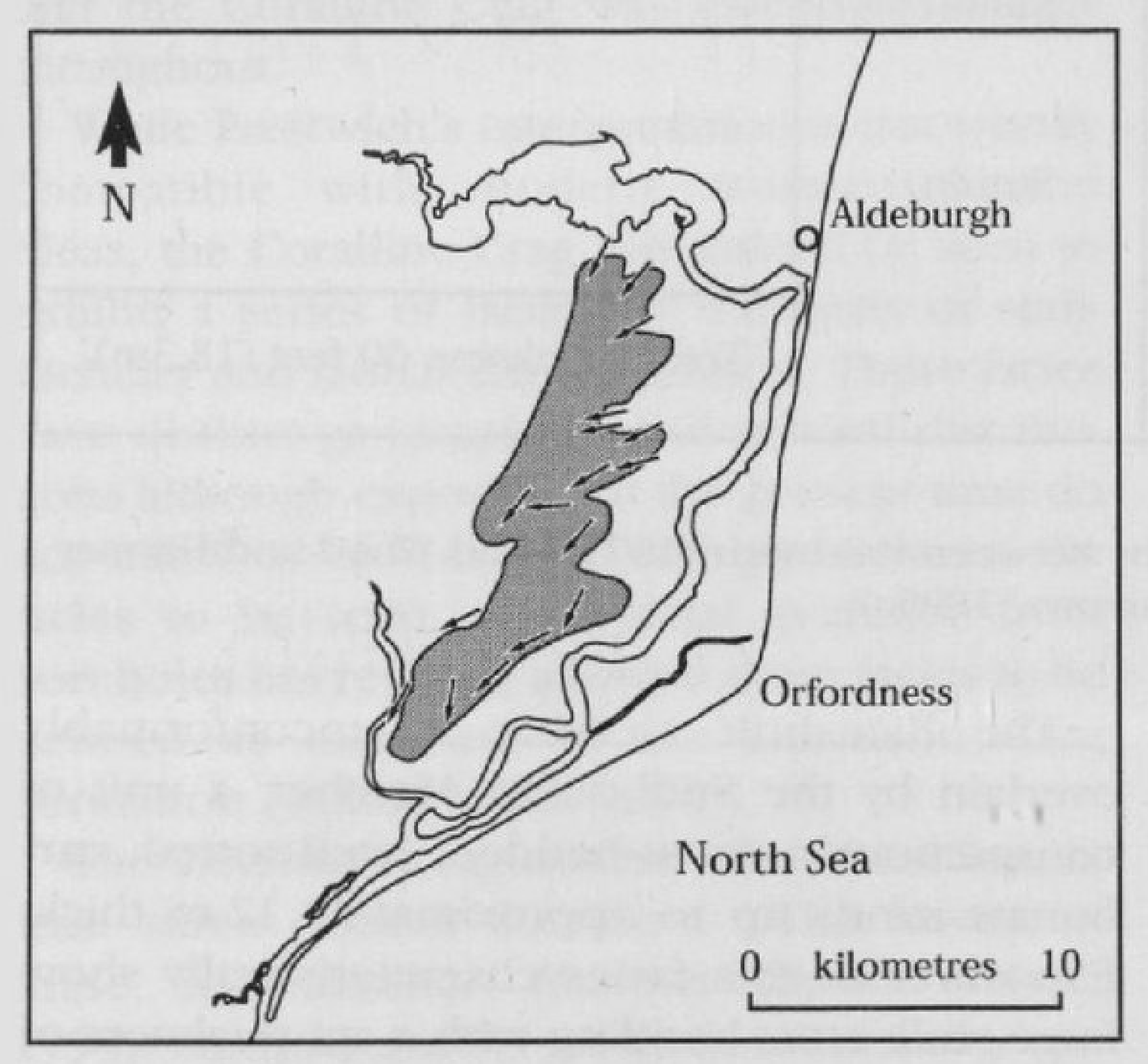

(Figure 10.2) Map showing the onshore surface outcrop of the Coralline Crag.



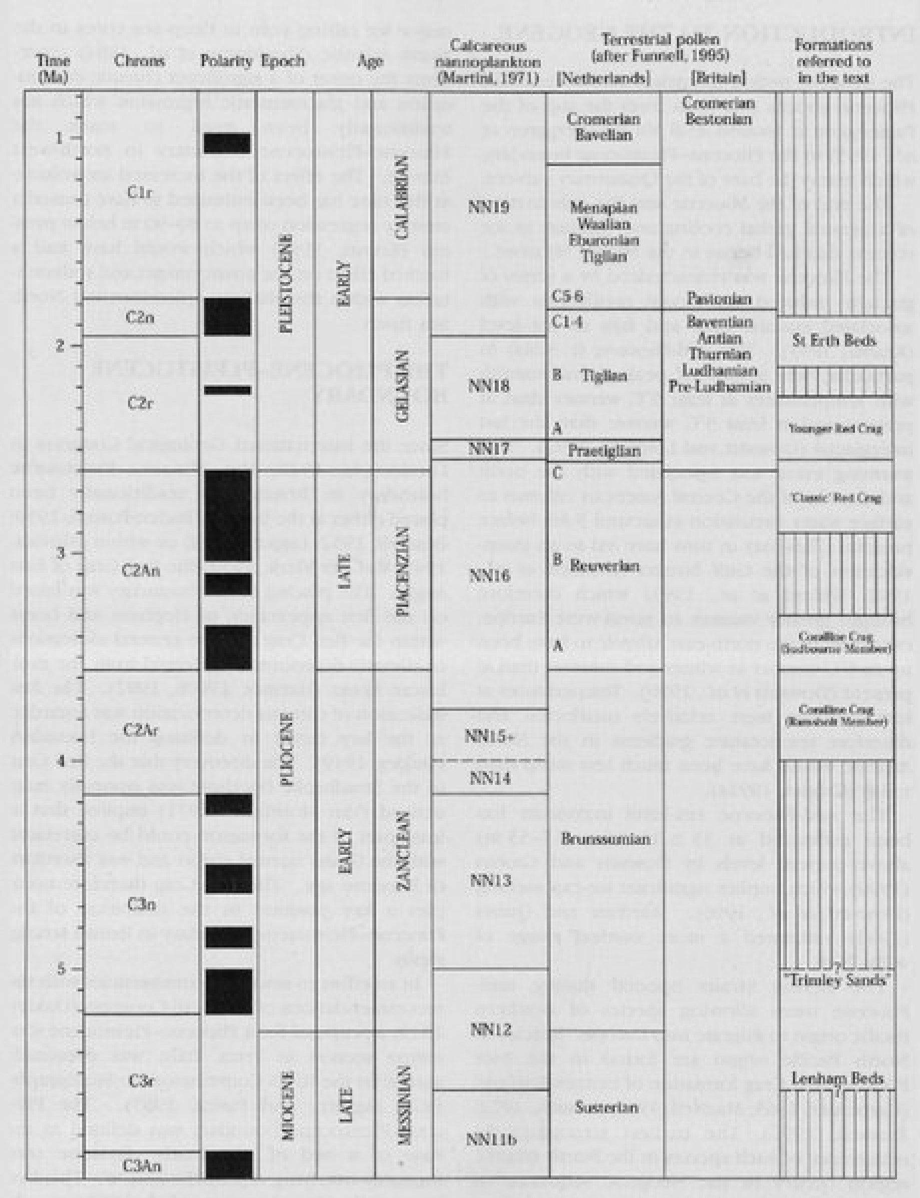

*(Figure 10.3) Coralline Crag localities on the main outcrop: 3, The Cliff, Gedgrave; 4, Gedgrave Hall; 5, Richmond Farm; 6, Broom Pit; 7, Sudbourne Park; 8, Crag Farm, Sudbourne; 9, Valley Farm; 10, Red House Farm; 11, Round Hill, Aldeburgh; 12, Aldeburgh Hall; 13, Crag Pit Nursery.*

| Division | Zone | Thickness | Character of beds | Localities | After Wood and Harmer (1872) |
|---|---|---|---|---|---|
| | | After Prestwich (1871a) | | | |
| 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).*




*(Figure 10.5) Sketch map of the outcrop of the Sudbourne Member showing sand transport directions inferred from foreset dip directions.  from a variety of unwalled vertical and sinuous burrow structures.*




*(Figure 8.1) Stratigraphical position of UK Neogene Formations. Standard Neogene Chronology after Berggren et al. (1995). For the purposes of this volume the Plio-Pleistocene boundary has been placed at the base of the Gelasian stage. The Olduvai subchron is C2n and the Gauss normal polarity chron is C2An. The Gauss/Matuyama boundary lies between C2An and C2r.*