British Tertiary Stratigraphy

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

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Chapter 11

The Red Crag

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INTRODUCTION

The Red Crag was first identified as a separate part of the 'crag-formation' by Charlesworth (1835) who named it after its characteristic reddish-brown coloration caused by iron oxides in surface exposures. For a fuller discussion see the section 'The Crags of East Anglia' in the previous chapter. At depth in boreholes and below the water table the sediments are grey in colour. Although later workers attempted to change the name (e.g. 'Middle Crag': Jones and Parker, 1864; or 'Upper Crag': Woodward, 1891), the term 'Red Crag' has remained in use to the present day.

The 'classic' Red Crag of early workers (e.g. Harmer, 1900b) is restricted to south-east Suffolk and north-east Essex (Figure 11.1). In this area the formation is up to 20 m thick and is separated from the Coralline Crag by a marked unconformity. The Red Crag unconformably overlies the London Clay Formation over most of its outcrop but oversteps Palaeocene Formations on to the Late Cretaceous Chalk to the west (e.g. Hascot Hill, Battisford). Locally it may overlie the Coralline Crag with marked unconformity as, for instance, at Ramsholt Cliff and Rockhall Wood, Sutton. At the base of the Red Crag is a discontinuous basal conglomeratic lag up to 30 cm thick. This varies from a deposit dominantly composed of pebbles of phosphatic mudstone to a deposit dominated by flint pebbles and cobbles. These phosphate-rich deposits were discovered in the mid-19th century and were the first rock phosphate deposits in the world to be commercially exploited for the manufacture of fertilizers. Production peaked around 1850–1880 but the discovery of more extensive deposits in the Cretaceous Cambridge Greensand in 1854 caused the demise of the Suffolk phosphate industry, and with it the closure of many pits in the Red Crag (Reid, 1890). The commercial exploitation resulted in extensive collections of fossils from these deposits that include a large vertebrate fauna including many species of marine and terrestrial mammal. Most of the major collections to be found in museum collections were assembled during this period. Phosphatic pebbles are also found at some places within the Red Crag, either scattered or in discontinuous layers. The basal lag deposit is occasionally exposed in the cliff sections at Bawdsey and Walton-on-the-Naze and has been proven in excavations around Rockhall Wood, Sutton.

This basal lag deposit has been known by many names including Suffolk Bone-Bed (Lankester, 1868), Nodule Bed (Reid, 1890), Coprolite Bed (Lankester, 1868), Basement-bed (Prestwich, 1871a,b), Boxstone Bed (Boswell, 1915) and sub-Crag Detritus Bed (Bell, 1915). The material that constitutes this deposit originates from many sources. The phosphatic mudstone pebbles, which form the dominant component in most places, originate from the London Clay Formation. Pebbles containing phosphatized crabs and lobsters and many of the phosphatized shark and ray teeth are similarly derived from the London Clay. Cobbles of a phosphate-cemented sandstone known locally as 'boxstones' or 'Suffolk boxstones', which often contain moulds of marine molluscs (e.g. Figure 8.4), are derived from a Neogene formation of muddy sands which formerly existed in the area. This former deposit was informally named the 'Trimley Sands' by Balson (1990a). A rich vertebrate fauna including terrestrial mammals like *Mastodon* and marine mammals including walrus and cetaceans may be partly contemporaneous with the 'Trimley Sands' but other members of the vertebrate fauna, e.g. the giant shark *Carcharocles megalodon* (Figure 8.3), are clearly older. Other components of the deposit include an assortment of exotic rock types including Jurassic limestone, Cretaceous Chalk flints and Mesozoic fossils including belemnites (Bell, 1915).

Since the work of Harmer (1900b) and others in the early 20th century it has become obvious that deposits of equivalent age to the Red Crag are found over a much wider area than that shown in Figure 11.1. To the west, the Red Crag has been traced as a near-continuous sheet of coarse-grained, locally shelly sediment extending to just beyond Bishop's Stortford (Mathers and Zalasiewicz, 1988). Beyond this, small isolated outcrops have been described from Rothamsted (Dines and Chatwin, 1930; Moffat and Catt, 1986) and, possibly, even further to the west (Moffat and Catt, 1986). This sheet ascends steadily inland at *c.* 1 m/km until at Bishop's Stortford the base is at +90 m OD, and at Rothamsted at +131 m OD. This rise is probably due to crustal warping (Van Voorthuysen, 1954; West, 1972; Moffat and Catt, 1986; Mathers and Zalasiewicz, 1988) which was also responsible for the elevation of the Lenham

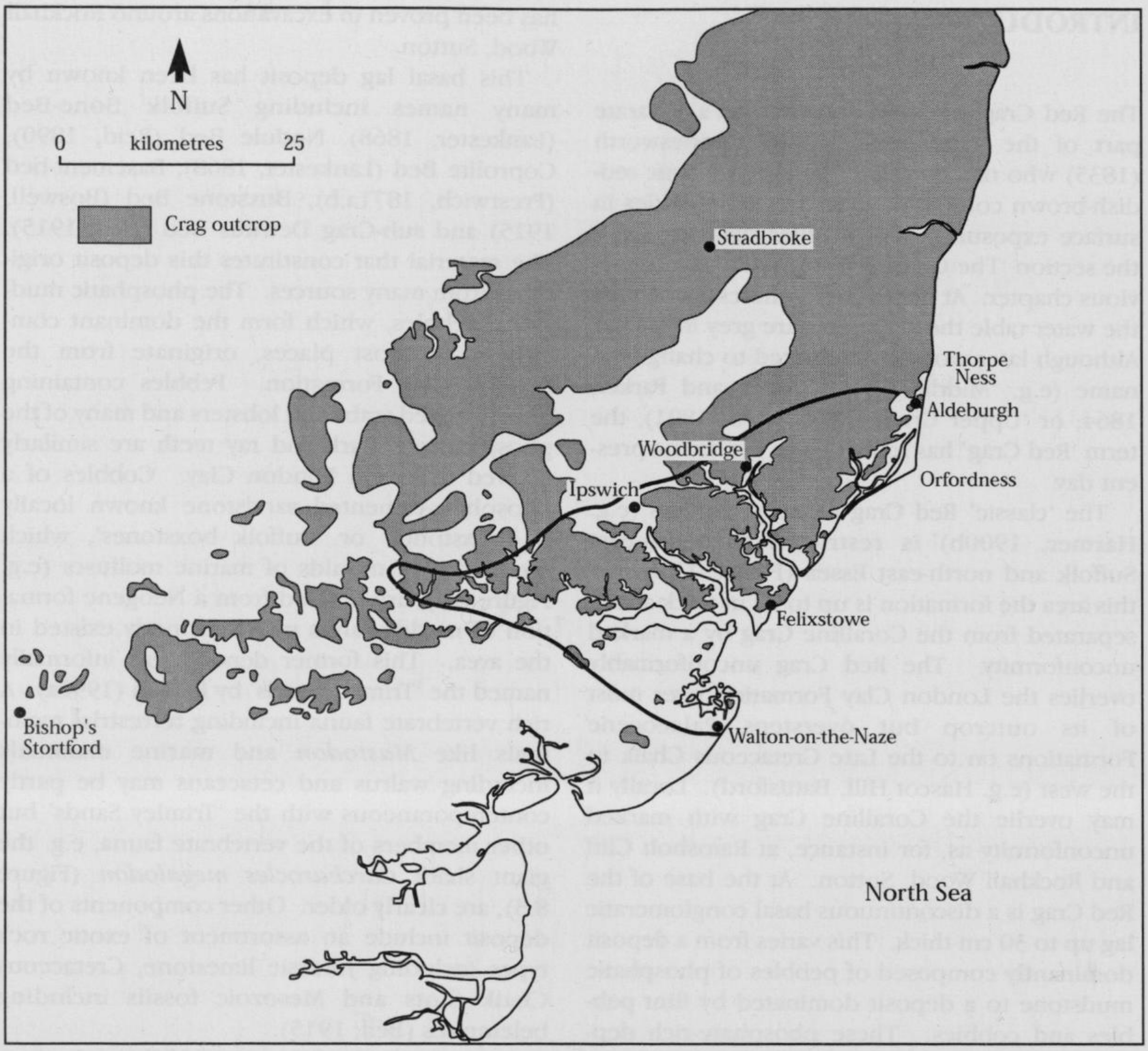


Figure 11.1 Map of the Crag outcrop in southern East Anglia. The Crag limit is after British Geological Survey (1985, 1989). The bold line indicates the limit of the 'Red Crag' after Harmer (1900b). The locations of the GCR sites are shown on Figure 11.2.

Beds described in Chapter 9.

To the north, sediments equivalent in age to the Red Crag were found in a borehole at Stradbroke (Figure 11.1). These sediments are finer-grained than the Red Crag further south and are believed to represent a more offshore facies. North of Aldeburgh the Red Crag succession has been divided into two members: a lower member of shelly coarse sands with interbedded clays (the Sizewell Member) overlain by cycles of shelly fine to medium sands (the Thorpeness Member). To the east, in the offshore southern North Sea, sediments of Red Crag age have an extensive outcrop (Cameron *et al*., 1984; Balson, 1989).

This report mainly concerns sites within the area of 'classic' Red Crag as defined by Harmer (1900b) but also includes the site at Hascot Hill, Battisford which was unknown at the time of Harmer's review (see Figure 11.2).

The relationship of the Red Crag to the succeeding Norwich Crag is difficult to assess. Zalasiewicz and Mathers (1985) found little evidence of a hiatus between the Red Crag and the Chillesford Sand Member of the Norwich Crag Formation. The stratigraphical arrangement of these deposits is shown in Figure 10.1.

The Red Crag is renowned for its mollusc fauna which numbers several hundred species. However, many of the mollusc species and other taxa within the Red Crag deposits may have been derived from reworking of the earlier Coralline

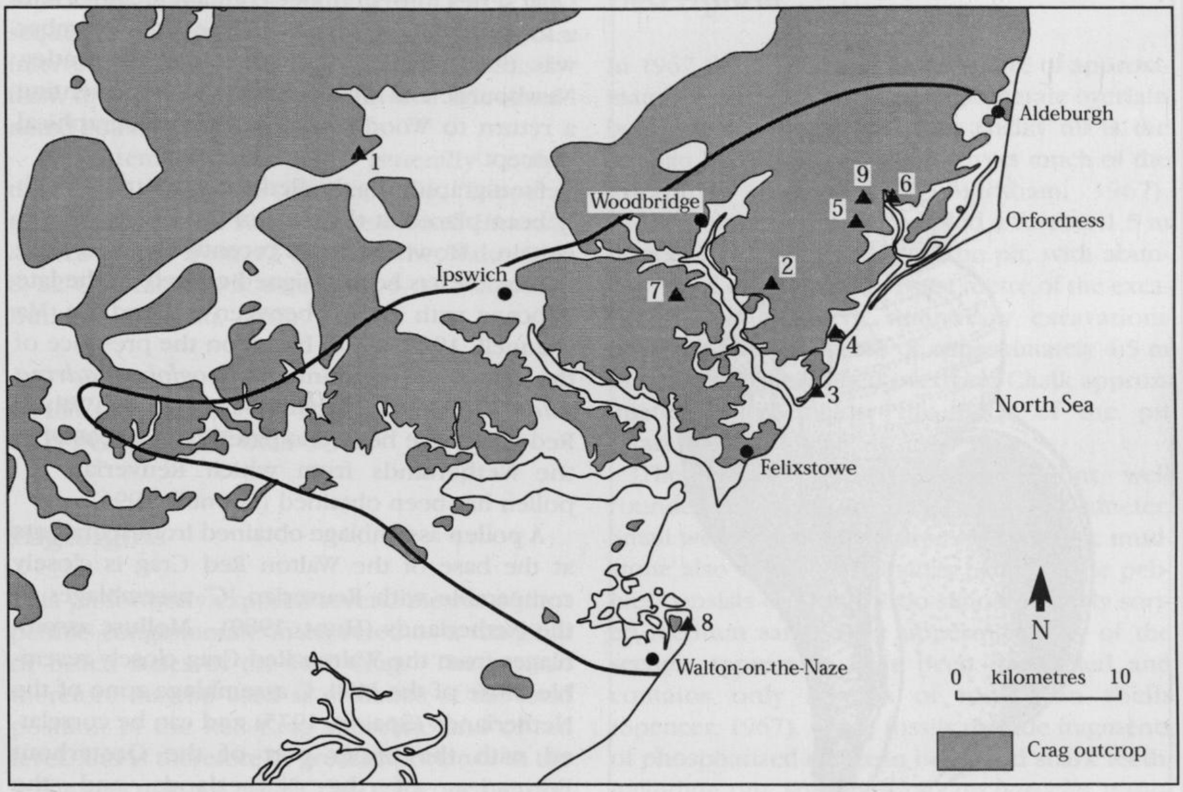


Figure 11.2 Location of Red Crag exposures described in this volume. 1, Hascot Hill, Battisford; 2, Vale Farm, Sutton; 3, Bawdsey Cliff; 4, Buckanay Farm, Alderton; 5, Broom Covert, Butley; 6, Orford Lodge, Chillesford; 7, Waldringfield Heath; 8, Walton-on-the-Naze; 9, Neutral Farm, Butley.

Crag deposits. Wood (1859) believed that up to 50 of the 240 mollusc species by then described could have been derived in this way. This list of derived species was later increased to 118 species (Wood, 1848–1882). A contrary view was expressed by Harmer (1900b) who did not believe that there was any significant derived component in the Red Crag fauna. Many shells that are abundant and well-preserved in the Coralline Crag occur only as abraded and worn specimens in the Red Crag; for instance, *Venericardia aculeata scaldensis* (Figure 10.7) and many bryozoan species. Small fragments of lithified Coralline Crag sediment occur commonly in the Red Crag indicating extensive reworking of the earlier deposit. Such fragments have even been found in the Red Crag of Walton-on-the-Naze (Prestwich, 1871b) which even Wood (1859) had believed contained no derivative shells. It is likely therefore that a proportion of the Red Crag fauna has been derived from reworking of the Coralline Crag. The controversy over the extent of this contribution was significant in the early debate over the age of the formation determined by the percentage test of Charles Lyell (Wood, 1859) and is an important factor to consider when using the fauna for palaeoenvironmental reconstructions or for stratigraphical comparison with formations of similar age elsewhere.

Although the subdivision of the Red Crag on the basis of mollusc faunas is usually attributed to Harmer (1900a), it was Wood who, in 1866, first divided the Red Crag on this basis. His divisions, which comprised the Walton Crag, Sutton Crag, Butley Crag and Scrobicularia Crag, were defined on geographical areas and an observed general increase in 'northern' or cooler water forms as the Red Crag was traced northwards (Wood,1866). Thus the Walton Crag in the south contained the warmest water fauna and the Scrobicularia Crag contained the most boreal. The sinistral gastropod *Neptunea contraria* (Figure 11.3) is an immigrant from the Pacific (Strauch, 1972) and first appears in the British Neogene in the Red Crag of Walton-on-the-Naze. The replacement of this species by dextral species of the genus as the Red Crag is traced

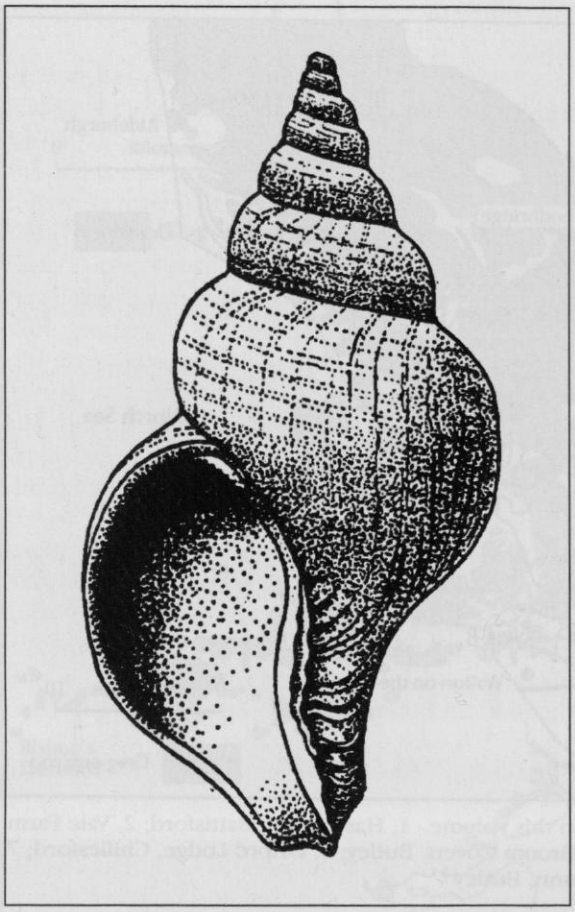


Figure 11.3 *Neptunea contraria*. The shell is 120 mm long. (Illustration after British Caenozoic Fossils, Plate 40:7 BM(NH), reproduced courtesy of The Natural History Museum, London.)

northwards was thought to reflect a progressive cooling with time.

Harmer (1900a) formalized Wood's divisions into three 'stages'. The southernmost Red Crag of Walton-on-the-Naze in Essex and nearby areas, the 'Walton Crag' of Wood (1866), was assigned to the 'Waltonian stage' which was believed to represent the oldest Red Crag sediments with the warmest water fauna, containing many species which are rare or absent elsewhere. It also contains the benthic foraminifer *Pararotalia serrata*, indicating warm temperate conditions. Further north, sediments belonging to Wood's 'Sutton Crag' became the 'Newbournian', and the 'Butley Crag' became the 'Butleyan' stage. These latter deposits were probably deposited under cool temperate conditions (Funnell and West, 1977).

In an attempt to erect a formal lithostratigraphy, Funnell and West (1977) divided the Red Crag series into an upper Ludham Member and a lower Red Crag Member. The latter member was then further subdivided into the Butley, Newbourne and Walton Crags thus representing a return to Wood's original lithostratigraphical concept.

Stratigraphically the Red Crag has traditionally been placed at the base of the Pleistocene in Britain. However, more recently the Red Crag Formation has been assigned entirely to the late Pliocene with an age between 3.2 and 2.4 Ma (Funnell, 1987, 1988) based on the presence of the planktonic foraminiferid *Neogloboquadrina atlantica*. Benthic foraminifera from the Walton Red Crag have been compared with deposits in the Netherlands from which Reuverian 'C' pollen has been obtained (Funnell, 1996).

A pollen assemblage obtained from sediments at the base of the Walton Red Crag is closely comparable with Reuverian 'C' assemblages in the Netherlands (Hunt, 1989). Mollusc assemblages from the Walton Red Crag closely resemble those of the MOL C assemblage zone of the Netherlands (Spaink, 1975) and can be correlated with the upper part of the Oosterhout Formation of the Netherlands and the Kruisschans Member of the Lillo Formation in Belgium (Funnell, 1996). Mollusc assemblages from the Butley Crag resemble those of the MOL B zone of the Netherlands.

The Red Crag of south-east Suffolk and north-east Essex was deposited near the mouth of a funnel-shaped embayment of the North Sea, which extended west-south-westwards through southern East Anglia towards the southern Midlands. The palaeogeography was probably similar to that during deposition of the Coralline Crag (Figure 8.2).

The Red Crag represents high-energy, tide-dominated shallow marine conditions, the sedimentology of which was most recently described by Dixon (1979) and Balson *et al.* (1991). An overall regional stratigraphical pattern seems to be present, with the lower part of the deposit being dominated by large-scale, high-angle, approximately planar tabular cross-sets (e.g. at Walton-on-the-Naze, Bawdsey, and the lowermost part of the sequence at Vale Farm, Broom Covert and Orford Lodge); a middle part with complex trough-cross-bedding, low-angle bedding and common mud-drapes (e.g. at Vale Farm, Broom Covert and Orford Lodge); and an upper, more heterogeneous part dominated by horizontal or near-horizontal bedding (e.g. at

Vale Farm, Broom Covert) (Figure 11.2). This sequence results from overall shallowing, as inferred by Dixon (1979), and more precisely from the increasing constriction of a tide-dominated embayment.

Palaeotemperatures were generally cooler than those during the Coralline Crag. Temperatures implied by a study of the bivalve *Hiatella arctica* range from 12–24°C in the Waltonian, 8–22°C in the Newbournian, to 5–17.5°C in the Butleyan (Strauch, 1968).

HASCOT HILL PIT, BATTISFORD, SUFFOLK (TM 061 538)

Highlights

This pit formerly exposed several metres of flint pebble conglomerate interpreted as a marginal or beach facies of the Red Crag. The section therefore may be used as evidence of the local position of the Red Crag shoreline and of sea level, and is therefore of great importance to the reconstruction of Red Crag palaeogeography. The Red Crag lies directly on the Chalk at this location.

Introduction

This site is a small overgrown pit in the side of a valley which cuts through Anglian Lowestoft Till to expose the underlying Crag deposits. The pit exhibits no permanent exposure at the present time. The pit was recorded by the Ordnance Survey in 1884 but the geological interest appears to have gone undescribed until relatively recently (Cambridge, 1949). In 1971 the pit became a geological reserve of the Suffolk Trust for Nature Conservation. A second pit just to the south of the road was worked during the 1970s and showed excellent exposures of both the pebble bed and almost 2 m of overlying sands. The sands are unfossiliferous and their age is unknown but they were believed to be of shallow marine origin (Dixon, 1978) and may be more or less contemporaneous with the pebble bed. This second pit was infilled and landscaped during the 1980s. Hascot Hill pit lies to the west of a Chalk ridge which separates the so-called Stradbroke Trough from the outcrop of 'classic' Red Crag to the east.

Description

In 1967 the pit showed an exposure of approximately 2 m of flint pebble conglomerate overlain by sand and chalky till. This chalky till is the Anglian Lowestoft Till which covers much of the interfluves of the area (Markham, 1967). Excavation at that time revealed a further 1.5 m of gravel below the floor of the pit, with abundant shell debris in the lowest metre of the excavation. Subsequent temporary excavations proved a total thickness of approximately 4.5 m of Red Crag pebble bed overlying Chalk approximately 2.5 m below the floor of the pit (Markham, 1976).

The pebbles are dominantly of flint, well rounded and between 10 and 100 mm diameter. Small well-rounded pebbles of phosphatic mudstone also occur. The matrix between the pebbles consists of heavily iron-stained, poorly sorted medium sand. The uppermost part of the section appears to have been decalcified and contains only moulds of molluscan shells (Spencer, 1967). Other fossils include fragments of phosphatized cetacean bone and shark teeth, including one specimen of *Carcharocles megalodon* (Spencer, 1966). Derived Mesozoic fossils occur and include belemnites, crinoid ossicles, echinoid spines, rhynchonellid brachiopods and fragments of *Inoceramus*. The calcareous fauna of the lower part of the section has been described by Markham (1971, 1975) and Dixon (1978) and includes many of the typical Red Crag mollusc species including *Neptunea contraria*. Many of the shells are badly abraded and the fauna is clearly transported. The presence of articulated specimens of sublittoral species such as *Mytilus edulis* and *Macoma obliqua* (Dixon, 1978) is evidence that reworking from older deposits is unlikely and that the length of transport for some shells was small.

The overlying sands contain ripple cross-lamination indicating flood and ebb tidal transport to the north-north-east and south-south-west, with the north-north-east direction apparently dominant (Dixon, 1978).

Interpretation and evaluation

Other pits in the area expose pebble beds which occasionally yield molluscs of presumed Red Crag age (Dixon, 1978) but none show such a thick development of the pebble bed or have yielded such an extensive fauna. The presence of a fauna of probable Red Crag age in the interstitial sediments between the pebbles of the conglomeratic deposit at Battisford is not in itself conclusive proof that the deposit is contemporaneous with Red Crag sediments further east. Most of the mollusc shells are very abraded and clearly reworked (Dixon, 1978) as would be expected in such a high-energy deposit. The presence of articulated *Mytilus* shells indicates that at least some of the mollusc fauna might be contemporaneous with the deposit, but *Mytilus* is not a diagnostic fossil of stratigraphical value. It therefore remains to be proven whether the pebble bed is unequivocally of Red Crag age.

Similar pebble deposits containing well-rounded flint, phosphatic pebbles, shark teeth and phosphatized bone are found elsewhere in Suffolk and north Essex. *Cerastoderma angustatum*, a fossil known only from the Red Crag, is recorded from a deposit at Hadleigh (Dixon, 1978). The pebble deposits are interpreted as beach or very shallow-water littoral deposits and therefore, if they were proven to be contemporaneous with each other and with the 'classic' Red Crag deposits, would provide important evidence of the limit and palaeogeography of the Red Crag sea.

Conclusions

In the past the pit at Hascot Hill exposed a conglomeratic flint pebble bed which yielded marine fossils indicating that the deposit may be contemporaneous with the Red Crag deposits further east. The pebble deposit has been interpreted as a beach or very shallow-water littoral deposit and as such yields important evidence of the nature and position of the coastline during Red Crag times.

BUCKANAY FARM, ALDERTON, SUFFOLK (TM 356424)

Highlights

This large pit exposes an excellent section of the Red Crag with cross-bedding which shows the influence of tidal cyclicity through rhythmic alternations of grain-size and foreset thickness within the cross-bedded sets.

Introduction

This pit, which lies approximately 1.5 km NE of the village of Alderton, was recorded as a 'sand

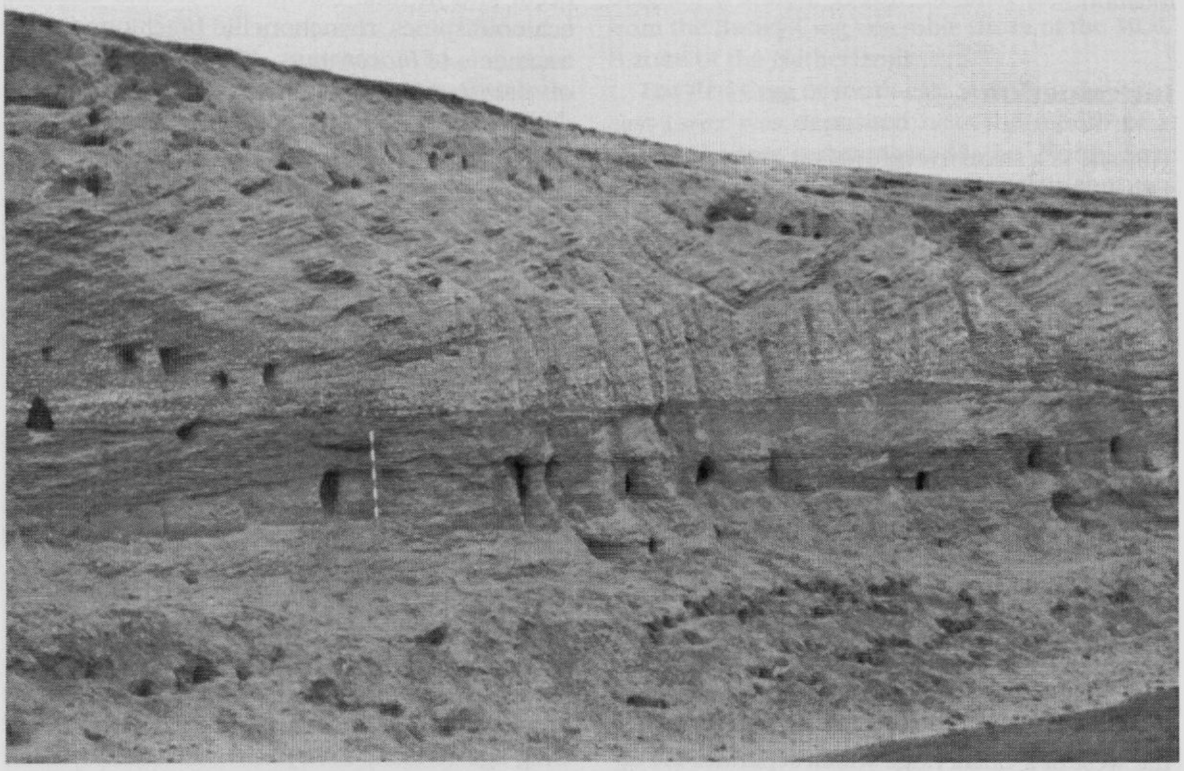


Figure 11.4 Face at Buckanay Farm showing the cross-bedded unit with abundant shell material (see Figure 11.5) overlying a smaller-scale cross-bedded unit depicted in Figure 11.6. Scale is 1 m long. (Photograph: P. Balson).

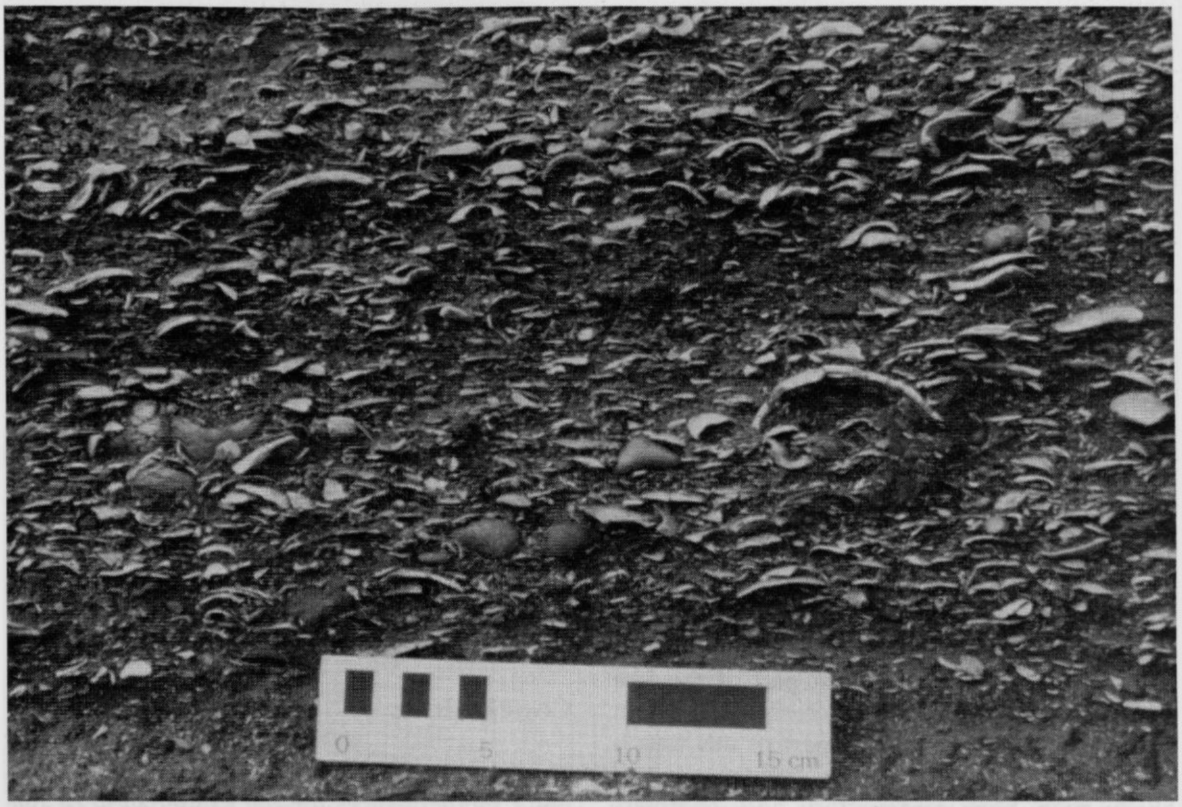


Figure 11.5 Coarse shelly sediment with pebbles near the base of the large cross-bedded unit shown in Figure 11.4. (Photograph: P. Balson.)

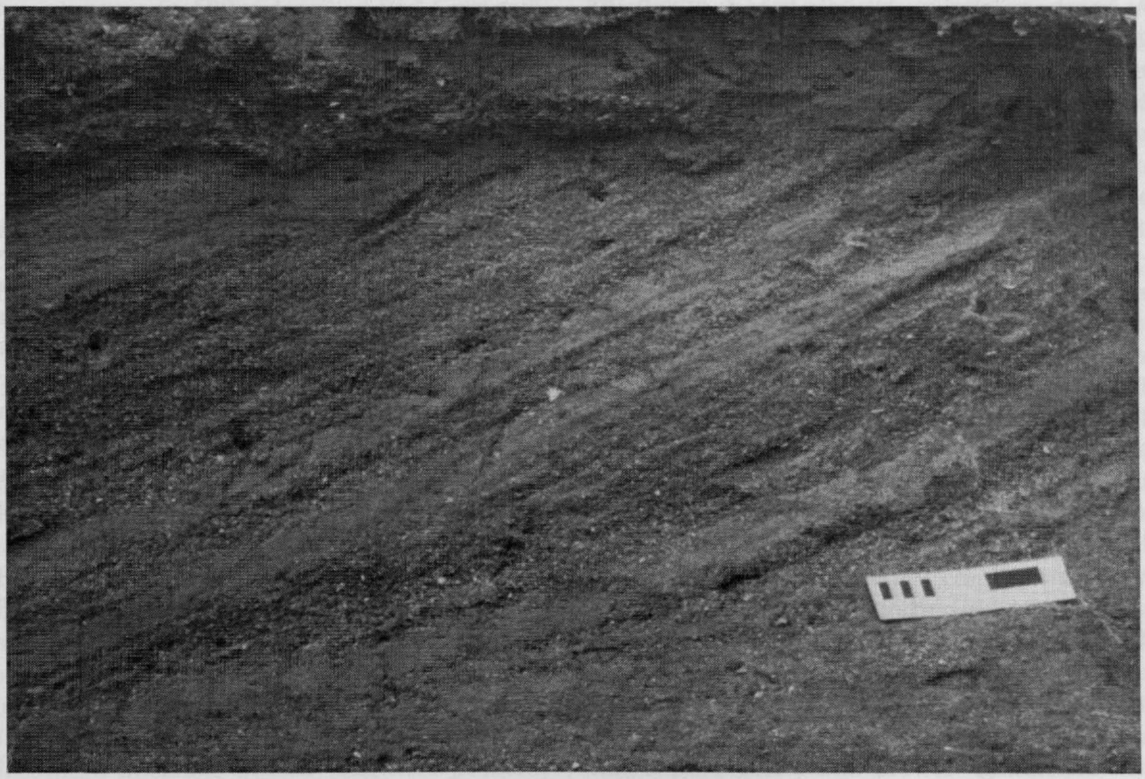


Figure 11.6 Alternating foresets of fine and medium sand reflecting possible tidal rhythms. Scale is 15 cm long. (Photograph: P. Balson.)

pit' by the Ordnance Survey in 1880 but appears to have received relatively little interest from geologists until recently. In 1911, Reid Moir claimed to have discovered human flint implements in material from a crag pit at 'Buckanay' although it is extremely unlikely that, if genuinely of human manufacture, they originated from within the Red Crag (Moir, 1911, p. 19). More recently, the pit has been described by Zalasiewicz *et al.* (1988).

Description

The pit presently exposes about 7.5 m of Red Crag. A borehole adjacent to the pit (TM 35594232) proved 11.9 m of Red Crag resting on London Clay at −2.8 m OD (Hollyer and Allender, 1982). Large-scale cross-bedding is present with foresets which dip towards the west-south-west (Figure 11.4). On the western side of the pit the uppermost part of the face consists of a single, large cross-bedded unit 4.8 m thick. The uppermost part of this unit is apparently decalcified but the lower part is very shelly with both fragmentary and complete shells, particularly those of *Neptunea*, *Nucella*, *Haustator*, *Arctica*, *Spisula* and *Cerastoderma*. A more extensive faunal list is given by Zalasiewicz *et al.* (1988). The base of this unit is marked by a thin lag gravel, mostly of flint pebbles up to 30 mm diameter (Figure 11.5). Below this unit is another, less shelly, cross-stratified unit with very clear alternations between finer- and coarser-grained foreset laminations (Figure 11.6). Such alternations are probably due to deposition by tidal currents with a marked diurnal inequality.

Several vertical fissures infilled by a soft, powdery white calcite are found at this site. These fissures were interpreted by Balson and Humphreys (1986) as tectonically induced joints. On the north-western face at this locality is an oblique fracture which appears to offset adjacent sedimentary laminae as a reverse fault.

Interpretation and evaluation

The pit at Buckanay Farm provides an excellent opportunity to examine a variety of features of cross-bedding in a tide-dominated shallow marine deposit. The direction of sand transport indicated by the dip direction of foresets is to the west-south-west, which is the dominant direction seen at many other Red Crag localities. At Bawdsey Cliff (TM 345385–350390) just over 4 km to the south, the dominant direction is to the north-north-east although smaller structures show subordinate transport to the west-south-west. These opposing directions are probably due to the dominance of either flood or ebb currents at each site. Evidence of tidal rhythms in the form of alternations in grain size and layer thickness in the foresets of the cross-bedded units is well shown at Buckanay Farm and is present at many Red Crag sites. The evidence of regional transport paths together with tidal cyclicity gives the opportunity to reconstruct the tidal regime within the Red Crag sea.

Non-marine molluscs are very rare in the Red Crag but have been recorded from this site and at Neutral Farm, Butley and Walton-on-the-Naze.

Conclusions

The Buckanay Farm pit is one of the best inland Red Crag exposures for the examination of the sedimentary structures associated with the cross-bedded tidal sandwave facies of the formation.

BAWDSEY CLIFF, SUFFOLK (TM 345385–TM 350390)

Highlights

The natural coastal cliff section at Bawdsey is the largest and most spectacular section of the Red Crag presently exposed. It is of great importance in the history of Crag research being one of the first recorded localities (Dale, 1704). The section provides one of the best exposures of large-scale cross-bedded shell sands with many sedimentary features indicative of deposition by tidal currents. The shelly fauna is abundant and well-preserved. This is one of the few localities where the basal contact of the Red Crag with the London Clay can be studied and where 'boxstones' have been found in the basal conglomeratic lag deposit.

Introduction

This cliff section (Figures 11.7 and 11.8) lies on the North Sea coast approximately 1.5 km north

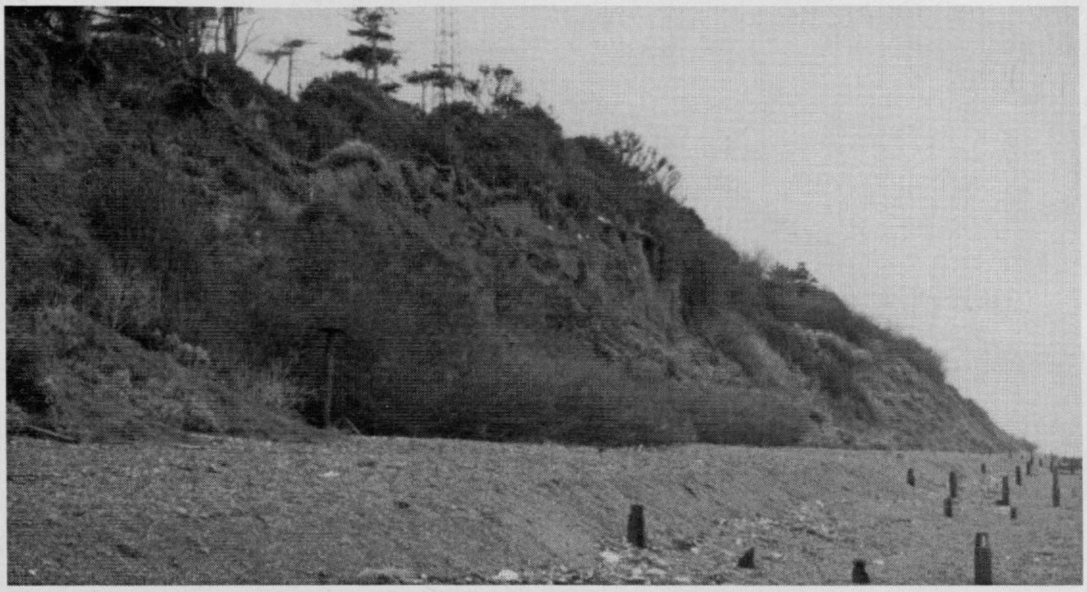


Figure 11.7 Bawdsey Cliff, looking northwards. (Photograph: P. Balson.)

of the mouth of the estuary of the River Deben. The section shows features attributed to high-energy subtidal bedforms from the lower part of the Red Crag succession and is the most extensive exposure (*c.* 500 m long) of Red Crag sediments exposed at the present time. Access to the site is along a coastal path on the seaward side of Bawdsey Manor from the quay. The cliff is unstable and subject to continued retreat.

Since 1704 when the presence of Crag at this location was first recorded (Dale, 1704) the section has been visited and described by many Crag workers and yielded many fossils to collectors.

Description

The extent of the Red Crag exposure at this locality has been very variable over the years, dependent largely on the rate of natural erosion along this undefended stretch of coastline. At the present time about 5 m of Red Crag are exposed (Figure 11.8) and there are small exposures, mostly at the northern end of the section, where the basal contact of the Red Crag with the London Clay is intermittently exposed about 5 m above the level of the beach shingle. The maximum thickness of Red Crag here probably exceeds 7 m.

The erosional contact between the London Clay Formation and overlying Red Crag is locally marked by a discontinuous lag deposit consisting of flint, phosphorite and quartz pebbles. This bed has apparently been better exposed in the past (e.g. Ovey and Pitcher, 1948). This lag deposit is immediately overlain by sediments containing layers of interlaminated mud and fine sand interbedded with shelly sands showing small-scale cross-bedding (unit 1). This is succeeded by a single large planar cross-set of shelly Red Crag (unit 2) which forms the bulk of the exposure in the cliffs (Figure 11.9).

At the southern end of the cliff section, the coarse cross-bedded shell sands of unit 2 rest upon a 25 cm thick bed of mud with thin continuous partings of very fine sand with subordinate silt. Below the muds are shelly cross-bedded sands. Foreset dip directions are west-south-west to west and thus opposed in direction to the laminae of unit 2 which are towards the north-north-east to north-east.

The foreset beds of unit 2 comprise alternating shell-rich medium- and coarse-grained and shell-depleted finer sand layers (Figure 11.10); mud drapes are absent. The shelly layers vary in thickness from 1–2 cm to approximately 50 cm and locally show inverse grading. Shell imbrication is particularly well shown. Bottomset beds tend to be finer grained and the shells more frag-

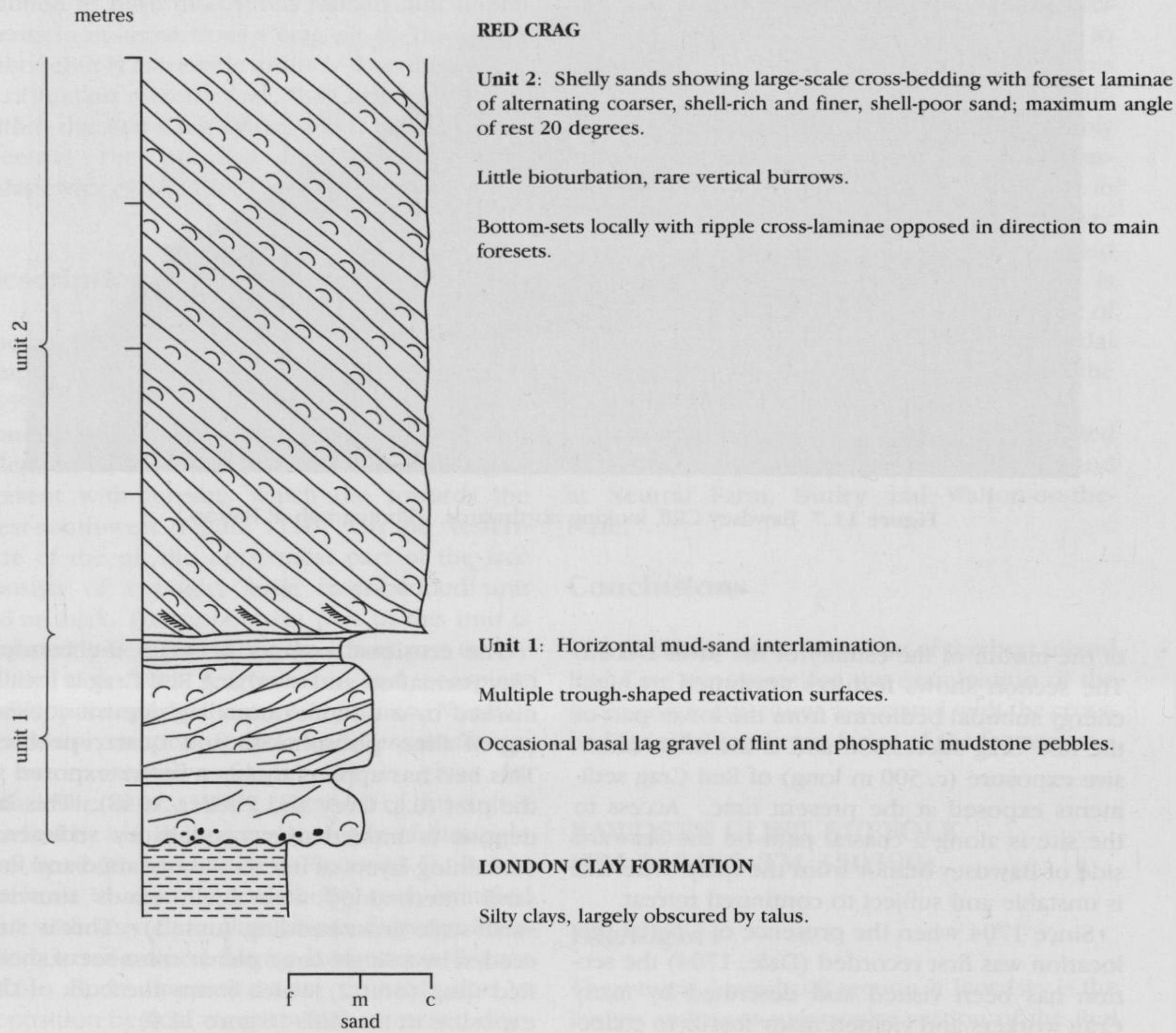


Figure 11.8 Composite summary log for Bawdsey Cliff. Metre scale approximate; f = fine, m = medium, c = coarse. (After Balson *et al.*, 1991.)

mented. Small-scale cross-bedding in a direction opposed to the main foreset direction is common in these bottomset beds. This lamination is intimately intercalated with thin avalanche beds that continue down from the foresets.

The dominant sand transport direction implied from the foreset dips to the north-north-east is diametrically opposed to the main dip direction measured at inland exposures, the nearest of which is only 4 km to the north (Buckanay Farm, Alderton). This may be the result of mutually evasive ebb-flood pathways if the tidal currents were channelized as commonly occurs in an estuary (Nio *et al.*, 1980). Measurements of the slope-directed cross-lamination in the Red Crag indicate bedform migration in a west-north-west direction, i.e. diagonal-

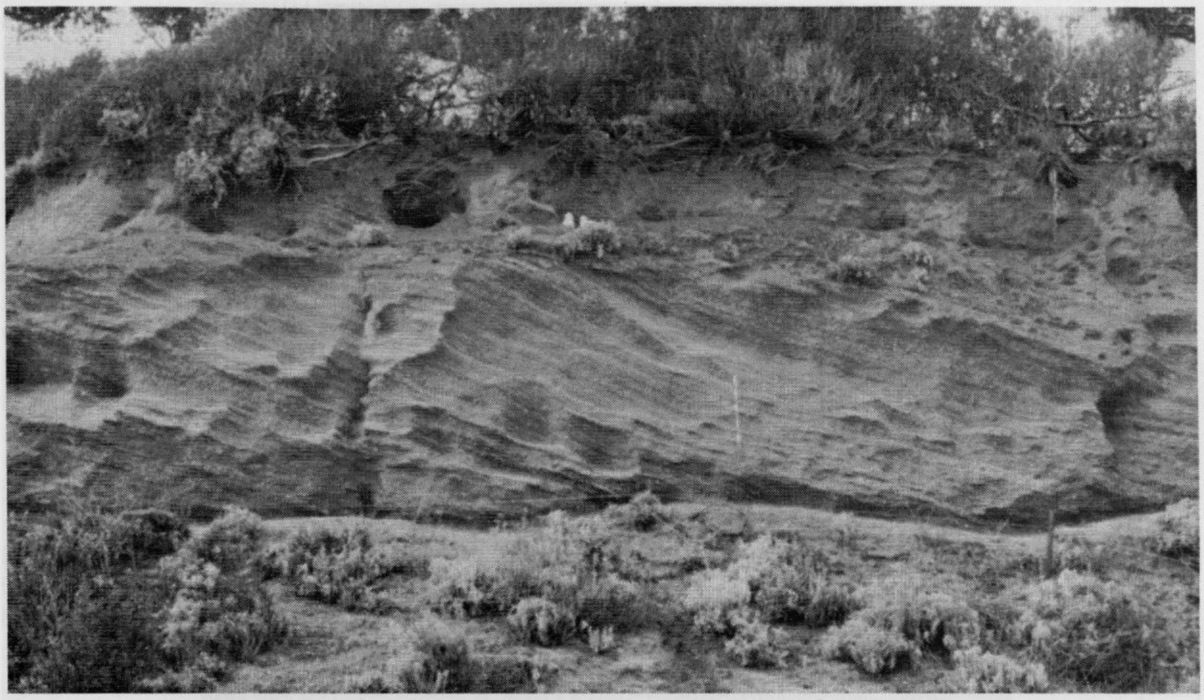


Figure 11.9 Large-scale cross-bedding in unit 2 at Bawdsey Cliff. Scale is 1 m long. (Photograph: P. Balson.)

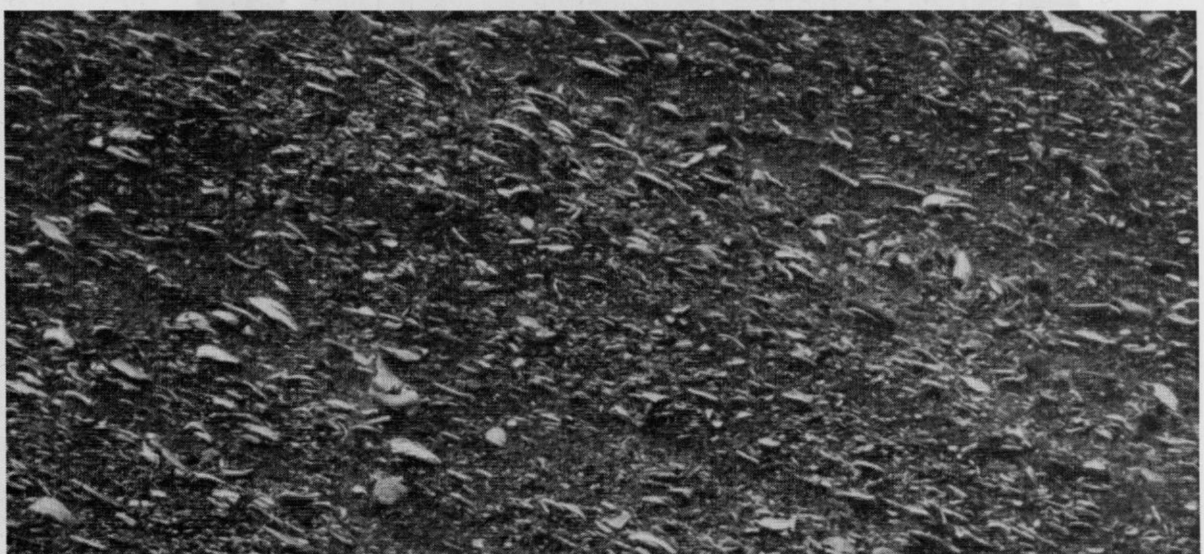


Figure 11.10 Cross-bedded shelly sediments of unit 2 at Bawdsey Cliff. (Photograph: P. Balson.)

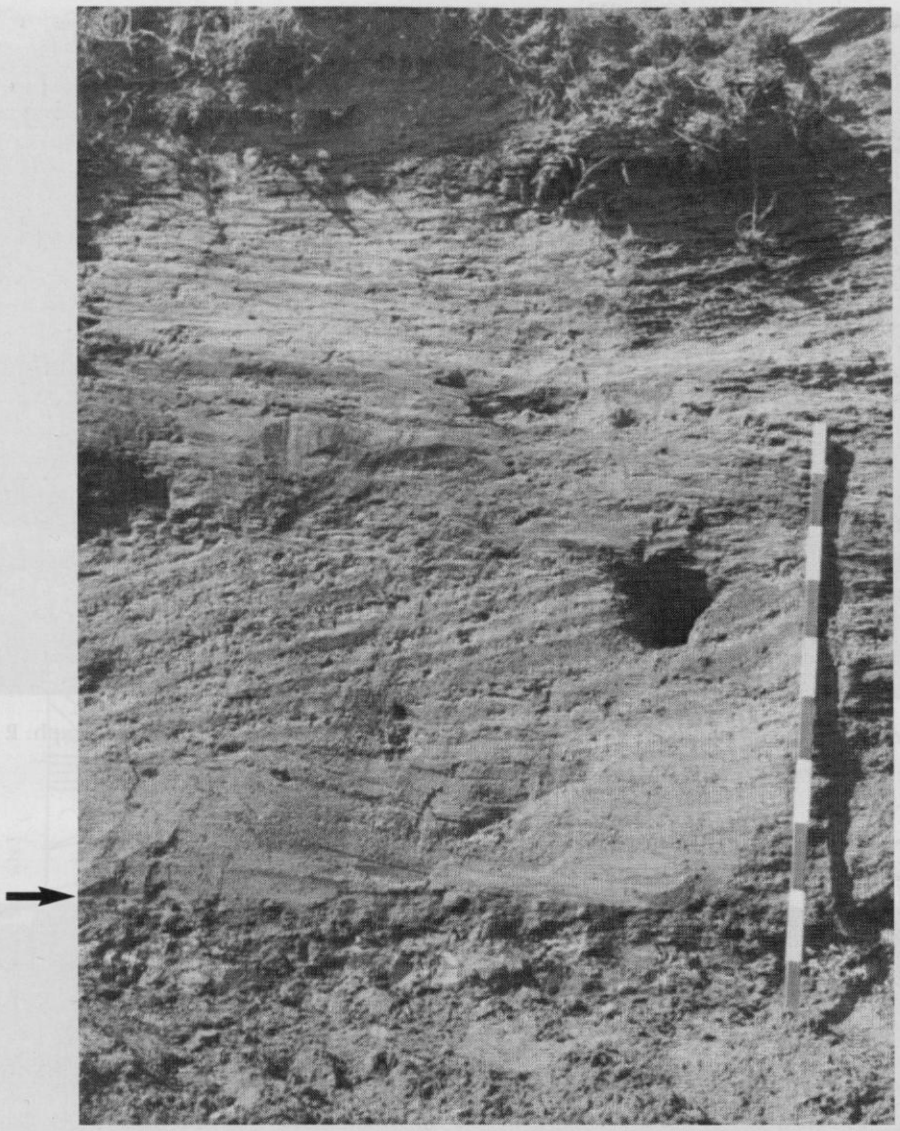


Figure 11.11 Red Crag overlying London Clay (the contact is arrowed) in an exposure at the north end of the section. Alternating sandy and silty foresets represent tidal cycles. Scale is 1 m long. (Photograph: P. Balson).

ly across the bottomsets and basal foresets. The Red Crag bedforms probably formed and migrated subtidally within large embayments, possibly a large tidal inlet.

Shells are abundant in unit 2 but include a high proportion of abraded and fragmentary specimens. Nevertheless collectors have identified many species of mollusc from this locality. As early as 1827, Taylor described '*Murex reversus*' (=*Neptunea contraria*) and '*Pectunculus*' (=*Glycymeris*) as the commonest species. A faunal list is given by Prestwich (1871b). Boswell (1928) lists *Serripes groenlandicus*, *Arctica islandica*, *Spisula constricta*, *S. solida* var. *ovalis*, *Mya arenaria*, *M. truncata*, *Mytilus edulis*, *Macoma calcarea* var. *obliqua* and *M. praetenuis* as the most abundant bivalves.

Further evidence of the tidal nature of the environment comes from small exposures near the northern end of the section where the London Clay is seen to be overlain by cross-bedded sediments with conspicuous alternations of fine- and coarse-grained sand foresets with occasional thin mud drapes (Figure 11.11). These alternations are probably the result of tidal current variations and therefore reflect tidal rhythms. The foresets dip to the west-south-west. The Red Crag sediments just above the London Clay surface contain numerous small, well-rounded phosphatic pebbles. The cross-bedded unit is overlain by a package of horizontally bedded silt drapes separated by thin laminae of fine sand (Figure 11.11) similar, and probably equivalent to, the laminated muds of Unit 1 at the southern end of the section.

Interpretation and evaluation

Bawdsey Cliff represents the largest and one of the most spectacular Red Crag exposures. Although not as renowned as other localities (e.g. Walton-on-the-Naze) as a fossil collecting locality, it is an excellent site for the study of sedimentary structures in a tide-dominated shallow marine environment. The thickness of the single cross-bedded set of unit 2 exceeds 5 m and is probably the largest of any exposed in the Red Crag. This indicates a bedform in excess of 5 m high and implies a more offshore location than for other Red Crag exposures. The large foresets dip to the north-north-east which is in an opposing direction to the regional direction implied by measurements in the lower part of the section at Bawdsey Cliff and at other localities. The section at Bawdsey Cliff is therefore important in the determination of the palaeotidal regime during Red Crag times.

The section at Bawdsey Cliff also represents one of the few sites where the basal contact with the London Clay can be examined (also at Walton-on-the-Naze and, by excavation, at Rockhall Wood).

Conclusions

The Bawdsey Cliff section is the largest section of Red Crag presently exposed. It is of great sedimentological importance to the study of the internal structure of tide-dominated marine sandwave deposits in the Red Crag.

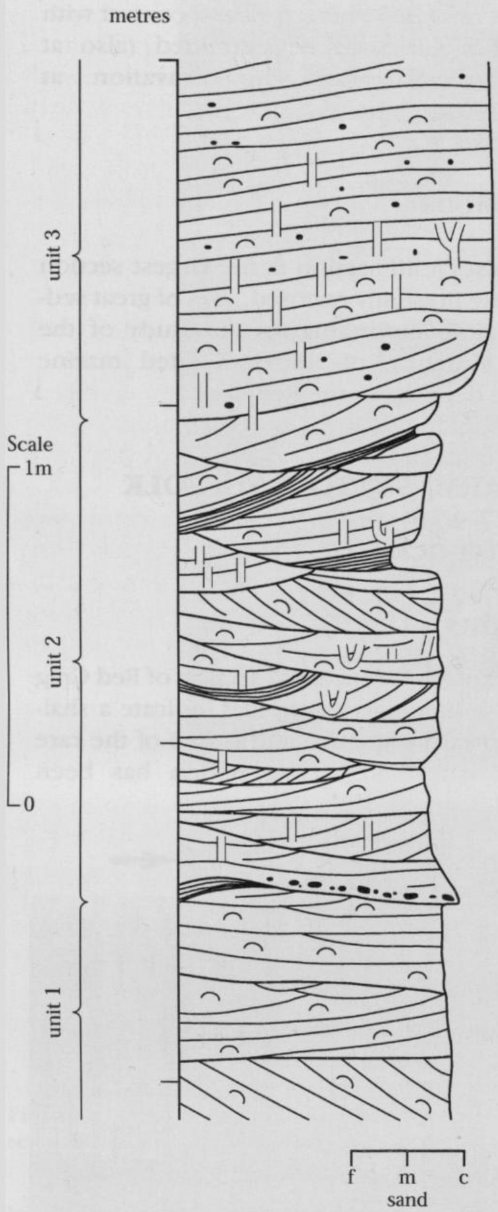
VALE FARM, SUTTON, SUFFOLK (TM 317 456)

POTENTIAL GCR SITE

Highlights

This pit exposes an excellent section of Red Crag showing sedimentary facies that indicate a shallowing-upward sequence and is one of the rare localities where Red Crag pollen has been recorded.

Figure 11.12 Red Crag exposure at Vale Farm showing possible spring-neap tidal rhythms in unit 2 and truncation by the overlying unit 3. Scale is 1 m long. (Photograph: P. Balson.)



RED CRAG

Unit 3: Shelly coarse-grained sands and pebbly sands. Local low-angle cross-bedding near base of unit. Numerous vertical burrows, some branching. Mollusc shells, mostly fragmentary, include *Mya, Glycymeris, Aequipecten, Arctica, Spisula, Cerastoderma* and *Hinia*. Undulose base to unit.

Unit 2: Shelly coarse-grained sands. Groups of interlaminated mud and sand laminae within trough cross-bedded deposits. Numerous internal erosion surfaces: rare ?ripple cross-bedding. Frequent pebbles of well-rounded phosphatic mudstone, quartzite and flint up to 5 cm in diameter. Abundant shells and shell fragments of *Macoma, Spisula, Mytilus, Glycymeris, Mya, Aequipecten, Haustator* and *Nucella*. Occasional reworked Coralline Crag fossils including the bivalve *Venencardia aculeata scaldensis* and the bryozoan *Turbicellepora*. Low to moderate bioturbation; both vertical and U-shaped burrows.
Basal lag of pebbles and mud intraclasts, locally replaced by mud-draped surface.

Unit 1: Planar cross-bedded shelly coarse-grained sands passing up into horizontally-bedded sands. Few mud drapes. No bioturbation. Abundant abraded shell debris with some intact shells. Molluscs include the bivalves *Macoma, Mya, Mytilus* and *Spisula*. Abundant abraded iron-stained barnacle plates and occasional small echinoids (*Echinocyamus*).

Figure 11.13 Composite summary log for the Vale Farm GCR site. Metre scale approximate; f = fine, m = medium, c = coarse. (After Balson *et al.*, 1991.)

Introduction

This pit is located approximately 1 km NNW of the village of Shottisham. The pit appears to be a relatively modern excavation and was unrecorded in the geological literature before the 1970s. Dixon (1979, fig. 7) and Balson *et al.* (1991) have described the facies relationships in this pit.

Description

This exposure consists of a single linear face approximately 40 m long in a shallow pit up to approximately 4 m deep (Figure 11.12). A nearby borehole (TM 3175 4589) proved more than 15.5 m of Red Crag in this area. Three units are recognizable in the face (Figure 11.13). Unit 1 consists of planar cross-bedded red-brown shelly sands (just visible below talus) passing up into horizontally bedded sands. The top of unit 1 is taken at the point where mud drapes first occur in the vertical sequence. The sediment is coarse-grained and contains rounded flint and phosphatic pebbles up to 1 cm in diameter.

The base of unit 2 is marked by a discontinuous lag of shell fragments, often convex up, with flint pebbles and mud horizons, either as laterally continuous lenses or as ripple drapes. This unit is dominated by trough cross-bedding and low-angle laminae, with characteristic trough-shaped mud drapes. Two types of burrow are present: vertical *Skolithos*-type tubes and clay-filled U-shaped tubes of *Lanicoidichna*-type or *Arenicola*-type. The top of unit 2 is eroded into by an undulatory sheet of coarse-grained, bioturbated shelly and pebbly sands of unit 3. The bedding of unit 3 is concordant with the basal scoured surface in the centre of the face, but low-angle stratification resembling lateral accretion bedding is also seen. One type of burrow occurs in large numbers within unit 3, which has a vertical shaft which tends to taper downwards. Many shafts show a bulbous swelling somewhere along their length. Burrow dimensions are typically in the region of 5–10 mm in diameter and several decimetres in length. These traces may be related to the ichnogenera *Lanicoidichna*, *Cylindrichnus* (although this is usually unbranched) or possibly *Psilonichnus*.

A number of vertical fissures filled with shelly sand derived from above or a friable micritic calcite are conspicuous at this locality. These fissures are part of an orthogonal joint system affecting both the Red and Coralline Crags in east Suffolk and north Essex. There is clear evidence of vertical displacement of *c.* 30 cm on one fissure in the pit. Balson and Humphreys (1986) suggested fissuring may have been caused by flexuring of the East Anglian landmass in response to subsidence in the adjacent North Sea and the tilting of East Anglia. Close inspection of the micritic calcite reveals root moulds and tubules and possibly even extant root material. These rhizoliths are believed to have formed during the Holocene due to root penetration down the fissure planes.

Excavation of unit 1 suggests a greater thickness of tabular-planar cross-bedding occurs at depth. Unit 1 is therefore probably the product of migration of a straight crested sandwave, and the horizontal beds at the top of the unit probably represent truncation and reworking of the bedform.

Unit 2 shows evidence for repeated truncation of bedforms. Packets of interlaminated mud and fine sand are laid down on the truncation surfaces and these pass into foreset laminae of coarser sand which are in turn truncated and overlain by muddy packets. This may reflect a modification of spring–neap tidal bedding. In general, deposits showing systematic variations in foreset thicknesses attributed to monthly tidal cyclicity have been recorded from estuaries, tidal channels or tidal inlets but are also recorded from shallow shelf deposits (e.g. Allen, 1981). The shallow scour structure at the base of unit 3 was filled more or less vertically and therefore contrasts with the lateral accretion infill expected from the migration of tidal channels. The scour also lacks a marked basal lag/intra-formational shell or mudstone pebble lag although the fill is generally very coarse. This feature represents a high-energy fill event, but the abundance of vertical burrowing suggests that multiple phases of infill took place, while the lack of any fining-upwards motif argues against deposition generated by major storm events. Although the interpretation of this structure remains problematic, it can be provisionally interpreted as the basal lag fill of a large tidal channel.

Harrison (1983) has described pollen from mud drapes at Vale Farm. The flora is dominated by tree pollen which include *Pinus* (pine), *Quercus* (oak), *Alnus* (alder) and *Tilia* (lime).

Interpretation and evaluation

Pollen in Red Crag sediments has only been recorded from two surface exposures: Vale Farm (Harrison, 1983) and Walton-on-the-Naze (Hunt, 1989). At Walton-on-the-Naze, tree pollen also dominate but pollen of grasses, heathers and other herbs are also found. The strongly oxidized nature of sediments in surface exposures usually precludes the preservation of pollen but these two studies, together with Gibbard and Peglar's (1988) record of pollen in the Coralline Crag at Rockhall Wood, indicate that, with careful selection of sample material, further study may be fruitful.

The section at Vale Farm shows a sequence that indicates a shallowing of the environment comparable with that seen at Orford Lodge, Waldringfield and Broom Covert.

Conclusions

The pit at Vale Farm exposes an important section for the interpretation of palaeoenvironments and facies change in the Red Crag and is one of only two from which pollen has been recovered.

BROOM COVERT, BUTLEY, SUFFOLK (TM 370494)

POTENTIAL GCR SITE

Highlights

The pit at Broom Covert exposes an excellent section in shallow water, possible intertidal Red Crag sediments overlying subtidal cross-bedded sands.

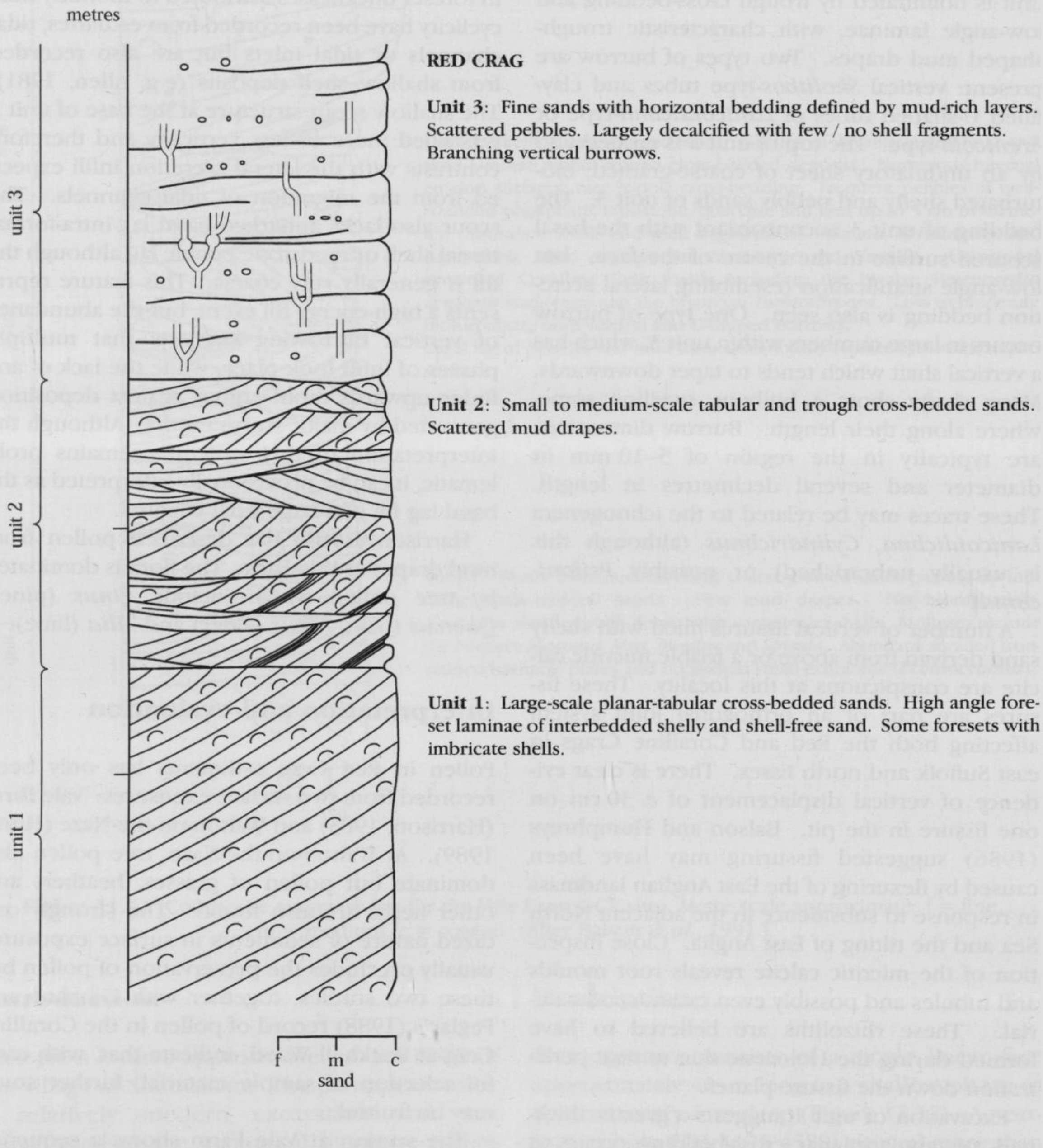


Figure 11.14 Composite summary log of Red Crag section at Broom Covert. Metre scale approximate; f = fine, m = medium, c = coarse. (After Balson *et al.*, 1991.)

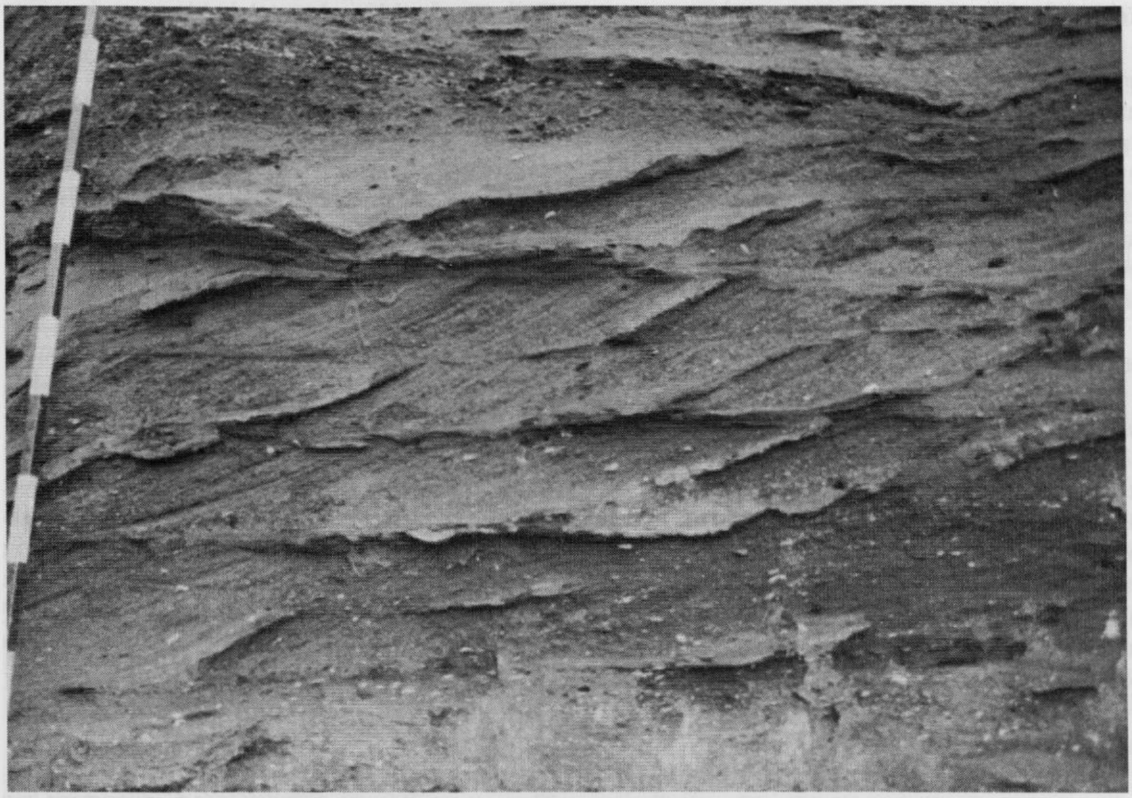


Figure 11.15 Small-scale cross-bedding in unit 2 at Broom Covert, showing regular mud drapes reflecting tidal rhythms. (Graduations on scale = 10 cm.) (Photograph: P. Balson.)

Figure 11.16 Vertical burrows in unit 3 at Broom Covert. (Graduations on scale = 10 cm.) (Photograph: P. Balson.)

Introduction

This pit has been excavated on the flanks of a small hill close to a minor road that connects Capel Green with Butley, passing north of Butley Abbey. It was recorded by the Ordnance Survey in 1881 and may be the pit 'half a mile west of Butley Abbey' figured by Prestwich (1871b, fig. 11) and illustrated by Boswell (1928, plate 1B).

Description

Boreholes in the area have proved up to 17.4 m of Red Crag (Hollyer and Allender, 1982). The pit exposes approximately 7 m of Red Crag (Figure 11.14). The base of the section shows up to 1.5 m of planar-tabular, cross-bedded sand with foresets alternately of shelly and shell-free sand (unit 1). At this locality foreset dip orientations indicate movement of the bedform towards the west. The unit is sharply truncated at the top by a surface which dips at 2° towards the east.

This unit is overlain by a complex cross-bedded unit (unit 2) (Figure 11.15). The shell content is less and the shells more comminuted than in unit 1. In the simplest section stacked sets of ripple cross-laminated sand pass up into larger-scale trough cross-bedded sand. Set boundaries are parallel. Clay-silt drapes are conspicuous, spaced at regular lateral intervals. Numerous scours filled with trough cross-bedded sands cut down into the rippled sands.

An undulatory boundary separates unit 2 from the uppermost, generally shell-free, unit 3 (Figure 11.16) which consists of an interlamination of horizontally bedded sands with indistinct ripple cross-lamination and mud partings. The mud forms thin laterally impersistent layers which drape ripple forms. The mud partings are typically spaced 10–20 cm apart, but where they are more closely packed they impart a flaser or wavy bedded appearance. Local pebble layers occur.

Conspicuous clay-lined burrows occur in unit 3. These are discrete, often with Y-shaped branches, with the main shaft and branches oriented normal to bedding. Although the shafts are comparatively narrow, averaging *c.* 1 cm in diameter, they can be traced vertically for over 40 cm.

The foresets seen at the base of the section (unit 1) are similar to those exposed in Bawdsey Cliff. The bedding thus probably records migration of a large sandwave, in a subtidal, possibly estuarine, environment. The numerous scours and cross-bedding on various scales which characterize unit 2 are reminiscent of the sediments produced by strong current action in a tidal channel environment such as those described by Terwindt (1971), De Raaf and Boersma (1971) and Nio *et al.* (1980).

The beds at the top of the section (unit 3), comprising alternations of flat-bedded sand laminae and mud partings or drapes, are the product of deposition under a regime of fluctuating current strength. The sand layers were deposited during periods of active bedload transport, whilst the intercalated muds document repeated periods of slack water with deposition from suspension. Holocene siliciclastic tidal flats fringing the margins of the southern North Sea are good modern analogues of sequences of thinly interbedded sand–mud layers with many of the structures described above (e.g. Evans, 1965).

Interpretation and evaluation

The pit at Broom Covert is an important site within a network of sites which expose the shallow water, possibly intertidal sand flat facies of the Red Crag, overlying subtidal cross-bedded facies (see also Orford Lodge, Vale Farm).

Conclusions

The pit at Broom Covert is an important site for the study of the vertical and lateral variations in sedimentary facies within the Red Crag.

ORFORD LODGE, CHILLESFORD, SUFFOLK (TM 390508)
POTENTIAL GCR SITE

Highlights

The pit at Orford Lodge is one of the best exposures in the sandflat facies of the Red Crag.

Introduction

This pit is excavated into the flank of a small hill which lies beside the estuary of the Butley River, approximately 1.5 km south of the B1084 and the village of Chillesford. The pit is approximately 60 m wide and exposes approximately 4 m of Red Crag. According to evidence from

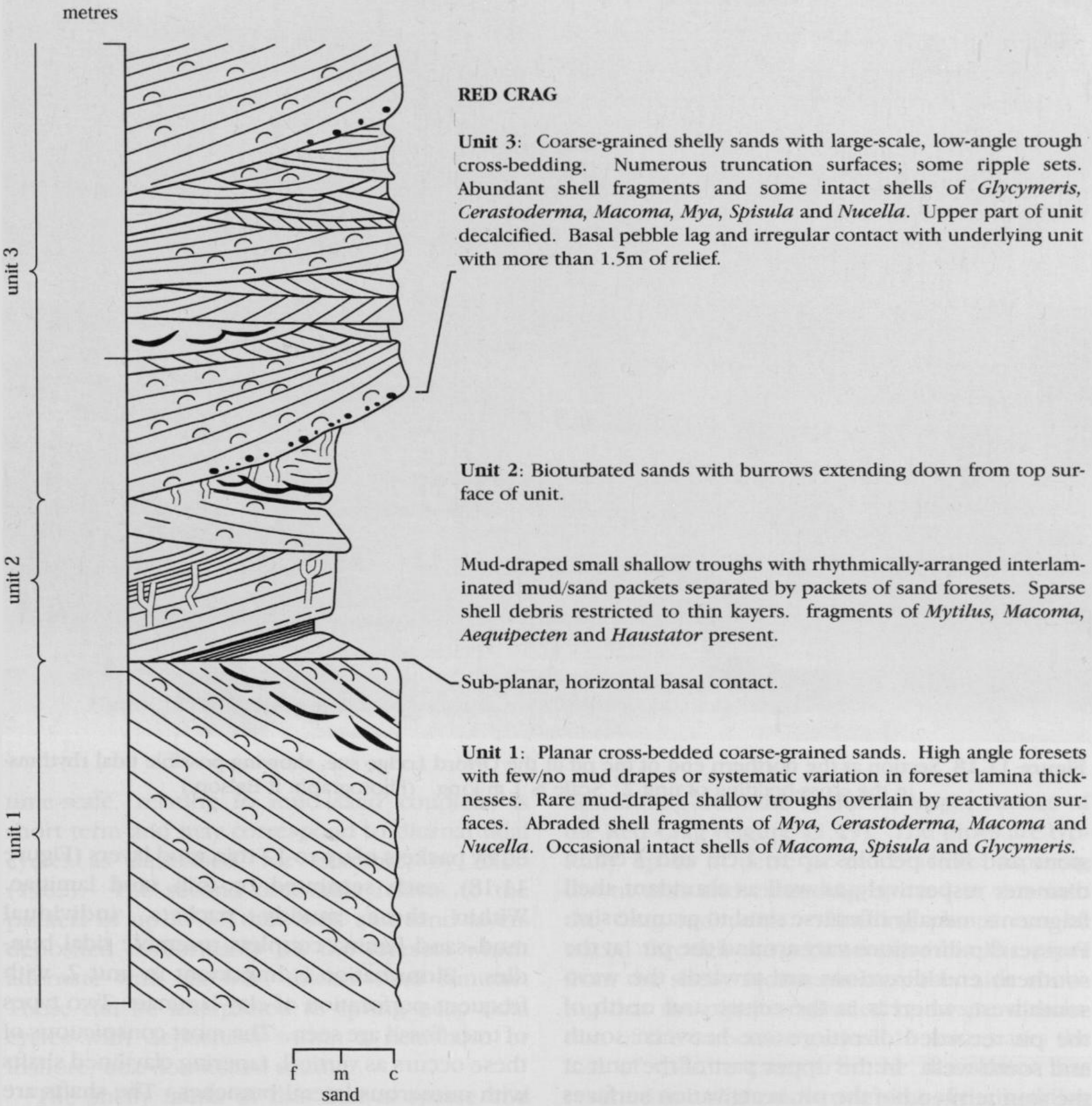


Figure 11.17 Composite section of the Red Crag section at Orford Lodge. Metre scale approximate. (After Balson *et al.*, 1991.)

old Ordnance Survey maps, the pit was excavated between 1881 and 1902. It was recorded by Spencer (1971).

Description

Three units are present (Figure 11.17). The lowest, unit 1, consists of tabular planar medium- to coarse-grained, cross-bedded sands with an abundance of comminuted shell debris. This is truncated by unit 2, a lens of bioturbated finer-grained, often shell-free sands with conspicuous mud drapes. The erosive boundary separating units 1 and 2 is approximately horizontal, with occasional shallow scours, and can be traced around the exposure. Unit 3 comprises trough cross-bedded shelly sands. It has a markedly undulatory base which is marked by a pebble lag including flint pebbles and clay clasts. Erosive scouring has removed unit 2 at the southern end of the pit so that unit 3 rests directly upon unit 1.

Unit 1 consists of planar cross-bedded coarse-grained sands which include phosphatic mud-

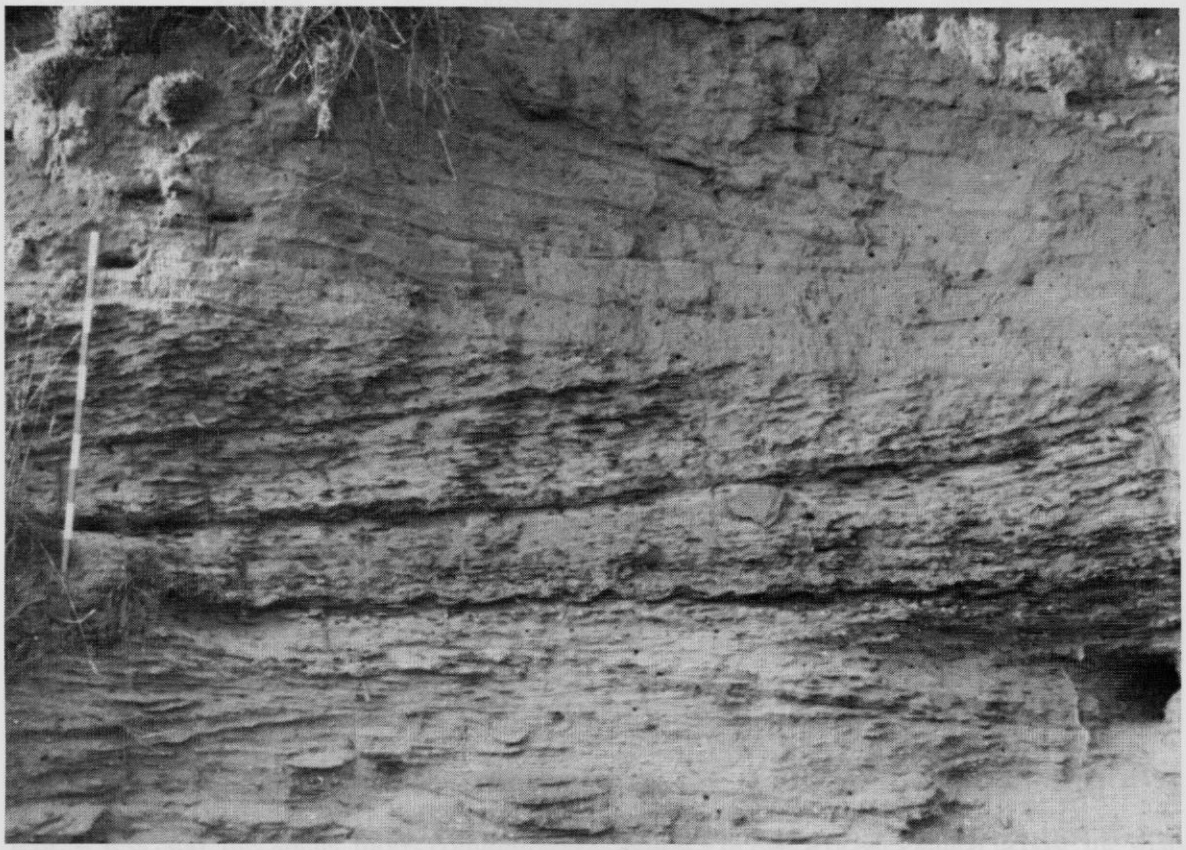


Figure 11.18 Section at the northern end of the pit at the Orford Lodge site, showing possible tidal rhythms in the cross-bedding of unit 2. Scale is 1 m long. (Photograph: P. Balson.)

stone and flint pebbles up to 1 cm and 3 cm in diameter respectively, as well as abundant shell fragments, usually of coarse sand to granule size. Foreset dip directions vary around the pit: at the southern end directions are towards the west-south-west, whereas in the centre and north of the pit recorded directions are between south and south-west. In the upper part of the unit at the southern end of the pit, reactivation surfaces are associated with horizons of shallow mud-draped small troughs. Rare small vertical burrows are present. The planar cross-bedding of unit 1 is the product of sandwave migration. Foreset dip directions suggest this sandwave had a slightly sinuous crestline.

Unit 2 is characterized by a finer mean grain size, the presence of clay drapes, bioturbation and the scarcity of shell debris. The bedding consists of low-angle trough sets with numerous truncation surfaces. Shallow scours with concordant sediment fills, locally with mud drapes at the base of the scour, are present, especially at the base of the unit. At the northern end of the pit, packets of sandy foreset laminae are separated by packets of up to 17 thin mud layers (Figure 11.18), each separated by thin sand laminae. Within these muddy packets, individual mud–sand lamina couplets resemble tidal bundles. Bioturbation is important in unit 2, with frequent perforation of clay laminae. Two types of trace fossil are seen. The most conspicuous of these occurs as vertical, tapering clay-lined shafts with numerous lateral branches. The shafts are up to 15 mm in diameter, slightly wider in places, and they usually thin to a few millimetres towards their base. They can be traced vertically for over 35 cm. The second type of trace consists of small clay-filled tubes, 2.5 mm or less in diameter, which have meandering and branching networks. These may compare with irregularly ramified boxworks which were attributed to the polychaete worm *Nereis* by Frey *et al.* (1973).

The clay partings of unit 2 exposed at the northern face of the pit reflect systematic variations in foreset lamina thickness and composition. The mud partings imply sedimentary cycles of two differing time-scales. The first

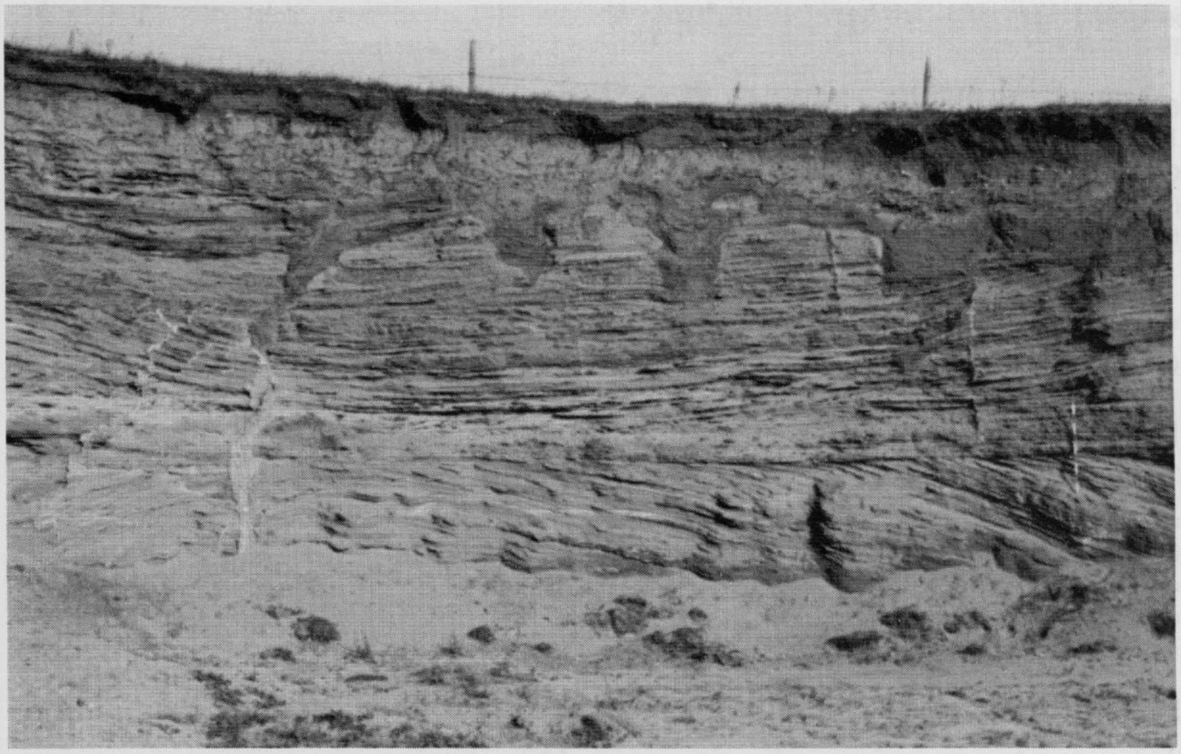


Figure 11.19 Section at Orford Lodge showing prominent solution pipes. Scale is 1 m long. (Photograph: P. Balson.)

time-scale, relating to mud–sand couplets, is short term and may correspond to diurnal tidal cycles as described, for example, by Allen (1982). The second time-scale relates to the packets of up to 17 thin mud and sand layers deposited conformably on the foresets which alternate with clay-free, thicker sand laminae. These can be interpreted as spring–neap tidal cycles with deposition within a nearshore or inshore, tide-dominated setting.

The shelly fauna in this unit is sparse and restricted to thin, scattered layers. Fragments of the umbonal region of *Mytilus* together with fragments of *Macoma*, *Aequipecten* and *Haustator* are present.

Unit 3 comprises coarse-grained shelly sands. The base of the unit is marked by a continuous pebble lag comprising quartz, flint and phosphatic pebbles, up to 2 cm, 5 cm and 1.5 cm in maximum dimension respectively. Clay rip-up clasts up to 15 cm are also present. The unit is characterized by shallow scours on various scales that are filled by low-angle trough cross-bedding or low-angle planar bedding. Smaller-scale ripple sets are also present.

Conspicuous solution pipes can be seen descending from the undulose upper surface of the Red Crag (Figure 11.19). The pipes are typically up to a metre or more across, tapering downwards and extending up to 2 or 3 m into the Crag sediments. Bedding planes can be traced through the sediments within the pipes from the shelly sediments on either side showing that the pipes originated by in-situ dissolution of the carbonate grains. In some cases the loss of volume caused by the dissolution has resulted in a slight downwarping of the bedding planes. Fissures seen in the face may represent joint planes as described by Balson and Humphreys (1986) and are often infilled with white powdery micritic calcite which may be in the form of conspicuous branching rhizocretions.

Interpretation and evaluation

The pit at Orford Lodge exposes an excellent section showing a typical Red Crag shallowing-upward sequence and can be compared with the sections at Neutral Farm, Butley and Broom Covert to the west. The section here lies close to the Coralline Crag outcrop to the east, the topographical form of which may have influenced Red Crag environments and deposition.

Conclusions

Orford Lodge is an important site for the study of vertical and lateral variations in the sedimentary environments of the Red Crag.

WALDRINGFIELD HEATH, SUFFOLK (TM 257447)

Highlights

The large working pit at Waldringfield Heath exposes the largest and most spectacular section in the uppermost parts of the Red Crag which consist of horizontally-bedded sands with abundant vertical burrows indicative of nearshore or intertidal sandflats.

Introduction

Although pits at Waldringfield are mentioned in the literature of the 19th century (e.g. Wood and Harmer, 1877; Reid, 1890), the pit at Waldringfield Heath 2 km west of the village of Waldringfield is more recent. The pit does not appear on the Ordnance Survey map of 1928 and appears as only a long and narrow incision after the remapping of 1938–1953. At present the pit is being backfilled as extraction continues, with active excavation concentrated in the south-west corner of the site. The Red Crag here is overlain by Glacial Sands and Gravels which are being exploited for building sands and aggregates. The Red Crag is being extracted primarily for use as constructional fill. Using the stratigraphical terminology of Harmer (1900a), this pit exposes the Red Crag 'Newbournian' Stage, named after the village of Newbourne which lies approximately 2 km to the south-south-east of this site.

This site was also independently selected for its Quaternary stratigraphy content, a more detailed account of which can be found in the GCR series volume *Quaternary of East Anglia and the Midlands* (Allen *et al.*, in prep.).

Description

Evidence from nearby boreholes (Allender and Hollyer, 1972) indicates that the Red Crag is approximately 13 m thick at this location, resting unconformably upon the London Clay at approximately +7.3 m OD. The record of a thin bed of Coralline Crag 6 inches (0.15 m) thick beneath the Red Crag at 'Waldringfield' relates to a former pit north-east of Waldringfield Church (Whitaker, 1885; Reid, 1890) approximately 3 km east of this site. The base of the Red Crag cannot be seen in the pit but has been reached by the excavation beneath the water table. In some places spoil material derived from excavations into the floor of the pit contains irregular

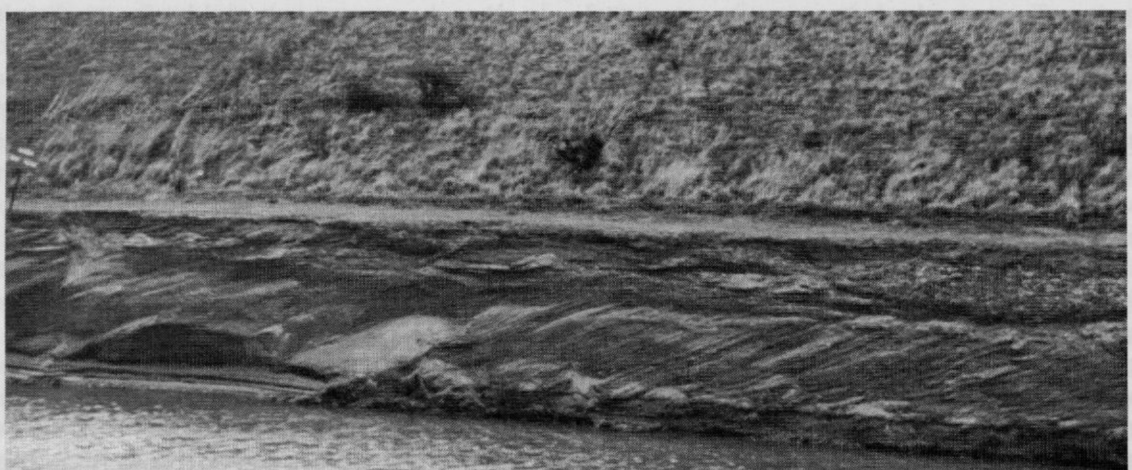


Figure 11.20 Large-scale cross-bedding in the lower part of the Red Crag section at Waldringfield Heath. (Photograph: P. Balson.)

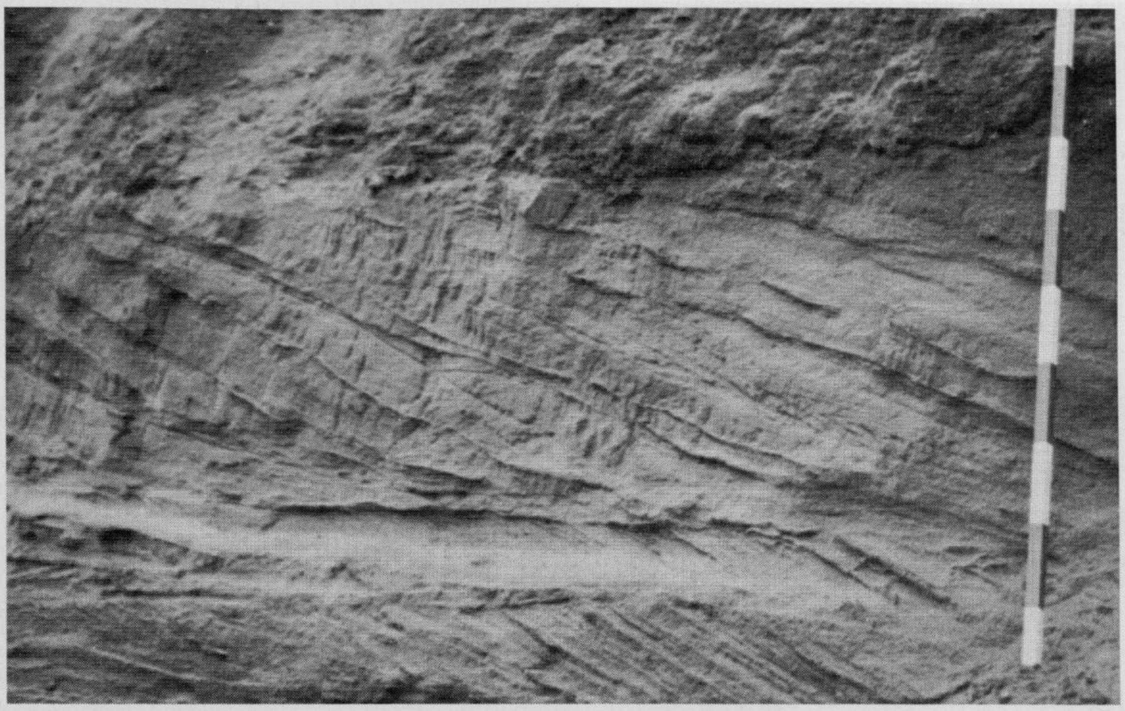


Figure 11.21 Cross-bedding with mud drapes in decalcified Red Crag, Waldringfield Heath. Scale is 1 m long. (Photograph: P. Balson.)

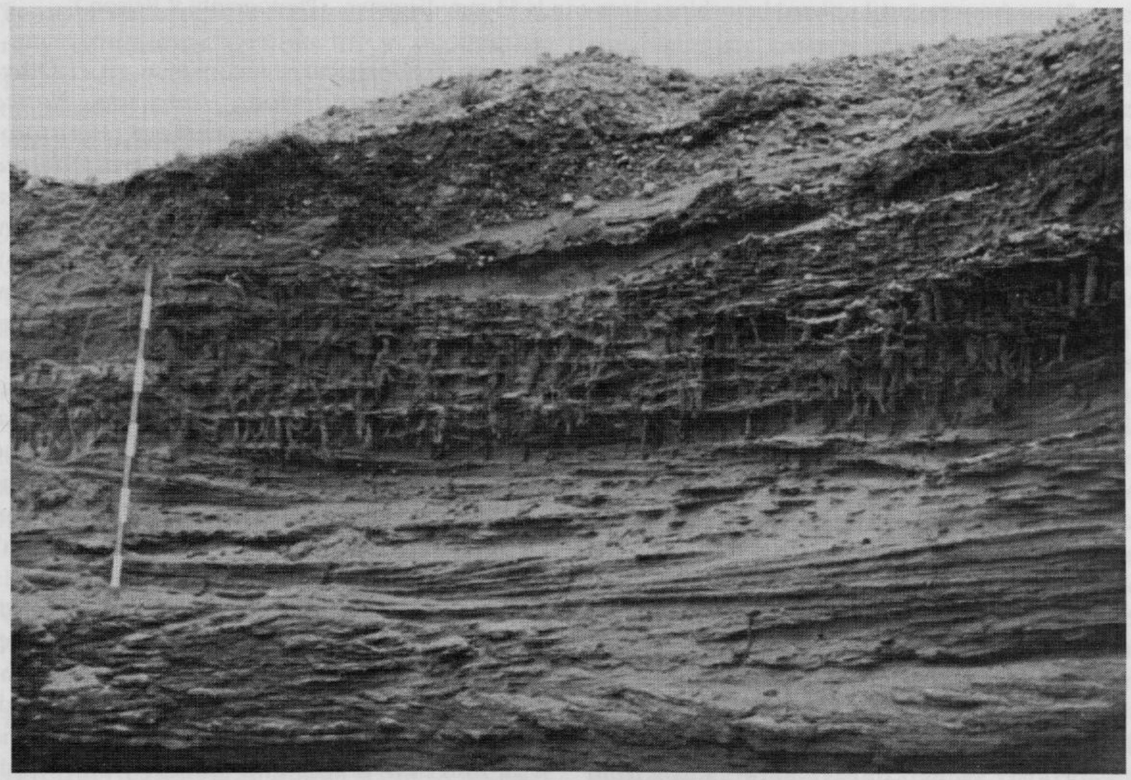


Figure 11.22 Trough cross-bedded possible tidal flat sands with abundant vertical burrows near the top of the Red Crag section at Waldringfield Heath. Scale is 1 m long. (Photograph: P. Balson.)

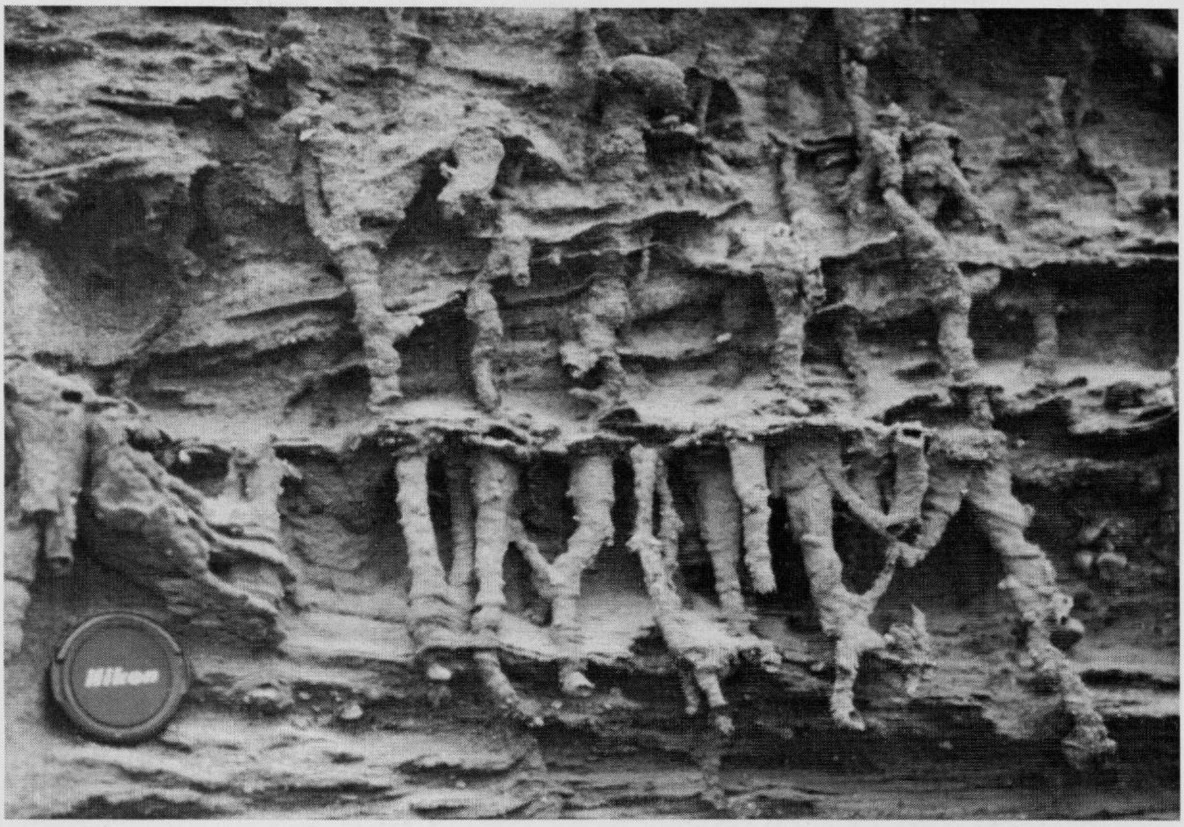


Figure 11.23 Well-preserved vertical burrows in decalcified Red Crag sediments at Waldringfield Heath. Note the occasional upward branching. Lens cap is 53 mm diameter. (Photograph: P. Balson.)

lumps of London Clay and abundant material from the basal conglomeratic lag deposit. This material includes small well-rounded phosphatic pebbles, phosphatized shark teeth and flint cobbles. The flints are commonly more than 40 cm in diameter and are subangular with fracture surfaces which may be encrusted with barnacles of Red Crag age indicating that the fractures are not due to damage during excavation. The presence of such large flints at the base of the Red Crag has formerly been interpreted as due to transport by ice (e.g. Lankester, 1912). Lyell (1852) described similar large flints encrusted by barnacles at Wherstead approximately 10 km to the west and observed that the distribution of barnacles indicated that the flints could not have been overturned during Red Crag deposition. The source of the flints and the time of their transportation into the area are unknown; the nearest outcrop of Chalk is 12 km to the north-west. In exposures above the water table the Red Crag can be seen to consist of cross-bedded shelly sands (Figure 11.20) from which a large fauna of molluscs can be obtained. Large *Neptunea contraria* and *Glycymeris glycymeris* are particularly conspicuous. Other common molluscs include *Hinia* spp., *Natica multipunctata*, *Scaphella lamberti*, *Haustator incrassata*, *Arctica islandica*, *Cerastoderma edule*, *Aequipecten opercularis*, *Mya arenaria*, *Mytilus edulis*, and *Spisula* spp. A more extensive list of the fauna is given by Markham (1966).

Decalcification which has removed all calcium carbonate from the sediments affects the upper parts of the Red Crag. The decalcification front is extremely irregular, often undulose, but may interfinger down individual foreset units so that there may be an alternation of decalcified and non-decalcified layers. Where decalcified, the cross-bedded Crag appears as a ferruginous, medium to coarse, poorly sorted sand with small rounded pebbles up to 20 mm diameter. In some of the more iron-cemented bands, moulds of mollusc shells are clearly visible. Silt drapes along foreset planes are locally present. On the south-eastern face of the pit these coarser sands are overlain by a cross-bedded unit of fine sand with thin silty drapes and scattered thin ripple drapes which may reflect tidal rhythms (Figure 11.21). This unit is overlain by trough cross-bedded medium to coarse sands, often with lenses of gravelly sand with abundant flint and quartz pebbles. The uppermost part of these trough cross-bedded sands is penetrated by large numbers of vertical burrows which descend from individual bedding planes (Figure 11.22). The burrows may exhibit complex upward-branching patterns (Figure 11.23). Occasional U-shaped burrows are also seen.

The upper surface of the Red Crag is cut by a number of shallow channels over 10 m across and with a sandy infill and gravelly channel lag at the base. It is not clear whether these channels are contemporaneous with Red Crag deposition or whether they are a later feature associated with deposition of the overlying Pleistocene Sands and Gravels. These overlying deposits are designated as the 'Waldringfield Gravels' and considered to be part of the middle Pleistocene fluviatile Kesgrave Sands and Gravel Formation by Allen (1984). Nearby boreholes have proved an average thickness of just over 4 m for this formation (Allender and Hollyer, 1972).

Interpretation and evaluation

The pit at Waldringfield Heath exposes large, laterally continuous sections in a shallowing-upward sequence in the Red Crag which can be compared to those exposed further north at Vale Farm and Broom Covert.

Conclusions

The section at Waldringfield Heath is an important site for the study of sedimentary environments in the Red Crag and, because of the active working, is continually exposing fresh sections. Excavations beneath the water table mean that material from a vertical sequence of over 13 m of Red Crag can be collected, making this one of the thickest available sequences for study.

NEUTRAL FARM PIT, BUTLEY, SUFFOLK (TM 37155105)

Highlights

The pit at Neutral Farm, Butley, is one of the best known localities which exposes the sediments of the 'Butleyan' stage of the Red Crag.

Introduction

The pit at Neutral Farm lies just south of a small lane linking Butley and Butley Mills. The pit has been known since at least 1871 when it was recorded by Taylor (1871), Bell (1871) and Prestwich (1871b), and may be the same as one described earlier by Wood (1864). Bell (1871) describes the section as 300 feet long (91.4 m) and 35 feet deep (10.7 m). He lists the fossils from the pit which include freshwater and terrestrial molluscs. A further list was given by Bell and Bell (1872). Although not specifically referred to by Harmer (1900a), this pit was later considered to be the type locality for Harmer's Butleyan stage (Ovey and Pitcher, 1948).

Description

At the present time the pit faces are much slipped and overgrown. In the 1970s, over 7 m of Red Crag were exposed (Markham, 1973) (Figure 11.24). The Red Crag is overlain by sandy gravel with quartz and quartzite pebbles typical of the Kesgrave Sands and Gravels (Rose, 1986).

Dixon (1977) described a section of over 6 m of Red Crag. A lower unit 2.55 m thick showed conspicuously cross-bedded shelly sands with foresets indicating a sand transport direction to the south-west. The shell-rich sands ranged from medium- to coarse-grained, with alternations between finer and coarser foreset laminae. A further 1 m of this unit was proved by excavation into the floor of the pit. The dip direction of the foresets indicated a dominant sand transport to the south-west with deposition in water depths of 10–20 m (Dixon, 1979).

The lower unit was unconformably overlain by 3.1 m of burrowed, trough cross-bedded sands which grade upwards into laminated silts and fine sands, reflecting an overall shallowing-upwards in the sequence.

The site has yielded an extensive fauna, with Bell (1871) listing 165 species and varieties of marine mollusc. Dixon (1977) listed over 100 species of mollusc and found that, in common with assemblages in other Red Crag sites in this area, the fauna was dominated by *Mytilus edulis*, *Spisula ovalis*, *Cerastoderma angustatum*, *Macoma obliqua* and *M. praetenuis*, which suggest a shallow nearshore marine environment. He further suggested that species like *Mytilus edulis* may have thrived in rocky areas formed by

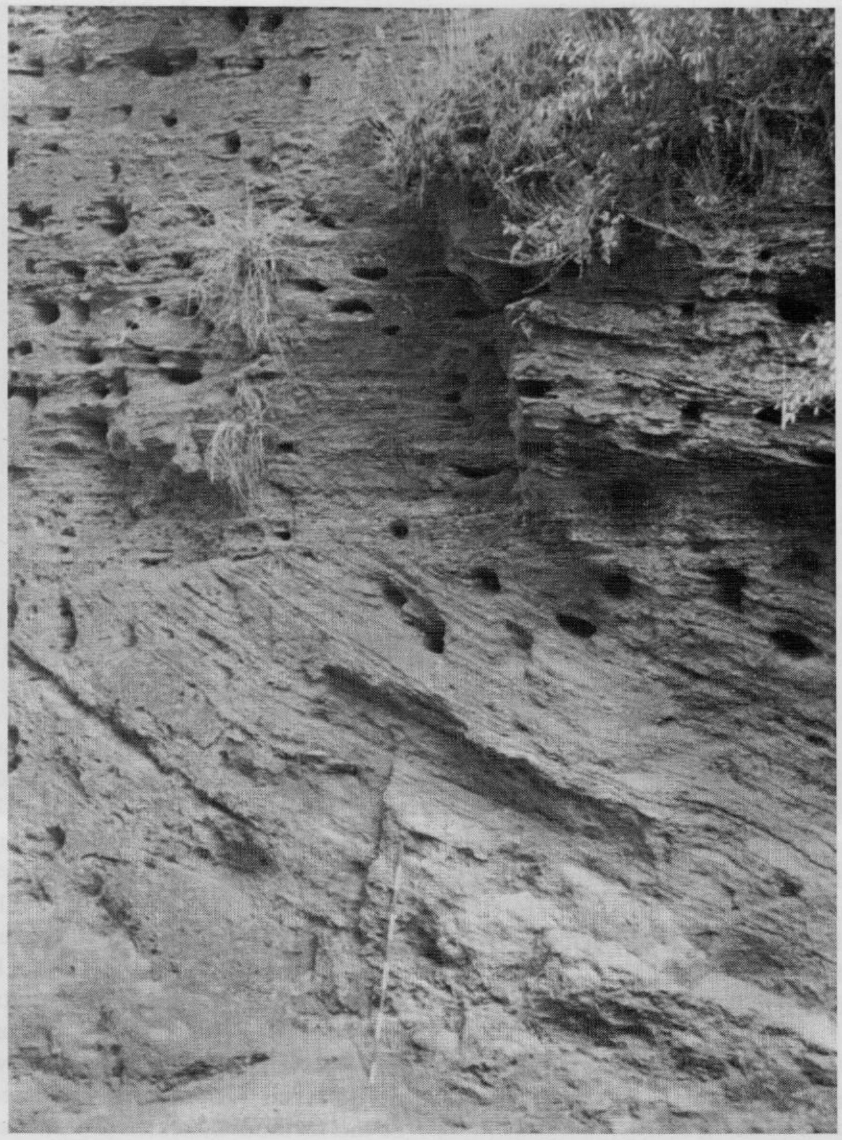


Figure 11.24 The Neutral Farm pit face in 1975 showing large-scale cross-bedding and a sharp horizontal truncation surface. Scale is 1 m long. (Photograph: P. Balson.)

an emergent ridge of Coralline Crag that may have existed a few kilometres to the east. The presence of species such as *Scrobicularia plana*, *Serripes groenlandicus* and *Mya pullus* were believed to be stratigraphically significant, indicating an early Pleistocene age.

Amino acid ratios for *Mya* shells from this site have been determined by Miller *et al.* (1979), but the stratigraphical implications were inconclusive.

The Neutral Farm site has long been known as one of the rare Red Crag sites that have yielded shells of freshwater and terrestrial molluscs. Bell (1871) lists seven species. These shells are believed to originate from sediments just above the unconformable junction between the two units described above (Dixon, 1977).

The foraminifera assemblage of the Neutral Farm Pit has been compared to the pre-Ludhamian zone of the early Pleistocene (Beck *et al.*, 1972) (Figure 8.1). The ostracod fauna is dominated by *Baffinicythere howei*, *Cytheropteron nodosum*, *Finmarchinella logani*, *Kuiperiana venepidermoidea* and *Leptocythere psammophila* (Lord *et al.*, 1988).

Interpretation and evaluation

The section at Neutral Farm is one of the most northerly of the 'classic' Red Crag sites. It lies

1.6 km SE of the borehole at Wantisden designated by Zalasiewicz and Mathers (1985) as the type section for the Red Crag Formation. The Neutral Farm section shows a shallowing-upward sequence which can be compared to those at Orford Lodge to the east and Broom Covert to the south. The sediment transport direction indicated by the foreset dips is to the south-west and was believed by Dixon (1979) to have been influenced by the Coralline Crag 'ridge' approximately 4 km to the east.

Conclusions

The pit at Neutral Farm is an important site for the study of Red Crag stratigraphy as a possible type locality for the 'Butleyan stage'. It is significant as it is one of the very few localities where terrestrial and freshwater molluscs have been recorded in the marine sediments of the Red Crag.

WALTON-ON-THE-NAZE, ESSEX (TM 266234–TM 266238)

Highlights

One of the most important sections in UK Neogene stratigraphy, the cliff section at Walton-on-the-Naze is the type locality of the Waltonian stage and has yielded a marine fauna comprising hundreds of species.

Introduction

The low coastal cliffs just north of Walton-on-the-Naze are one of the most frequently visited sites for the study of the Red Crag. Over 70 publications describe the section or record its fauna. In Crag research (Red and Coralline Crags) this number is exceeded only by the Coralline Crag section at Rockhall Wood, Sutton.

The presence of fossiliferous deposits at Walton-on-the-Naze was first noted by Dale (1704). Parkinson (1811) described the Crag section as being 'twenty or thirty feet' thick (6.1–9.1 m) and 'about 300 paces in length'. These dimensions are of the same order as for the section today but Parkinson may have included some of the overlying Pleistocene sediments within his estimate of the Crag thickness. The location is renowned for its mollusc fauna which was already attracting attention by 1812 (Sowerby, 1812). The site was visited by Charles Lyell in 1829 who made a collection of the molluscs and subsequently figured the sections in the first edition of *Principles of Geology* (Lyell, 1830–1833).

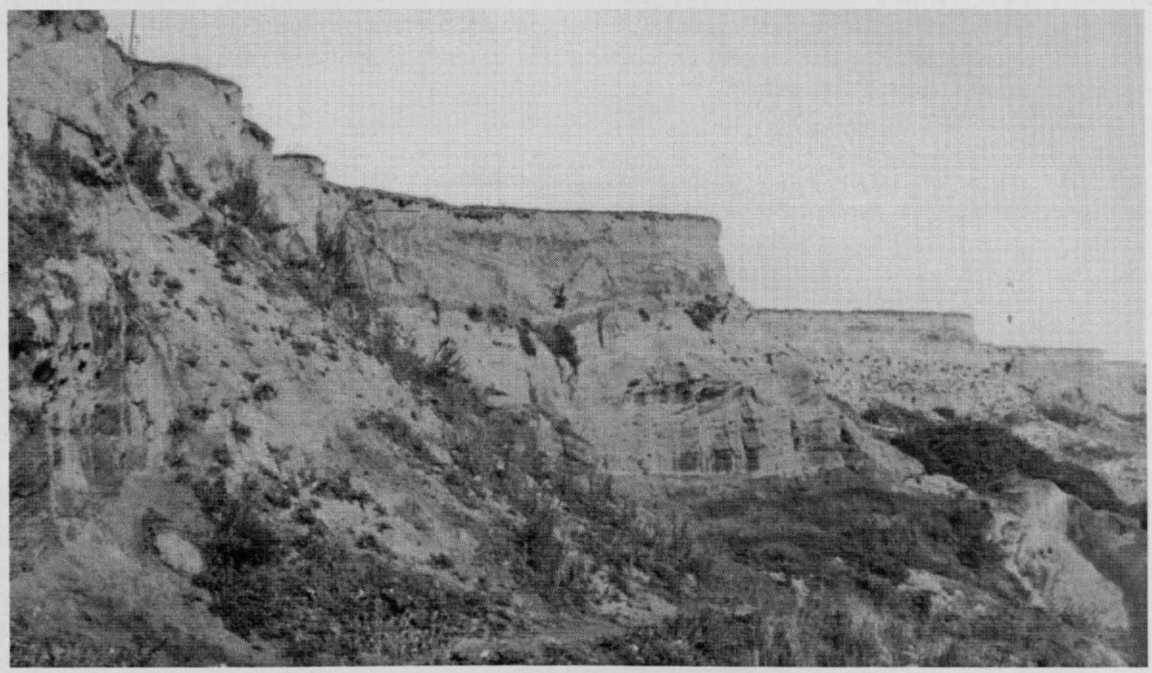


Figure 11.25 Walton-on-the-Naze. View looking north showing the slumped undercliff and low cliffs of Red Crag overlain by Pleistocene sands and gravels. (Photograph: P. Balson.)

Figure 11.26 Cross-bedded Red Crag sediments, Walton-on-the-Naze. Lower limit of decalcification is arrowed. Graduations on scale = 10 cm. (Photograph: P. Balson.)

The Red Crag is exposed in natural cliff sections on the east side of The Naze (Figure 11.25), an area of high ground just north of the town where coastal erosion causes cliff recession of just over 0.5 m/year (Gray, 1988). The cliffs are fronted by numerous active slumps. The degree of exposure of the Red Crag is dependent on the extent of the frequent slumping. The section can change rapidly and features which are visible one year may be gone the next.

Wood (1859, p. 33) considered the sediments here to represent 'the type of the Red Crag' when compared to other localities which he regarded as 'disturbed', i.e. which contained a much higher proportion of reworked material. The section is the type locality for the 'Waltonian' stage of Harmer (1900a), the oldest of his three stages of the Red Crag and which showed a significantly warmer water fauna compared to that of localities further north.

In the mid-19th century, a shell of the bivalve *Glycymeris* with a crudely carved representation of a human face upon it was alleged to have been found *in situ* within the marine sediments of the Red Crag at Walton-on-the-Naze (Stopes, 1882). Although its authenticity and antiquity were later questioned (e.g. Christy, 1914) it played a part in the controversial debate over the antiquity of humans in the early part of the 20th century.

This site was also independently selected for its fossil plants, birds and Quaternary stratigraphy content, a more detailed account of which can be found elsewhere in the GCR series (*Mesozoic to Tertiary Palaeobotany of Great Britain* (Cleal and Thomas, in prep.); *Fossil Mammals and Birds of Great Britain* (Benton *et al.*, in prep.); *Quaternary of East Anglia and the Midlands* (Allen *et al.*, in prep.)).

The Palaeogene geology of this site is discussed in Chapter 3.

Description

At Walton-on-the-Naze, Red Crag sediments are exposed for several hundred metres overlying the Eocene London Clay Formation (see Chapter 3) in low slumped cliffs. The thickness of the formation varies laterally from approximately

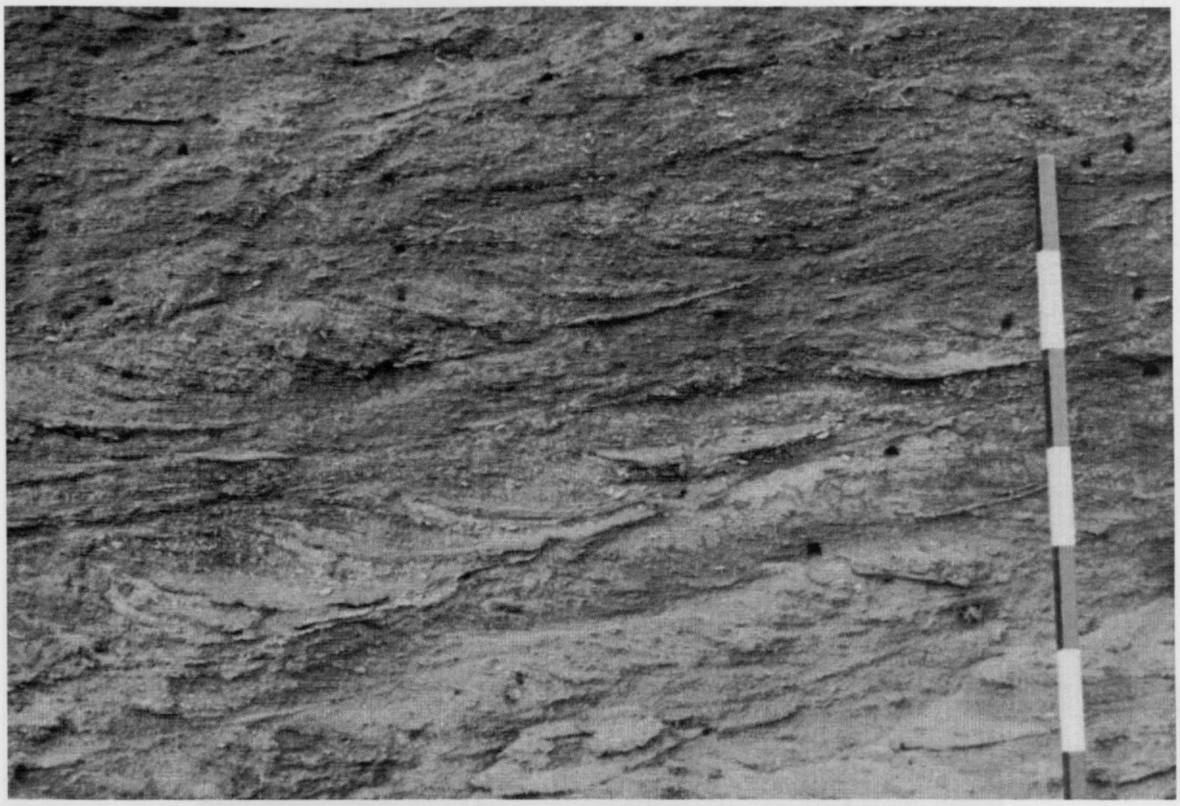


Figure 11.27 Small-scale cross-bedding reflecting migration of smaller bedforms (possibly ebb-oriented) up the face of a larger sandwave. Graduations on the scale = 10 cm. (Photograph: P. Balson.)

Figure 11.28 Shell layer in Red Crag showing characteristic convex-upward orientation of bivalve shells. Coin is 30 mm in diameter. (Photograph: P. Balson.)

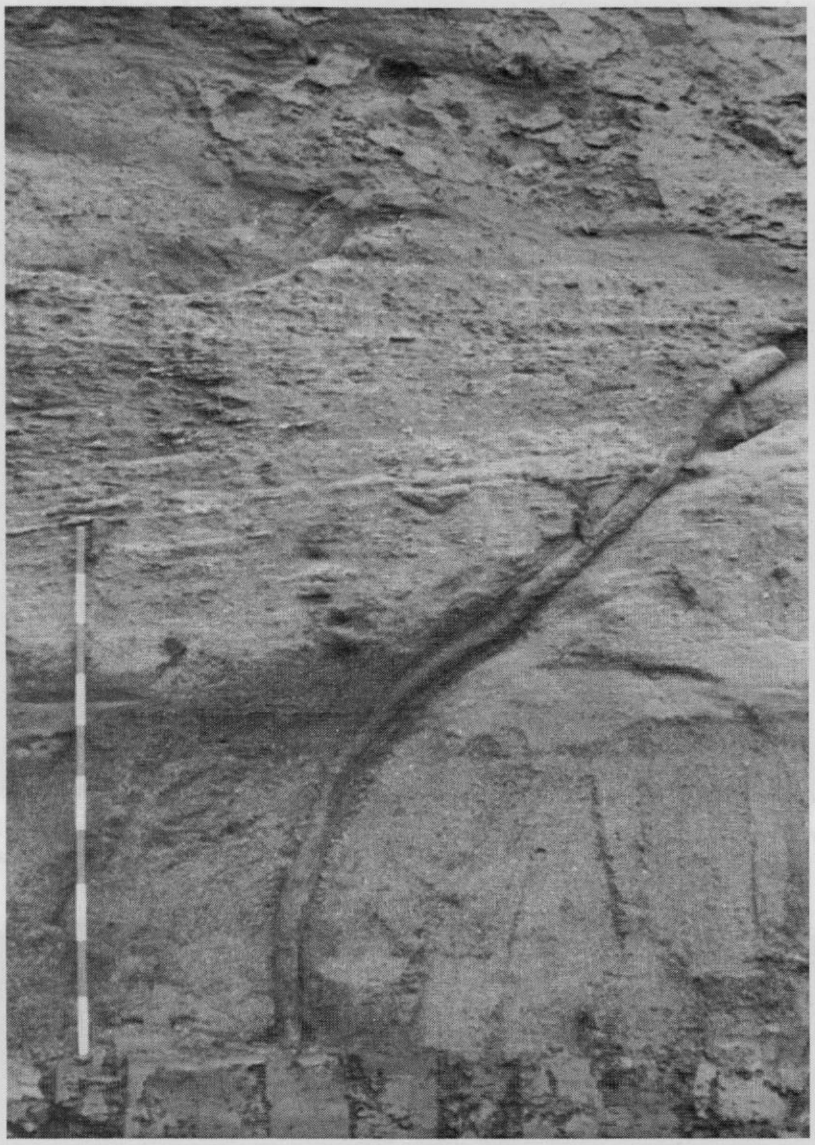


Figure 11.29 Very large trace fossil ascribed to *Psilonichnus* by Humphreys and Balson (1988). Scale is 1 m long. (Photograph: P. Balson.)

4 to 5 m at the south end of the exposed section to wedge out as the cliff height diminishes northwards. The thickness at the present time is thus comparable with the section of 15 feet 6 inches (4.72 m) seen in 1863 (Kendall, 1931). The basal contact of the Red Crag lies at approximately 15 m OD and is often marked by a prominent spring line in the cliff which is largely responsible for the frequent slumping. The unconformity surface is also marked by a discontinuous conglomeratic lag deposit a few centimetres thick consisting mostly of small, rounded, polished phosphatic mudstone pebbles. Occasional 'boxstones' occur. The basal sediments have also yielded many well-preserved and articulated bivalves in the past. Bell (1911, 1912) placed this fauna within the Boytonian Stage, which together with the Gedgravian, constituted the time represented by Coralline Crag deposition. Therefore, Bell considered the fauna of the lowermost sediments of the Red Crag at Walton-on-the-Naze to be equivalent in age to part of the Coralline Crag. The Red Crag is overlain by up to 5 m of middle Pleistocene deposits (Figure 11.30). Compared to the Red Crag, these deposits have received relatively little attention. The deposits show periglacial involutions and ice wedges which may penetrate the Red Crag and be associated with diapirs of the underlying London Clay (Hails and White,

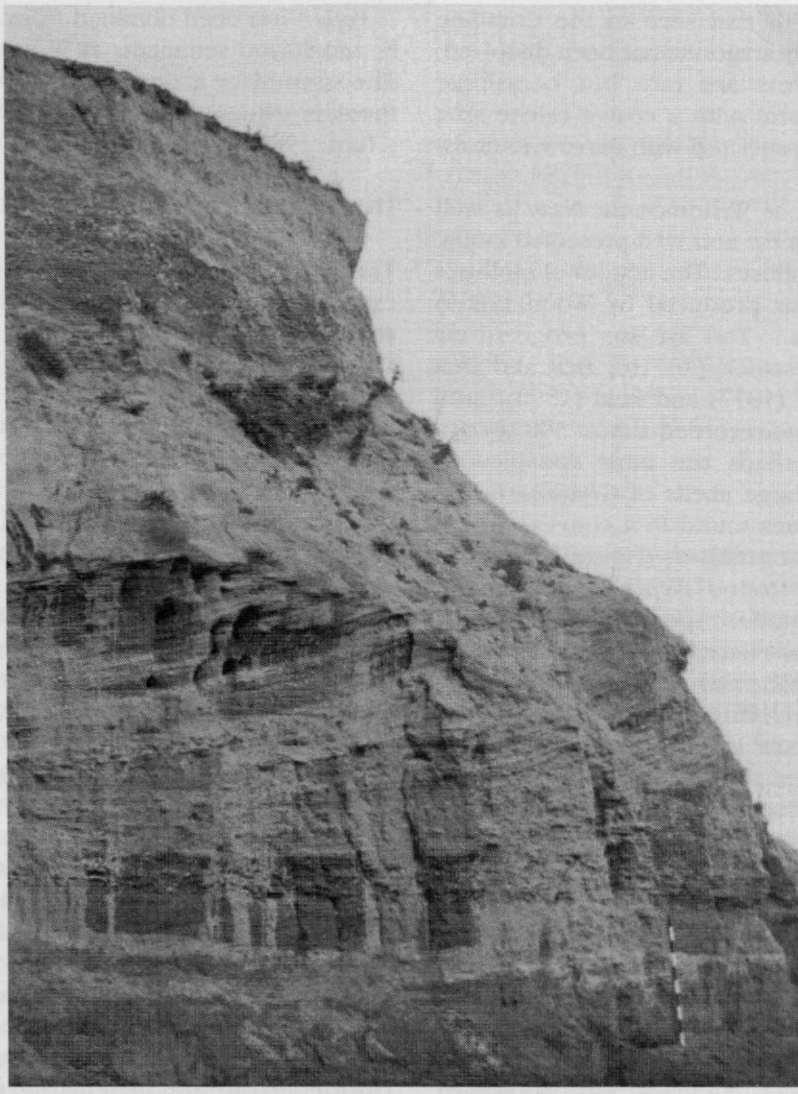


Figure 11.30 Cross-bedded Red Crag at Walton-on-the-Naze overlain by Pleistocene sands and gravels. Scale is 1 m long. (Photograph: P. Balson.)

1970). These Pleistocene deposits are described in more detail by Bowden *et al.* (1995) and Allen *et al.* (in prep.).

The Red Crag sediments consist of marine, shelly, quartz-rich sands conspicuously stained with iron oxides from which the Red Crag takes its name. Small pebbles including phosphatic nodules and clasts of London Clay may be common within the Red Crag sediments in some parts of the section. Phosphatic pebbles washed out of the Red Crag were occasionally exploited from the beach during the 19th century (Whitaker, 1877). The sediments are often cross-bedded (Figure 11.26), indicating deposition by submarine sandwaves, with the foresets dipping predominantly to the south-west. Smaller scale cross-bedding with dip directions opposed to the main foreset dip direction can be seen comparable to that at Bawdsey and probably representing deposition from the subordinate tidal current. In contrast to Bawdsey, however, the dominant direction represented by the large-scale cross-bedding at Walton-on-the-Naze is southwards and is thus similar to the subordinate direction shown by the smaller-scale cross-bedding at Bawdsey. The foresets at Walton-on-the-Naze show evidence of cyclic deposition which may reflect tidal rhythms (Figure 11.27).

The uppermost metre or so of the Red Crag sequence may be completely devoid of carbonate due to post-depositional leaching. The undulose lower boundary of this leached zone often cuts across the cross sets and other sedimentary structures (Figure 11.26). This dissolution contrasts with that seen in the Coralline Crag in which only aragonite has been dissolved. Carbonate cements are rare but occasional patches of sediment with a coarse calcite spar cement may be associated with narrow joint fissures.

The Red Crag at Walton-on-the-Naze is well known for its diverse and well-preserved fauna, particularly of molluscs. The first list of molluscs from this site was produced by Wood (1866) with 118 species. The list was progressively increased by Prestwich (1871b), Bell and Bell (1872), Whitaker (1877) and Reid (1890), until Kendall (1931) had recorded almost 300 species of mollusc. Perhaps the most conspicuous species are the large shells of *Glycymeris glycymeris*, sometimes found in a convex-upward orientation, in distinct layers (Figure 11.28), and the sinistral gastropod *Neptunea contraria*. Other common mollusc species include *Spisula ovalis*, *Spisula arcuata*, *Aequipecten opercularis*, *Pholas cylindrica*, *Cerastoderma* spp., *Hinia reticosa*, *Hinia granulata* and *Natica* spp. Other fossils include the solitary coral *Balanophyllia* and the small irregular echinoid *Echinocyamus pusillis*. An extensive list of the fauna from this locality was given by Whitaker (1877) and Kendall (1931). Trace fossils found here include small *Skolithos* and occasional very large vertical burrows, sometimes up to 2.5 m long (Figure 11.29), ascribed to the ichnogenus *Psilonichnus* by Humphreys and Balson (1988). Terrestrial mollusc shells, which are extremely rare in the Red Crag, have been recorded at Walton (Bell, 1884; Kennard and Woodward, 1900).

The majority of the section at Walton-on-the-Naze consists of subtidal cross-bedded shell sands deposited by migrating sandwaves. Water depth was interpreted as 20–30 m by Dixon (1979). Strong tidal currents were able to transport large shell fragments and small pebbles. In-situ fauna is rare, as in the case of the cross-bedded Coralline Crag at Crag Farm (see Chapter 10), although some units are extensively burrowed. The abundance of the benthic foraminifer *Pararotalia serrata* indicates warm temperate conditions (Funnell and West, 1977). Dinoflagellates such as *Tectatodinium pellitum* also suggest temperatures warmer than the present North Sea (Hunt, 1989).

Pollen has been obtained from some relatively unoxidized sediments at Walton-on-the-Naze. The assemblage is dominated by tree pollen but there is evidence of nearby coastal saltmarsh (Hunt, 1989).

Interpretation and evaluation

The section of Red Crag at Walton-on-the-Naze is extremely important in the study of UK Neogene stratigraphy. The site gave its name to the Walton Crag of Wood (1866) and the Waltonian Stage of Harmer (1900a) which later became synonymous with the Red Crag Formation (Mitchell *et al.*, 1973b). As a stratotype, the section at Walton-on-the-Naze leaves much to be desired. Firstly, the basal part of the sequence has formerly been assigned to another stage, the controversial Boytonian (Bell, 1911, 1912). Secondly, the sequence is dominated by large-scale cross-stratified sets which result from the migration of large marine bedforms. Evidence from the rhythmic bedding which may reflect tidal cyclicity indicates that deposition took place rapidly and therefore a single cross-stratified set represents only a few months or years of deposition as the bedform migrated laterally at rates of several tens of metres per year. Superposition by the next cross-stratified set may not have taken place immediately but it is likely that the entire sequence represents no more than a few decades of deposition.

Pollen is extremely rare in the Coralline and Red Crags because of their generally sandy and oxidized nature and their marine facies. The discovery of pollen and other organic walled microfossils at Walton-on-the Naze is thus especially important. The pollen assemblage is closely comparable with the Late Pliocene Reuverian 'C' assemblages of the Netherlands (Hunt, 1989).

Conclusions

In terms of number of species, the Red Crag at Walton-on-the-Naze is one of the most fossiliferous of all UK Neogene localities. One of the earliest recorded sections in the Red Crag, and often cited as the earliest formation in the British Quaternary, the cliff section at Walton-on-the-Naze is one of the most important Neogene sections in Europe.