British Tertiary Stratigraphy

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Chapter 3

London Basin: eastern localities

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INTRODUCTION

To the east of London, the outcrop of Palaeogene strata is bounded to the south by the North Downs and to the north by the extension of the Chiltern Hills towards East Anglia. Throughout much of the area, it occurs below a cover of Quaternary deposits, although in the north-east it is overlain unconformably by Neogene strata. Although once considered to represent a more or less continuous depositional sequence, these Palaeogene strata are now known to contain major breaks in the succession (Figure 3.1).

Numerous publications reflect an interest in the Palaeogene geology of this area extending over a period of more than two hundred years. More recent research in part reflects the extensive investigation of the thick Palaeogene succession in the North Sea area and the opportunity to clarify the origin and age of the onshore succession that this has provided.

At one time, numerous clay and sand pits provided a large number of exposures in the Palaeogene deposits of this area. Nowadays, these are relatively few, of which three were selected for the GCR: Lower Upnor Sand Pit, Charlton Sand Pit and Elmstead Rock Pit (Figure 3.2). Of the three coastal Palaeogene GCR sites in Kent, those of Pegwell Bay and Herne Bay are particularly important for strata older than the London Clay. That of Sheppey Cliffs is especially famous as the source of much of the 'London Clay Flora', whilst well to the north of the Thames, the stratigraphically restricted but significant sites of Wrabness, Harwich and Walton-on-the-Naze provide testimony of early Palaeogene vulcanism and links with the extensive Palaeogene succession to the east, present beneath the North Sea (Figure 3.2). Correlation across the London Basin showing the relationship between the component units of the Thanet Sand Formation, Lambeth Group and Thames Group is shown in Figure 3.3.

Recent revision of the stratigraphical nomenclature has clarified relationships between the various units of the Palaeogene in the London Basin and East Anglia (Ellison *et al.*, 1994) but has in some cases changed the meaning of certain stratigraphical terms. To avoid confusion in this geographical area with regard to the meaning of London Clay, 'London Clay' (with inverted commas) is used for the former broader usage (i.e. including the former Harwich Member)

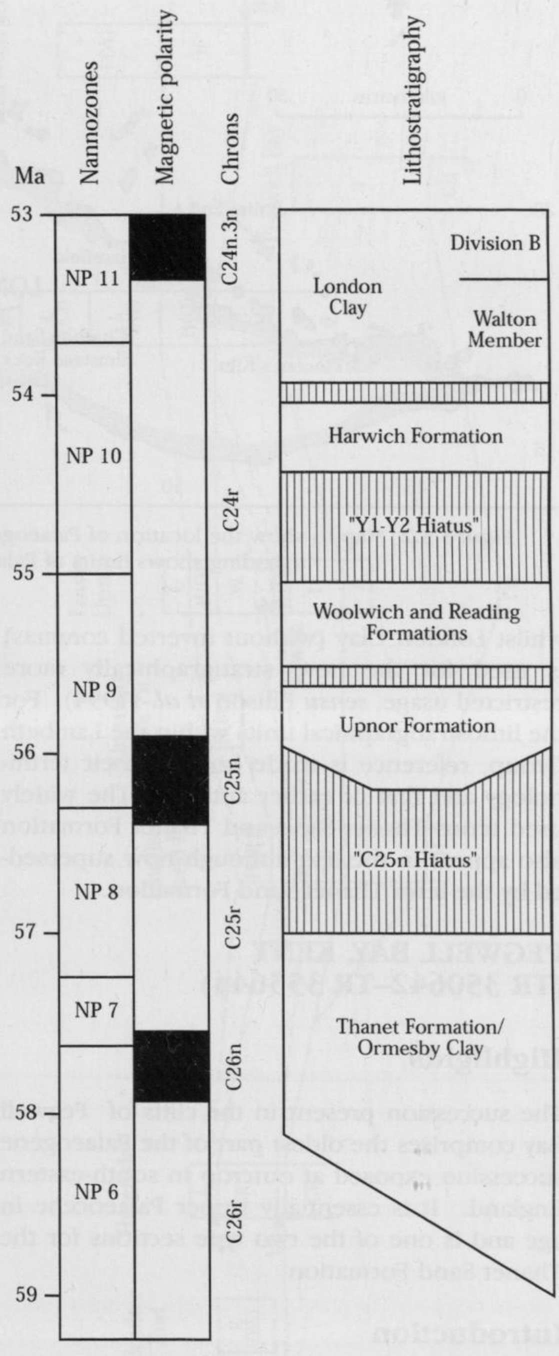

Figure 3.1 Nannozones and the lithostratigraphical and magnetostratigraphical succession in the eastern part of the London Basin, together with the major hiatuses (after Ali and Jolley, 1996, fig.12). Normal polarity: black; reverse polarity: white.

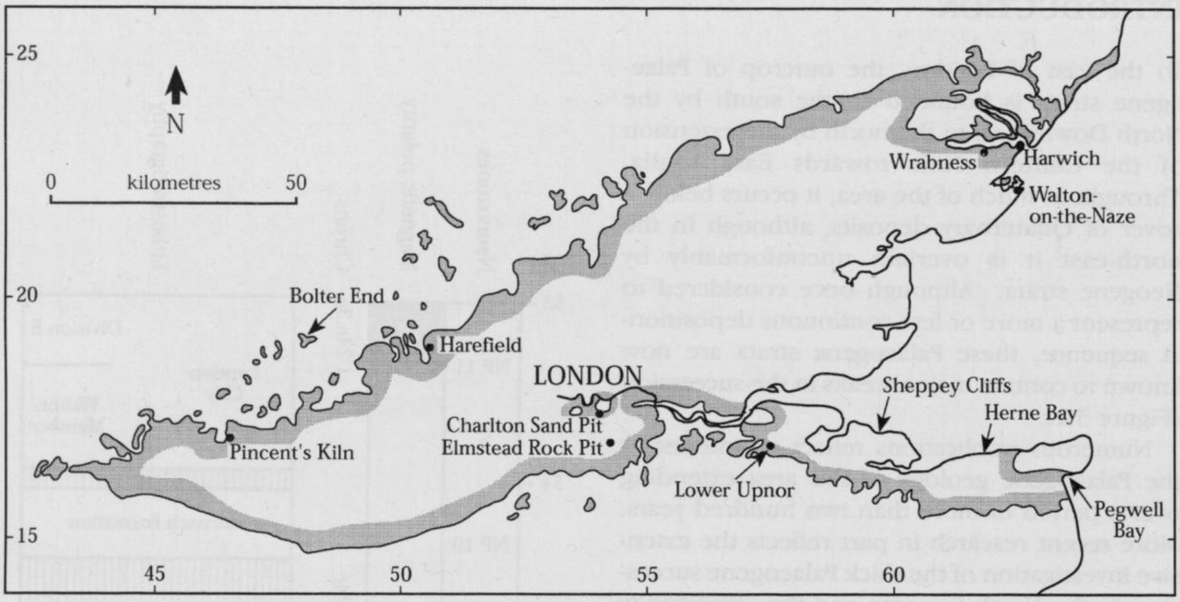

Figure 3.2 Map to show the location of Palaeogene stratigtaphy GCR sites in the London Basin area (shading shows limits of Palaeogene together with outliers).

whilst London Clay (without inverted commas) is used for the new, stratigraphically more restricted usage, *sensu* Ellison *et al.* (1994). For the lithostratigraphical units within the Lambeth Group, reference is made both to their terminology and that of earlier authors. The widely used terms Thanet Sand and Thanet Formation also appear in the text although now superseded by the term Thanet Sand Formation.

PEGWELL BAY, KENT (TR 350642–TR 355644)

Highlights

The succession present in the cliffs of Pegwell Bay comprises the oldest part of the Palaeogene succession exposed at outcrop in south-eastern England. It is essentially Upper Palaeocene in age and is one of the two type sections for the Thanet Sand Formation.

Introduction

Although older Palaeocene sediments are present in Norfolk, the oldest to occur at outcrop are those of Pegwell Bay (Figure 3.4; see Cox *et al.*, 1985; Knox *et al.*, 1990; Jolley, 1992). Hence, as the site where the oldest exposure of Palaeogene rocks in Britain occurs, the importance of Pegwell Bay is indisputable. Formerly, a single continuous section existed on the northern side of Pegwell Bay (see Shepard-Thorn, 1988, plate 7). This was truncated in the 1970s by an access road to the newly developed Ramsgate International Hoverport, leaving two smaller sections, the easterly of which has been called the 'Cliffs End Section' (TR 355644) and the westerly the 'Car Park Section' (TR 350642) by Ward (1977). At the former, some 7.5 m of the Thanet Formation rests unconformably on the Upper Cretaceous Chalk, whilst at the latter, a few metres of the upper part of the Formation occur below a drift cover.

The section of Palaeogene sediments in Pegwell Bay has interested geologists since the middle of the 19th century when it was first described by Prestwich (1852). He was the first to use the term Thanet Sands for these sediments, although subsequently, Whitaker (1866, 1872) considered the term Thanet Beds more appropriate to a unit comprising a variety of lithologies, as for example here at Pegwell Bay where muds, silts and sands overlie the basal rudaceous Bullhead Bed.

Other early accounts were given by Gardner (1883), Burrows and Holland (1897), whose paper on the foraminifera of the Thanet Beds included a detailed measured section, and White (1928), who gave an excellent account of the succession and its fauna. After the hoverport was built, the section was re-described by Ward

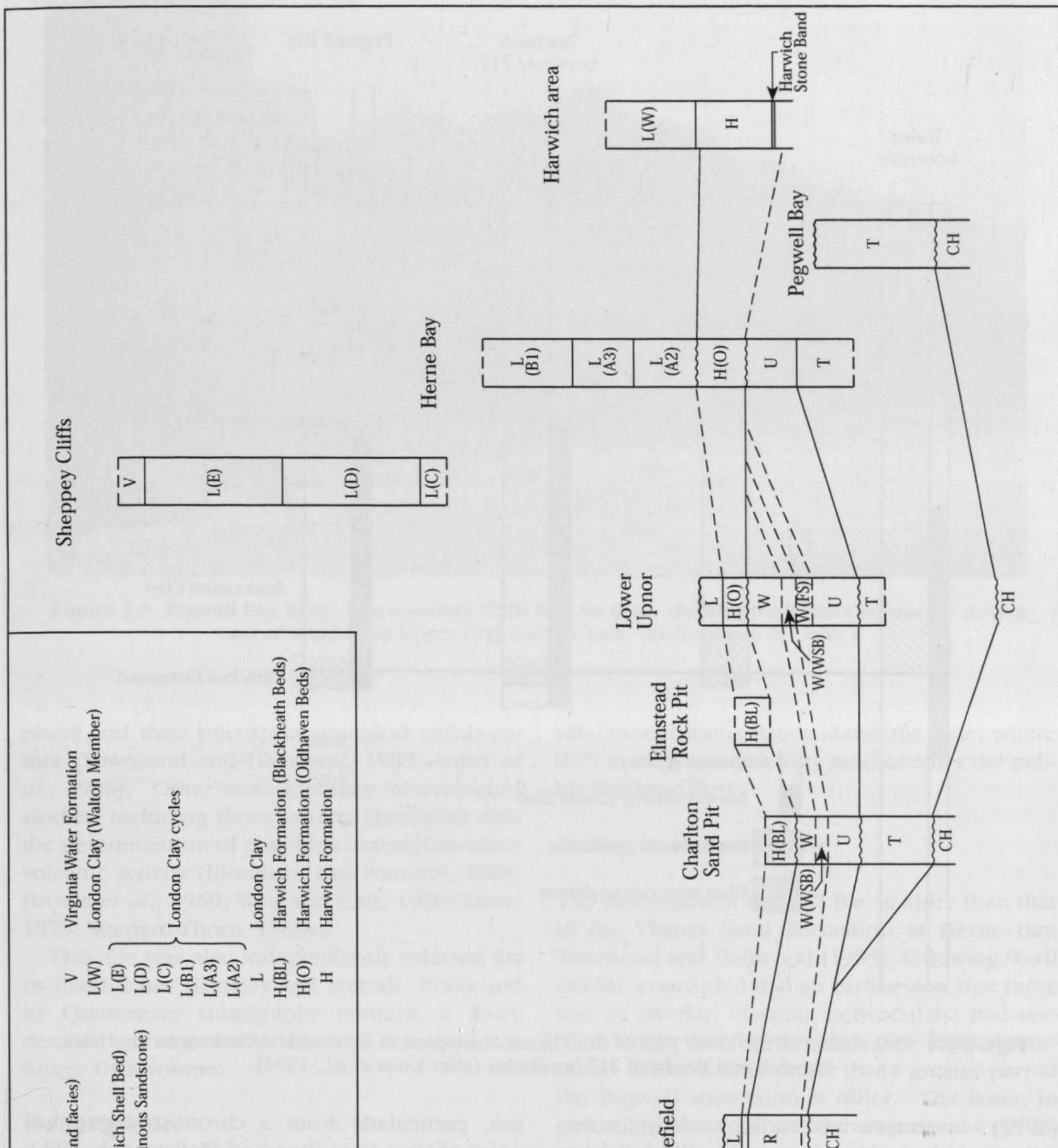

Figure 3.3 Lithostratigraphical correlation of Palaeogene sites in the London Basin.

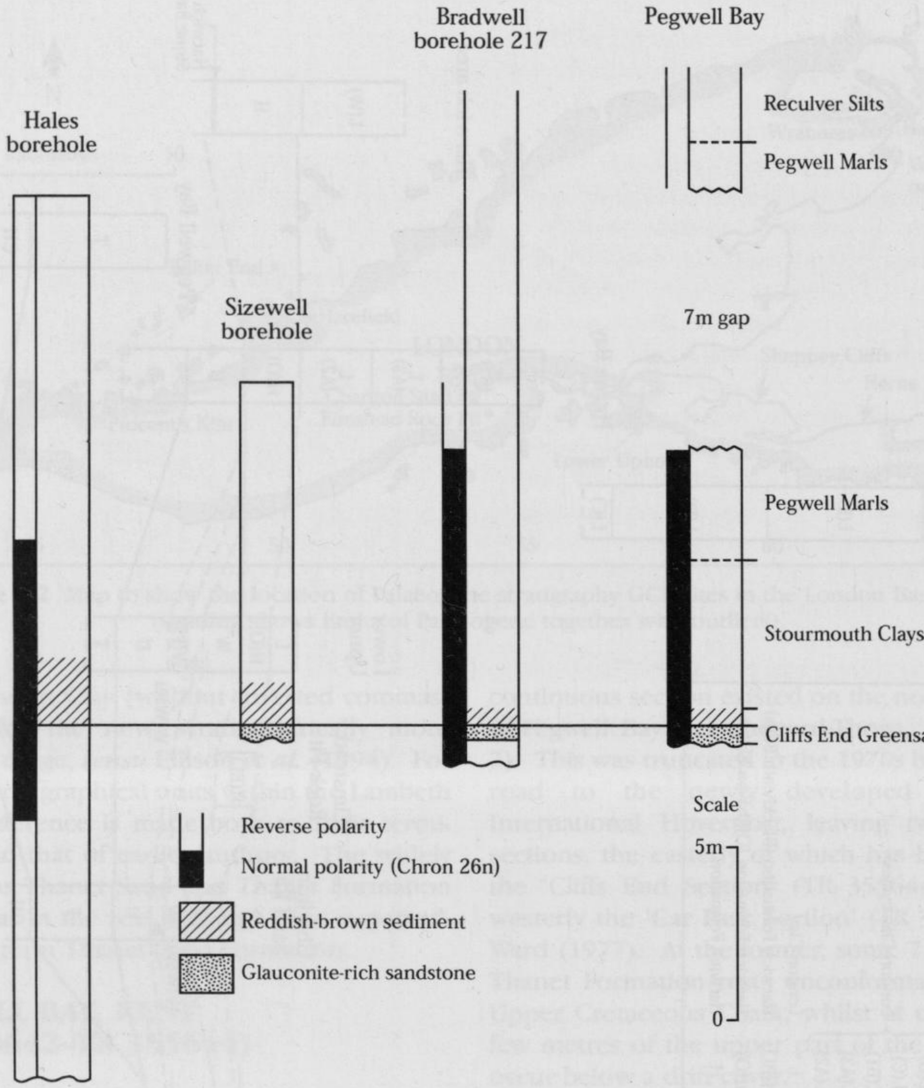

Figure 3.4 Correlation of the lower part of the Thanet Formation in Kent with sediments in the Hales, Sizewell and Bradwell 217 boreholes (after Knox *et al.*, 1994).

(1977) who summarized earlier work on the section, including the stratigraphical subdivision and nomenclature of earlier authors.

The latter part of the 20th century has witnessed the development of a renewed interest in the micropalaeontology of this site. The foraminifera were studied by Haynes (1955, 1956–1958) and included those reworked from older strata (Haynes and El-Naggar, 1964). The section was sampled by Downie *et al.* (1971) and later by Powell *et al.* (1996) as part of broader studies of dinoflagellate associations in south-eastern England, whilst a number of workers have investigated it for calcareous nannoplankton, particularly from a chronostratigraphical point of view (Hamilton and Hojjatzadeh, 1982; Aubry, 1983, 1986; Godfrey and Lord, 1984; Aubry *et al.*, 1986; Siesser *et al.*, 1987). Other palaeontological work includes that of Stinton (1965a), as part of his broader investigation of the 'Lower London Tertiaries', whilst a list and distribution of the macrofauna was given by Ward (1977).

A need to date the oldest of the exposed onshore Palaeogene rocks in south-eastern England led to their radiometric dating, using glauconites from this section (Fitch *et al.*, 1978a, b) and the attention of the magnetostratigra-

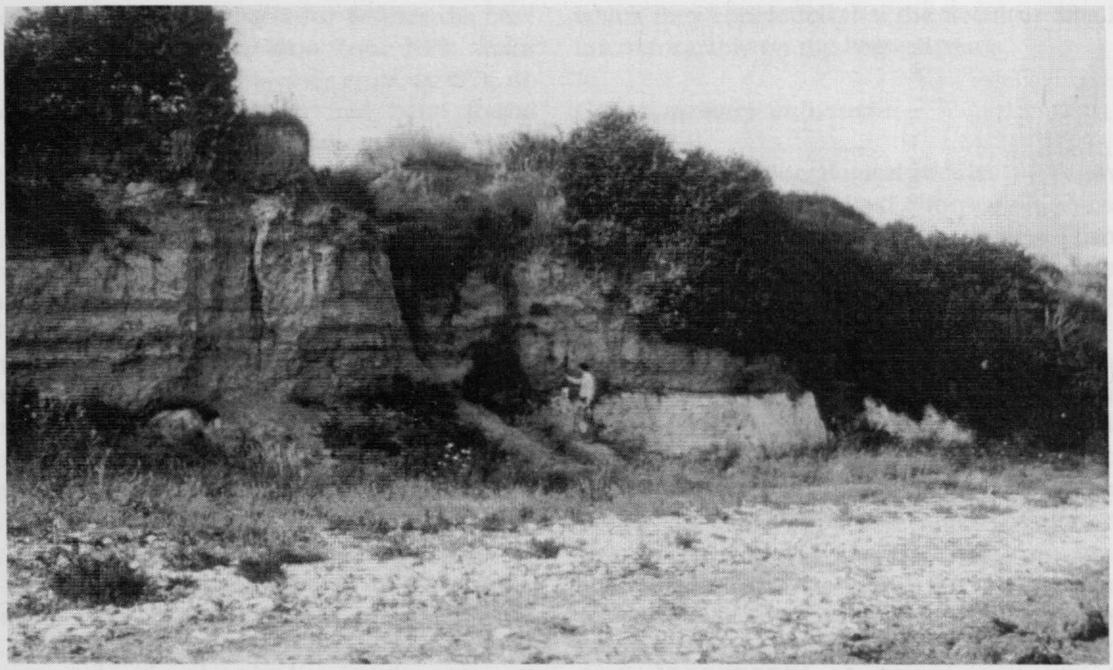

Figure 3.5 Pegwell Bay, Kent. The so-called 'Cliffs End Section', showing the Thanet Formation resting unconformably on Upper Cretaceous Chalk. (Photograph: B. Daley.)

phers and their micropalaeontogical collaborators (Townsend and Hailwood, 1985; Aubry *et al.*, 1986). Other work includes mineralogical studies, including those aspects associated with the determination of possible contemporaneous volcanic activity (Blondeau and Pomerol, 1968; Brown *et al.*, 1969; Weir and Catt, 1969; Knox, 1979; Shepard-Thorn, 1988).

This site was also independently selected for its fossil fishes (Dineley and Metcalf, 1999) and its Quaternary stratigraphy content, a more detailed account of which will be discussed in a future GCR volume.

Description

At Pegwell Bay (Figure 3.5), the Thanet Sand Formation rests unconformably on Upper Santonian Chalk of the *Marsupites testudinarius* Zone (Pitcher, 1958), with the famous Bullhead Bed, comprising unworn, green-coated (by glauconite) flints, at the base (Ward, 1977, fig. 5).

Lithological succession

The Thanet Sand Formation (Figure 3.6) is some 24 m thick in Pegwell Bay and, according to Ward (1977), mainly comprises clays, marls and silts, except immediately above the base, where 0.75 m of glauconitic silty sand overlies the pebbly Bullhead Bed.

Dating and correlation

The succession at Pegwell Bay is older than that of the Thanet Sand Formation at Herne Bay. Townsend and Hailwood (1985), following Ward (1978), concluded that an earlier view that there was an overlap of strata between the two sections might not be the case (see later discussion). There is little doubt that a greater part of the Pegwell succession is older. The latter, in particular, has attracted the attention of geologists, since the section provides the opportunity to determine conditions at the time when the Palaeogene sea first began to transgress this part of the south-eastern British area. Dating the succession palaeontologically has not been without difficulty, since the lowest part of the succession contains no fossils suitable for this purpose. Haynes (1956), however, recognized four foraminiferal faunules from the middle and upper strata here and concluded from pelagic foraminiferids found at Reculver (TR 224693) that the succession was Upper Palaeocene in age (Haynes, 1955, p. 189). He doubted the value of

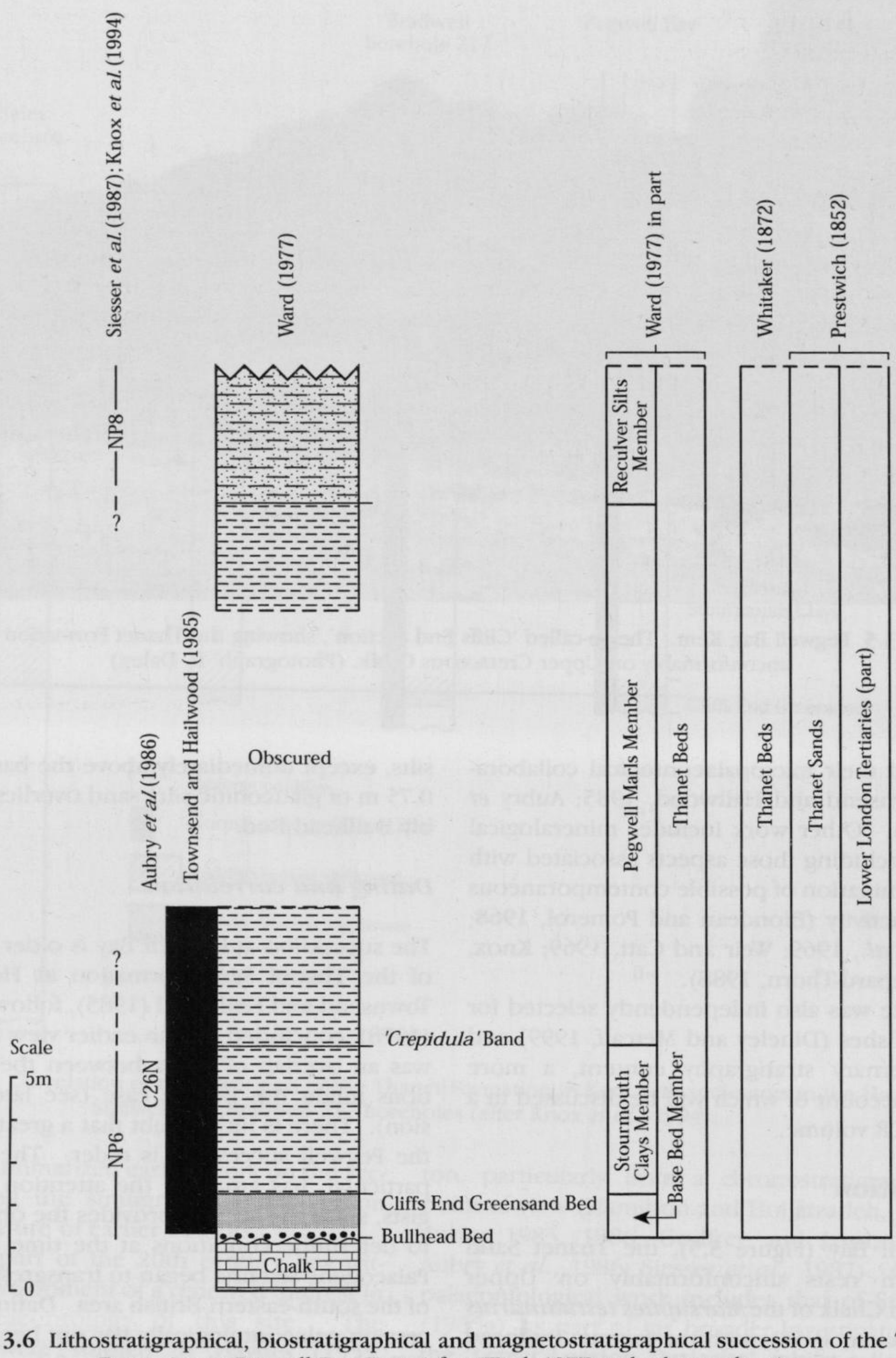

Figure 3.6 Lithostratigraphical, biostratigraphical and magnetostratigraphical succession of the Thanet Formation at Pegwell Bay, Kent (after Ward, 1977 and other authors).

the term Thanetian, suggesting that the Thanet Beds were deposited in the first half of the Landenian cycle and should be referred to the Lower Landenian Substage (lower Upper Palaeocene) (see also further discussions of the Thanetian in the account of Bishopstone Cliffs, Herne Bay).

Aubry (1986) found only reworked Cretaceous nannoplankton at Pegwell Bay. However, towards the top of the section in the Reculver Silts, both Hamilton and Hojjadzadeh (1982) and Godfrey (1984) found *Heliolithus* *riedeli*, whose first occurrence defines the base of calcareous nannoplankton Zone NP8. Prior to the investigations of Siesser *et al.* (1987), no indigenous nannoplankton had been found below this level, but these authors obtained the latter from a 4 cm band near the top of the Stourmouth Clays Member (almost certainly from the 'Crepidula Band' at the base of the Pegwell Marls, according to D.J. Ward, pers. comm.) and from their findings determined an NP6/7 date. Apart from this occurrence, no other indigenous nannoplankton have been found here below the Reculver Silts. More recently, comparisons with richer and better preserved material from coeval strata in the Bradwell (Essex) borehole led Knox *et al.* (1994) to conclude that the basal part of the succession at Pegwell lies within the upper part of NP6.

Pegwell Bay has also provided an opportunity for dating these oldest exposed Palaeogene strata of Britain by other techniques. Using glauconites from the 'basal' Thanet Beds of Pegwell, Fitch *et al.* (1978a) obtained an age of 59.5 ± 0.9 Ma. Townsend and Hailwood (1985) found that all samples from the Thanet Sand Formation in Pegwell Bay have a normal polarity magnetization and from this evidence established the Thanet magnetozone. Subsequently, with Aubry (Aubry *et al.*, 1986), they concluded that this normal polarity magnetozone may be correlated with zones NP6–NP7 and Chron 26N. Knox *et al.* (1994) believed that the base of the succession lies somewhere within the lower part of the latter.

Local hinterland

Derived fossils are not without their uses and their occurrence in the strata at Pegwell Bay has provided some insight into the nature of the hinterland at the beginning of Palaeogene times. Haynes and El-Naggar (1964) found that the microfauna of the Bullhead Bed was entirely silicified and derived from the Campanian Chalk with no derived material from the Danian. More recently, Siesser *et al.* (1987) found the nannoplankton species *Bianthollthus sparsus* in a number of samples from this locality. Since this species is thought to have become extinct in Zone NP4, derivation from earlier, but locally non-surviving, Palaeocene strata is implied.

Recent work by Powell *et al.* (1996) recognized the presence of two dinoflagellate cyst 'sequences' in the Pegwell Bay section, from which they concluded that the Reculver Silts lie unconformably on the Pegwell Marls.

Contemporary vulcanism

A number of mineralogical studies of Pegwell Bay material have provided information on contemporary volcanic events. The lowest Thanet Beds here contain euhedral, and hence non-detrital, crystals of the zeolite mineral clinoptilolite, a mineral often formed by the alteration of glassy and other volcanic minerals (Brown *et al.*, 1969; Weir and Catt, 1969). In a later study, Knox (1979) identified igneous grains in association with these zeolites at this locality and concluded that both had originated from contemporary ash falls comparable in age to tuffs from the North Sea and to the main phase of Hebridean vulcanism. The 45–65% of smectite (Ca-montmorillonite) reported by Wheatley (in Shepard-Thorn, 1988) from the Basal Thanet Beds is compatible with this suggestion (cf. discussion in Gilkes, 1968).

Interpretation and evaluation

The exposures of the Thanet Sand Formation on the northern side of Pegwell Bay are of considerable significance. The section here provides the earliest onshore evidence of the beginnings of the long period of clastic sedimentation in southern England extending from Palaeocene to at least Oligocene times. Moreover, Pegwell Bay exposes part of the first of the many transgressive units that characterize the Palaeogene succession of southern England.

The Thanet Sands Formation may be seen elsewhere, such as Herne Bay and Lower Upnor, but at neither of these localities are the lower beds and the unconformable contact with the underlying Chalk exposed. Both Ward (1977) and Shepard-Thorn (1988) referred to Pegwell Bay as the type locality, although, as the former author pointed out, it can only be inferred that it is the original type section for the Thanet Sands since Prestwich (1852) did not overtly cite it as such.

Dating the succession

Determining the age of the Pegwell Bay section is very important regarding an interpretation of British Palaeogene history, since it includes the oldest Palaeocene exposed at outcrop of the

British 'onshore' succession. The precise age of the formation, particularly its lower part, was for some time disputed (see discussion in Aubry *et al.*, 1986), but moved closer to resolution following the work of Siesser *et al.* (1987) and was recently resolved by Knox *et al.* (1994). There is now no doubt that the upper part of the succession at Pegwell Bay is entirely of NP8 age, since the suggestion by Godfrey and Lord (1984) that NP9 was present at the top of the sequence here was based on their incorrectly identifying a single specimen of *Heliolithus* as the NP9 zone fossil *Discoaster multiradiatus* (Siesser *et al.*, 1987, p. 95). However, the fossil composition of the lower 4 cm nannoplankton band of the latter authors was ambiguous. The problem was that whilst this band has nannoplankton indicative of NP6, they were unable to find any trace of *Discoaster mohleri*, the species whose first occurrence indicates NP7. Their conclusion was that this band was either in NP6 or was in NP7 with *D. mohleri* absent for environmental or diagenetic reasons. In fact, Siesser *et al.* (1987) concluded that they would choose 'to make a conservative assignment' of this horizon to NP6/7, since their material did not enable them to resolve the matter further. These authors suggested that at least the lowermost 4.2 m of the succession be similarly assigned.

In a subsequent paper on Thanetian and early Ypresian chronostratigraphy, Knox (1990) proposed that the basal 8 m of the formation at Pegwell be assigned to NP6/7 whilst preferring an NP7 age with the second of Siesser *et al.*'s (1987) alternatives above invoked to explain the absence of the characteristic zone fossil. Only more recently has the age been confirmed as NP6 by Knox *et al.* (1994) (see above).

Origin and age of the Bullhead Bed

The Bullhead Bed at the base of the succession has generated a great deal of discussion over many years. Although Gardner (1883), Boswell (1917) and Wooldridge (in Dewey *et al.*, 1925) considered it a basal conglomerate, it is not in the conventional sense of this term. It does not comprise the round, and hence transported, often black, flints that characterize most of the pebble beds in the remainder of the Palaeogene of south-eastern England, but instead consists of flints that are green-coloured and unabraded.

Such features have caused a great deal of speculation over its origin (see discussion in Smart *et al.*, 1966, p. 177). Hughes (1866) held the view that it was formed by solution of the Chalk after the deposition of the Thanet Beds. Dowker (1864) believed the flints of the Bullhead Bed resulted from the subaerial solution of the Chalk prior to the deposition of the Thanet Beds and, later, Wrigley (1949) and Haynes (1958, p. 87) expressed similar opinions. Wrigley regarded it 'as a gentle redisposition, by an advancing sea, of clay-with-flints which had accumulated on a long exposed land surface'. Weir and Catt (1969, p. 29) found material in the matrix of the Bullhead Bed that was possibly derived from the dissolution of the immediately subjacent Chalk, but also detrital material introduced from elsewhere. Later, Knox (1979) found igneous grains in this matrix which he considered originated in ash falls of Thanetian age. The significance of a detrital component of the matrix is however complicated by the possibility of downward infiltration of granular material from above or the 'piping down' of the latter by burrowers such as those referred to by Knox (1979).

On balance, the Bullhead Bed appears to be a Chalk residuum that was altered and supplemented in a low-energy marine environment. Detritals, including igneous grains, were introduced and there may have been minimal reworking at the same time or prior to a period of glauconitization that stained the flints and altered some of the detrital, including igneous, grains. Precisely when the process started is not clear. A lack of Danian microfossils led Haynes and El-Naggar (1964) to suggest that land might have existed here from the Maastrichtian to the Danian and the residuum could have started to form as early as this. No contemporaneous microfauna occurs in the Bullhead Bed to determine when the submarine phase of the Bullhead Bed development occurred, though glauconites from 'the Thanet base bed at Pegwell Bay' (Fitch *et al.*, 1978a, p. 10) indicate a 59.5 ± 9 Ma age.

Comparison with the section at Herne Bay

From stratigraphical evidence alone, it is clear that most, if not all, of the Thanet Sand Formation section here is older than that at Herne Bay. Ward (1978) referred to a lithological resemblance between the uppermost part of the Pegwell Bay succession and his unit A (*Eutylus* Bed) at Herne Bay but conceded that there were also differences. His conclusion that there is no overlap has been supported by recent magnetostratigraphical work by Townsend and Hailwood (1985) who found that samples from the main 'Cliff End Section' at Pegwell Bay gave normal polarity magnetization (on which they established the Thanet magnetozone) whilst samples from the Thanet Beds in Herne Bay all show reverse polarity. As these authors point out, future sampling of the youngest beds at Pegwell Bay (in the 'Car Park Section') and the oldest beds at Herne Bay may allow the polarity transition between the two magnetozones to be located. Knox *et al.* (1994, fig. 4) in fact show the uppermost part of the Pegwell Bay section as having reverse polarity. Recent dinoflagellate work by Powell *et al.* (1996) supports the view that there is no overlap of the Thanet Sand Formation of Pegwell Bay with that in Herne Bay.

Palaeoclimatology

The fossils from Pegwell Bay represent the earliest marine transgression in this area in Palaeogene times. Ward's (1977) faunal list includes invertebrates and vertebrates (fish), with the most diverse faunas obtained from the Reculver Silts. What is particularly interesting about the fauna is that it provides an insight into the climate of the times. Haynes and El-Naggar (1964) noticed the absence of certain foraminiferids, for example the typically tropical, keeled *Globorotalia*, and suggested that, since such forms only penetrated high latitudes during climatic optima, the climate was likely to be cooler than the preceding Dano-Montian or the succeeding Eocene. Stinton (1965a), who described five new species of otolith from the section, commented that the fish fauna implied that the local Thanetian Sea was at least temperate if not definitely boreal. Such conclusions support the view that world climates in the Palaeogene were relatively cool (cf. Axelrod and Bailey, 1969).

Contemporaneous vulcanism

The mineralogy of the lower part of the Pegwell Bay succession has turned out to be palaeogeographically significant in indicating contemporaneous igneous activity. Where Pegwell Bay is particularly important is that it shows that pyroclastic events occurred in south-eastern England prior to 'London Clay' times (Elliot, 1971a; Knox and Ellison, 1979) and before the deposition of the ash-bearing Herne Bay Member of King's (1981) Oldhaven Formation (now the Harwich Formation) in Herne Bay (Aubry *et al.*, 1986, p. 731). That ash falls occurred whilst the Thanet Sands were accumulating is also supported by the work of Morton (1982b), who recognized euhedral (and hence non-detrital) grains of the igneous minerals aegirine, arfvedsonite and apatite from, in particular, the offshore borehole 79/7A. The Pegwell Bay volcanic material is most closely correlatable with the earlier of the two pyroclastic phases that are represented in the North Sea Basin (Knox and Morton, 1988). However, Knox (1984) referred to this earlier phase as probably spanning the interval from late Zone NP8 into early Zone NP9. From earlier discussion of the age of the Thanet Beds in Pegwell Bay, it seems likely that this Pegwell material represents an even earlier pyroclastic phase. Such an earlier phase is indicated by a tuff band in the North Sea referred to by Fitch *et al.* (1978a, fig. 9).

Conclusions

Pegwell Bay has attracted geologists since the middle 19th century, not surprisingly, since it comprises the oldest part of the Palaeogene exposed at outcrop in south-eastern England. Although somewhat older Palaeogene sediments are now known from boreholes in eastern East Anglia, the importance of the succession here is that it represents the earliest of the transgressive events that characterize much of the British onshore Palaeogene. Whilst it is essentially of Upper Palaeocene age, the Bullhead Bed at the base may be older. As it consists, in part, of a residual deposit derived from the underlying Chalk, its formation may have commenced in earlier Palaeogene or even late Cretaceous times.

Whilst the lower part of the succession is poorly fossiliferous, aspects of the palaeontology have shed some light on both contemporary and earlier geography. Derived fossils from the Chalk suggest the possibility that land may have existed in the area in Maastrichtian and Danian times, whilst the nature of the foraminiferal and otolith assemblages supports the view that the Palaeocene had a relatively cool climate.

The stratigraphical importance of the section at Pegwell Bay is recognized in its being one of the two type sections for the Thanet Sand Formation and for the Thanetian Stage. More recently, it has also been established as the type section for the Thanet magnetozone.

Mineralogical studies of the basal part of the succession here have given a useful insight into early Palaeogene vulcanism. Zeolites and other minerals found provide evidence for the oldest volcanic event recorded in an exposure of the British onshore Palaeogene and one which may predate the earliest of the two major phases of pyroclastic activity represented in the North Sea Basin.

HERNE BAY (BISHOPSTONE CLIFFS) KENT (TR 193685–TR 224693)

Highlights

Stratigraphically, Herne Bay is the most important Palaeogene site in the London Basin and is one of the two type sections for the internationally important Thanetian Stage and for the Thanet Sand Formation. Evidence from this site has contributed to a realization that, locally, the base of the Thames Group lies unconformably on older strata. The Oldhaven Beds (Harwich Formation) can be correlated with the 'Ash Marker' of the North Sea succession.

Introduction

This site (Figures 3.7 and 3.8) consists of cliff and foreshore exposures extending from the eastern part of the town of Herne Bay (grid reference TR 193685) north-eastwards towards Reculver (TR 224693). The strata dip gently to the west giving continuous exposure from the upper Thanet Sand Formation to the 'London Clay'. Foreshore exposures are particularly important with low-water spring tides providing optimum access (Figure 3.9). In his account of the sections in 1978, Ward described it as 'probably the best and most accessible section of Lower Tertiary strata in the south-east of England'. Over the years, however, coastal 'protection' has affected the extent and quality of exposure. In a paper on local landslides, Bromhead (1978) remarked that 'In recent years these cliffs have been subjected to extensive coast defence and cliff stabilisation work and now bear little resemblance to their former appearance'; although this statement really only applies to the more westerly part of the section. Whilst to the west of Bishopstone Glen (Figure 3.7) much of the cliff is vegetated, good exposures persist further east (Figure 3.8).

In a brief summary of research on the section, Ward (1978) cited the classic early work of

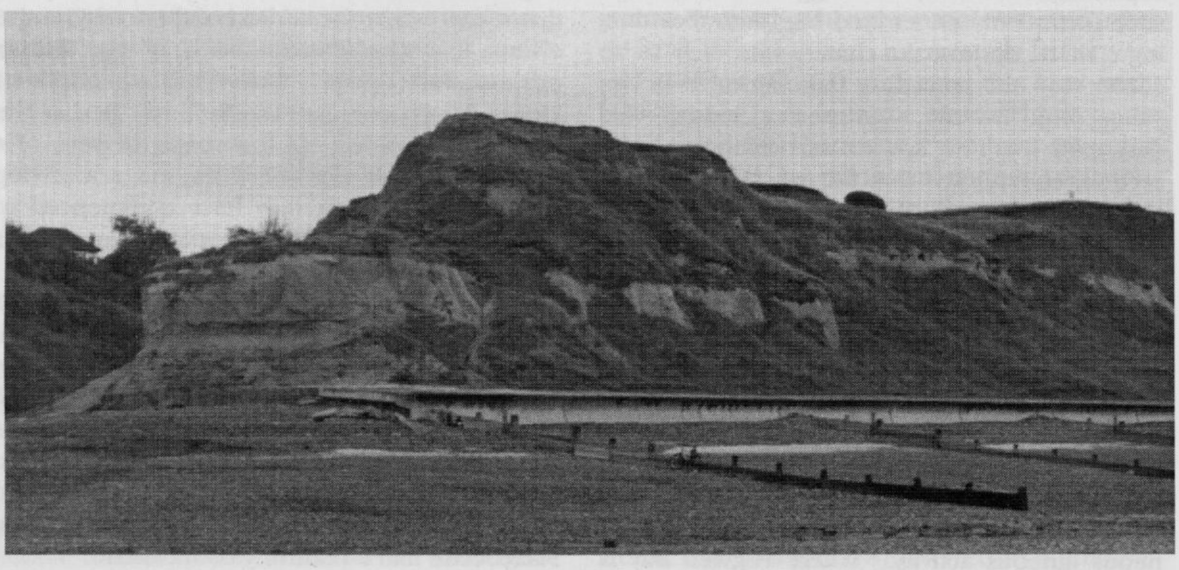

Figure 3.7 Herne Bay, Kent. General view of the cliff section to the west of Bishopstone Glen (extreme left of photograph). At the seaward end of the glen, the Upnor Formation (near vertical formation) rests on the Thanet Formation. Above, the partly vegetated Oldhaven Beds (Harwich Formation) extend westwards to Beltinge Cliff where they are succeeded by the darker-coloured London Clay. (Photograph: courtesy of D.J. Ward.)

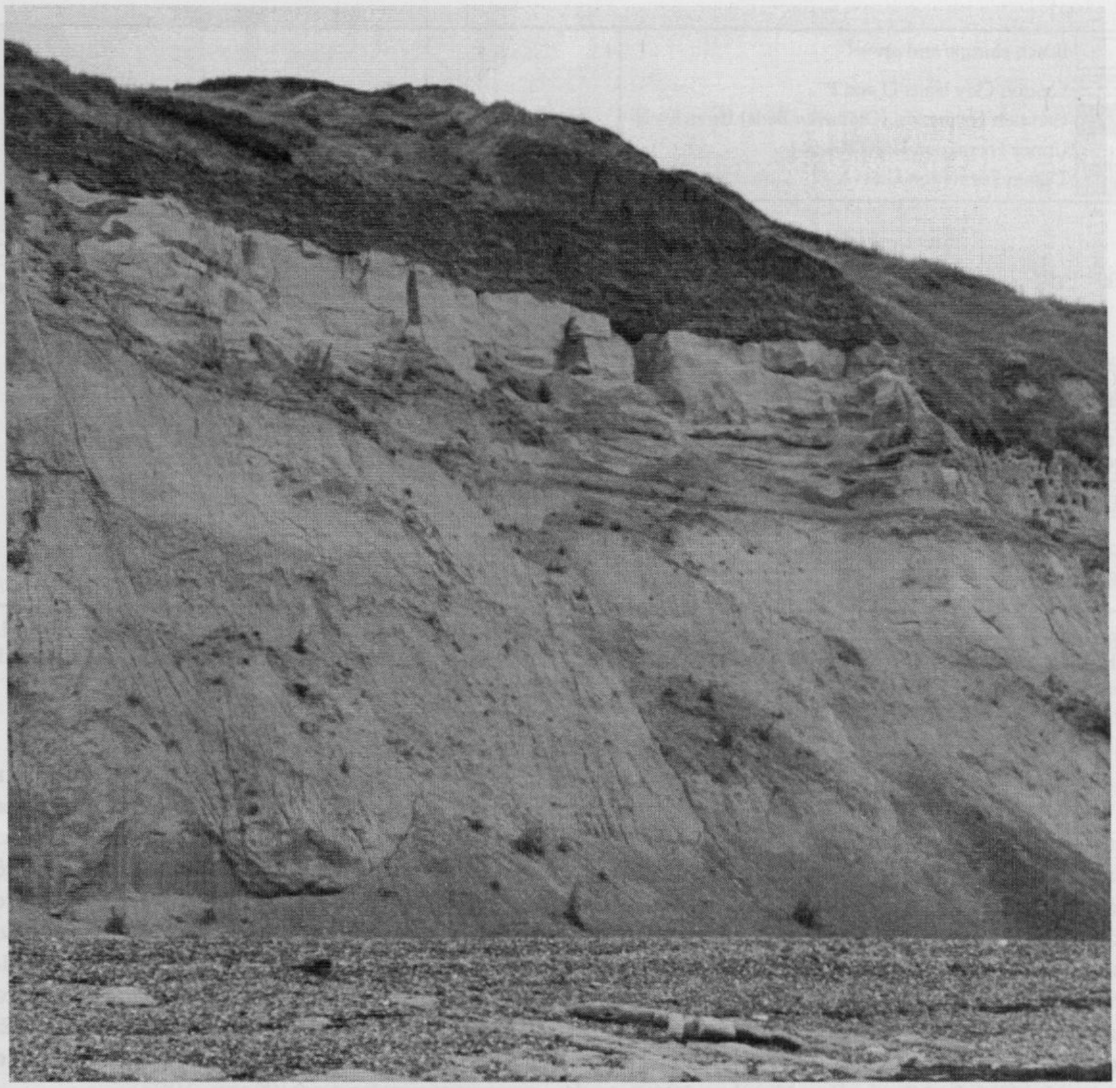

Figure 3.8 Herne Bay, Kent. The section below the Coastguard Station, where the Thanet and Upnor Formations (difficult to distinguish on this photograph) are overlain by the more obviously bedded Oldhaven Beds (Harwich Formation) and the darker London Clay above. (Photograph: courtesy of D.J. Ward.)

Prestwich (1850, 1852, 1854a) followed by that of Whitaker (1866, 1872). Both authors provided faunal lists. Prestwich (1852) included a diagrammatical cliff section, as did Whitaker in the Geological Survey Memoir of 1872. As Ward (1978) pointed out, a later account by Gardner (1883) is hard to follow and his sections are more difficult to interpret.

Twentieth century accounts include those of Dewey *et al.* (1925), Cooper (1934) and that in the Geologists' Association Guide to the area (Pitcher *et al.*, 1958, 1967). Recent descriptions include that by Ward (1978) on the pre-'London Clay' strata and King (1981) on the 'London Clay'. A brief general account appears in Holmes (1981) which, as the Memoir for the local 1:50 000 geological sheet (Faversham), portrays the site in a broader regional Palaeogene context, whilst also providing important lists of references.

Because of its geological importance, Herne Bay has been the venue for a number of field meetings of the Geologists' Association (Dowker, 1864; Whitaker and Dowker, 1885; Leighton, 1894; Whitaker, 1912; Brown, 1936; Stinton, 1965b; Gamble, 1968; Hutchinson, 1968) and the Tertiary Research Group (e.g. Rundle, 1970a). No doubt, the increasing development of coastal defence works for over two decades explains a diminution of such meetings

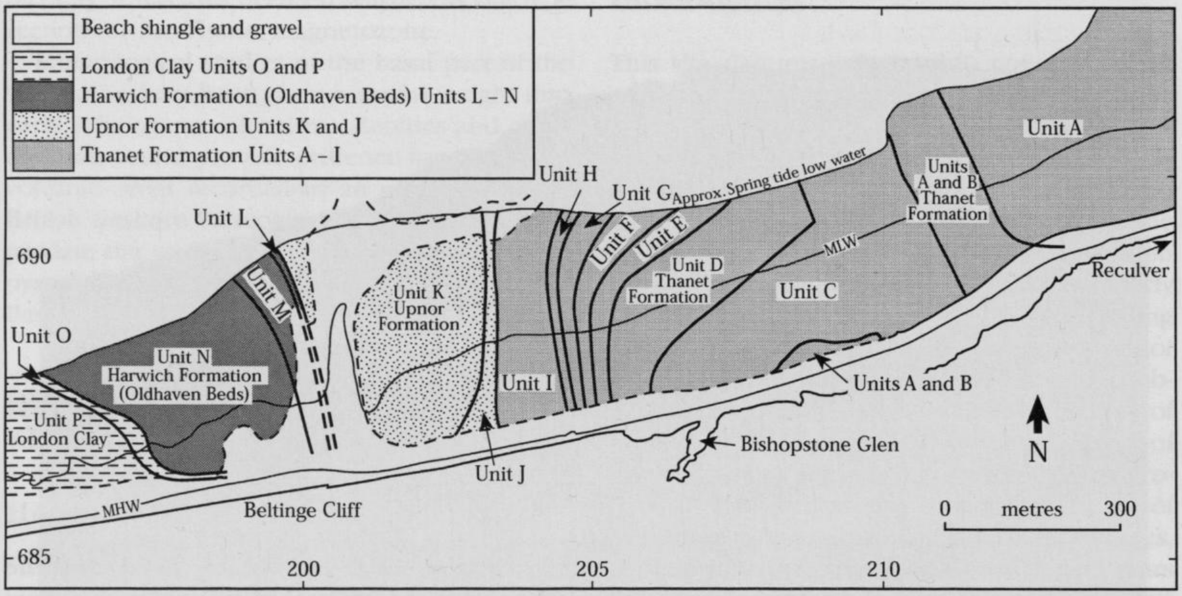

Figure 3.9 Geological map of part of the foreshore between Herne Bay and Reculver, Kent, to show the distribution of units within the Thanet Formation, Upnor Formation, Harwich Formation (Oldhaven Beds) and the London Clay (after Ward, 1978, fig. 2).

in more recent years.

Palaeontologically, the site has attracted interest since the 19th century. For the 'London Clay', Cooper (1977) summarized previous collecting and provided comprehensive fossil lists. Ward (1978) included similarly comprehensive lists for the 'Lower London Tertiary' (Palaeocene) strata present. Amongst papers making particular reference to the molluscan faunas, are that by Cooper (1934), various papers by Wrigley (including Wrigley, 1949) and King (1981), whilst the vertebrates, particularly fishes, were dealt with by Gurr (1963), Ward (1975, 1978) and Gamble (1979). In addition, various workers have investigated the micropalaeontological remains. Haynes (1956–1958) studied the foraminifera, whilst subsequent attempts to date the section involved research on the dinoflagellates (Costa and Downie, 1976) and calcareous nannoplankton (Martini, 1971; Hamilton and Hojjatzadeh, 1982; Aubry, 1986; Siesser *et al*., 1987). Non-palaeontological, chronostratigraphical work on the section was included in a wider magnetostratigraphical investigation by Townsend and Hailwood (1985), whose findings were elsewhere integrated with a study of the nannoplankton biostratigraphy (Aubry *et al*., 1986).

Relatively few workers have studied the section from a detailed lithostratigraphical and sedimentary facies viewpoint and have done so only as part of broader regional studies (Hester, 1965; King, 1981; Ellison, 1983). Mineralogical work on the section has included a detailed study of glauconite and the problems associated with its use in age determination (Fitch *et al*., 1978a; Curry *et al*., 1978), provenance studies using heavy minerals (Blondeau and Pomerol, 1962, 1968; Weir and Catt, 1969; Morton, 1982a) and work investigating the possibility of contemporaneous volcanism (Knox, 1983).

Description

The section between the town of Herne Bay and Reculver to the east (TR 193685 to TR 224693) comprises Palaeogene beds dipping gently westwards at an average angle of 3°. The following units are present in ascending order: Thanet Sand Formation, Upnor Formation, Harwich Formation and London Clay.

Following the development of coastal defence works, the foreshore exposures (best seen at low-water, equinoctial spring tides) have become an increasing important aspect of the site. Parts of the cliff section are now poorly exposed. For example, King (1981) refers to cliff exposures of 'London Clay' at this site as perhaps, at 35 m, the thickest preservation of the

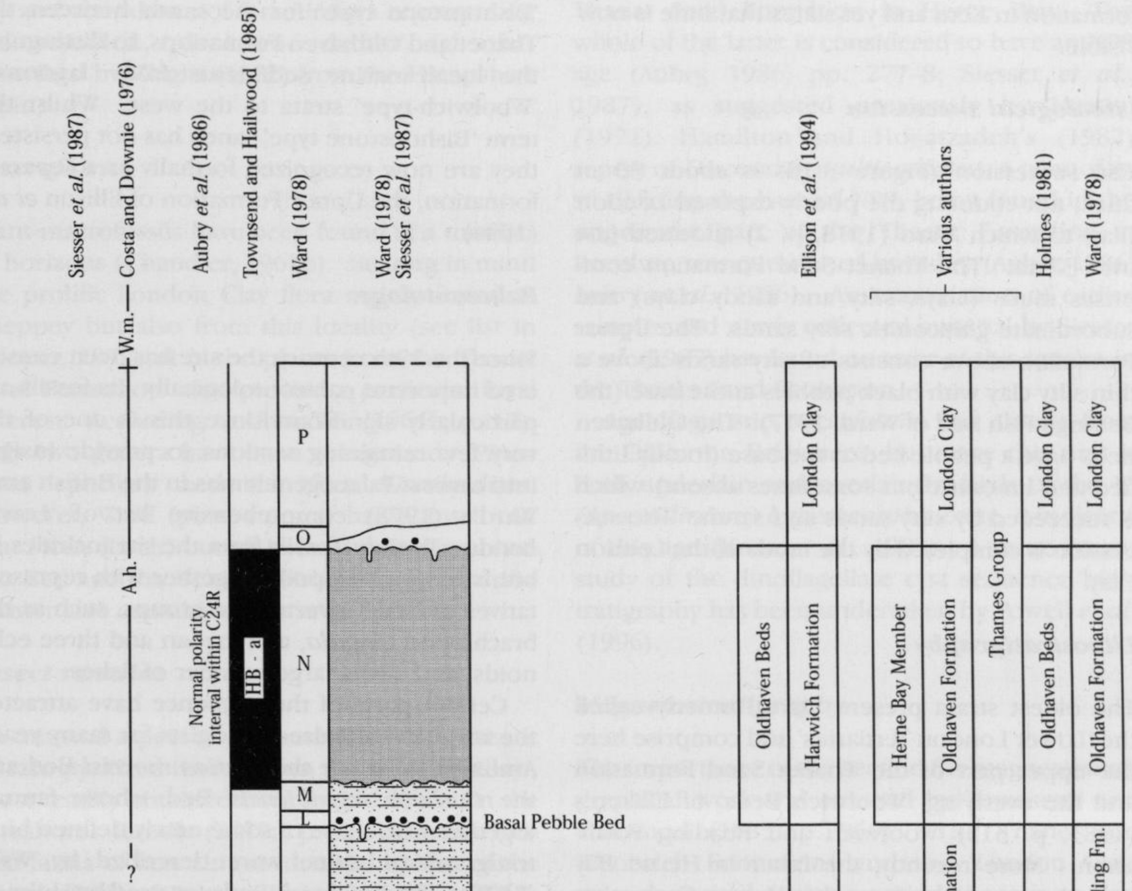

Figure 3.10 Lithostratigraphical, biostratigraphical and magnetostratigraphical succession of the Thanet Formation to London Clay at Herne Bay, Kent (after Ward, 1978, fig. 1; Siesser *et al.*, 1987, fig. 5, and other authors).

formation in Kent and yet states that little is now visible.

Lithological succession

The succession (Figure 3.10) is about 30 m thick, not counting the poorly exposed London Clay, to which Ward (1978, p. 2) allocated just over 37 m. The Thanet Sand Formation comprises muds (clays, silty and sandy clays) and subordinate glauconitic silty sands. The Upnor Formation above consists of silty sands above a thin silty clay with black pebbles at the base (the Beltinge Fish Bed of Ward, 1977). The Oldhaven Beds have a pebble bed at the base (locally lithified and limonitic but sometimes absent) which is succeeded by silty sands and sands. The succession is completed by the muds of the London Clay.

Lithostratigraphy

The oldest strata present were formerly called the 'Lower London Tertiaries' and comprise here the upper part of the Thanet Sand Formation and the overlying 'Woolwich Beds' of Ellison's (1983, p. 312) Woolwich and Reading Formation. More recently, the latter in Herne Bay have been assigned to the Upnor Formation (Lambeth Group) of Ellison *et al.* (1994). These are overlain unconformably by the Thames Group of King (1981): the 'Oldhaven Beds' (Oldhaven Formation of King, 1981) of the Harwich Formation of Ellison *et al.* (1994) and the succeeding London Clay.

There has been disagreement over where the boundary between the Upnor Formation and the underlying Thanet Sand Formation should be placed. Hester (1965) and Holmes (1981) followed Prestwich (1854a) and Whitaker (1866) in including the *Corbula regulbiensis* Bed in the 'Bottom Bed' of the Woolwich and Reading Formation (as the Upnor Formation was formerly named), whilst by contrast, Ward (1978) and Siesser *et al.* (1987) followed Gurr (1963) in placing the *C. regulbiensis* Bed in the Thanet Sand Formation.

King (1981) made Herne Bay the type section for his Oldhaven Formation and the Herne Bay Member of the latter, the name arising from the use of the alternative locality name Oldhaven Gap for Bishopstone Glen (TR 207687) towards the western end of the cliff section (Figure 3.9). Earlier, White (1931) had proposed the name 'Bishopstone type' for the sands between the Thanet and Oldhaven Formations, to distinguish the local marine sediments from 'lagoonal' 'Woolwich-type' strata to the west. Whilst the term 'Bishopstone type' sands has not persisted, they are now recognized formally as a separate formation, the Upnor Formation of Ellison *et al.* (1994).

Palaeontology

Since the 19th century, the site has been considered important palaeontologically. Its fossils are particularly significant since this is one of the very few remaining sections to provide insight into earliest Palaeogene times in the British area. Ward's (1978) comprehensive list of 'Lower London Tertiary' fossils from the site includes 34 bivalves, 26 gastropods, together with representatives of other invertebrate groups, such as the brachiopod *Lingula*, a bryozoan and three echinoids, and also a large number of fishes.

Certain parts of the sequence have attracted the attention of palaeontologists for many years. Amongst these are the *Arctica morrisi* Bed and the *Corbula regulbiensis* Bed whose faunas, together with those of some newly defined biostratigraphical units, were described by Ward (1978). The Woolwich Beds (as used by Holmes, 1981, but see later discussion) have proved to be particularly important. Hester (1965) considered that 'no other sections in the Bottom Bed have yielded such a prolific fauna as that found at Bishopstone Glen', although this reflects his inclusion of the *C. regulbiensis* Bed in the Woolwich and Reading Formation, contrary to the view of Ward and others (e.g. Ward, 1978). Within this part of the sequence, Ward (1978) found 'an abundant vertebrate fauna consisting of shark's teeth and vertebrae, chimaeroid plates, teleost teeth and bones, crocodile and turtle bones and scutes' in a thin unit defined by him as the 'Beltinge Fish Bed' (= Woolwich Bottom Bed *sensu* Gurr, 1963, p. 419).

The 'London Clay' fossils from the site are discussed by King (1981, pp. 54–56) although little of the formation is now exposed. The most comprehensive record, including fossil lists, is that of Cooper (1977). Most of the macrofauna and macroflora are represented by specimens found loose on the foreshore. The majority of the recorded 'London Clay' molluscs probably came from King's (1981) 'Division B', which a little above its base shows a rapid increase in diversity and abundance of foraminifera representing the so-called 'planktonic datum' (cf. that described by Wright (1972) from the Hampshire Basin).

Macroflora

Plant macrofossils have been found at a number of horizons (Chandler, 1961b). Bearing in mind the prolific London Clay flora mainly found at Sheppey but also from this locality (see list in Cooper, 1977), it is the plants from the Thanet Sand Formation that provide a particular local interest. According to Chandler (1961b, p. 17), only two genera have been recognized: *Pinus* (two species) and the fern *Osmundites*. However, Ward (pers. comm.) has pointed out that *Picea* (larch) occurs in both the *Astarte tenera* Bed and the Beltinge Fish Bed, and that the former also contains a rich seed flora.

Insect remains

An unusual aspect of the fauna is the occurrence of rare pyritized insects from the 'London Clay', most readily obtained from pyritic debris on the foreshore. Rundle (1970a, p. 8) obtained a limited fauna of taxa almost identical to that of the 'Beetle Bed' of Bognor Regis (Venables, 1963) but with beetle fossils probably more common here than at Bognor. Perhaps even more unusual is the presence of a pyritized coleopterid larva from the 'London Clay' (Rundle and Cooper, 1971).

Chronostratigraphy

With the section at Pegwell Bay, Herne Bay has been designated the co-stratotype for the Thanetian Stage (Pomerol, 1982).

In the search for a reliable chronostratigraphical scheme based on microfossils, the Herne Bay section has not been neglected. Three zones based on the dinoflagellate *Wetzeliella* have been recognized: the *W. (Apectodinium) hyperacantha* Zone (the top of which lies in the basal few metres of the 'London Clay' here), the *W. meckelfeldensis* Zone (5–18 m above the base) and the overlying *W. varielongituda* Zone (Costa and Downie, 1976).

Unlike Pegwell Bay, where indigenous nannofossils are uncommon, rich and moderately well-preserved nannofossil assemblages have been found at all but the uppermost levels of the Thanet Sand Formation in Herne Bay. The whole of the latter is considered to have an NP8 age (Aubry, 1986, pp. 277–8; Siesser *et al.*, 1987), as suggested previously by Martini (1971). Hamilton and Hojjatzadeh's (1982) report of *Discoaster multiradiatus*, a nannofossil defining the base of NP9, being found in the uppermost part of the Thanet Formation at Reculver, was questioned by Aubry (Aubry, 1986; Aubry *et al.*, 1986). An examination of earlier samples and newly collected material by Siesser *et al.* (1987) has found no trace of this species in the Thanet Sand Formation.

Age-diagnostic microfossils are absent from the Oldhaven Beds here, but since this unit is both underlain and overlain by beds of the *W. (Apectodinium) hyperacantha* Zone, it is clearly of this age (Knox *et al.*, 1983). A more recent study of the dinoflagellate cyst sequence biostratigraphy has been undertaken by Powell *et al.* (1996).

Magnetostratigraphy

The importance of the section for magnetostratigraphical work was stressed by Townsend and Hailwood (1985, p. 969). The Thanet and Woolwich Formations and the 'London Clay' were deposited during a period of reverse polarity. However, for the Oldhaven Beds, the situation is a little more complicated. Up to the lower part of Unit M of Ward (1978) (Figure 3.10) reverse polarity is represented, but in the upper part of M and above (i.e. some 90% of the Oldhaven Beds), normal polarity is indicated. On the basis of the latter, Townsend and Hailwood (1985) established the Oldhaven magnetozone for which Herne Bay is the type locality, recognizing that it is incomplete since its upper boundary coincides with the sharp and presumably erosional surface at the base of the overlying 'London Clay'. More recently, Ali *et al.* (1996, p. 202) have raised questions concerning the reliability of this magnetozone and have suggested that the section be restudied to assess its validity.

Glauconite dating

The presence of glauconite in the succession in Herne Bay has allowed various researchers to date the Thanet Sand Formation radiometrically (Odin *et al.*, 1969, 1978; Fitch *et al.*, 1978a, b; Odin and Curry, 1985). Ages determined (in millions of years) include: 68.1 ± 4 (Odin *et al.*, 1969; Thanet Beds, 2 m below the Woolwich Bottom Bed); 53.1 ± 3.3 and 56.0 ± 3.2 (Odin *et al.*, 1978; Thanet Beds, Corbula Bed and 'near top' respectively); 56.8 ± 0.6 and 60.2 ± 2.7 (Fitch *et al.*, 1978a; 5 m below top of Reculver Sands and 2 m above base of Oldhaven Beds respectively). In a later paper, Fitch *et al.* (1978b) suggested an age range of 60.95 to 57.6 Ma for the Thanet Beds of East Kent as a whole.

Sedimentology

Although generalized lithological descriptions of the site appear in numerous publications, the sedimentological aspects of the section have not received the same degree of attention as have the fossils. King (1981, p. 54), for example, pointed out that there is no published description of the lithostratigraphy of the 'London Clay' and, nowadays, little of the 35 m originally exposed remains visible. Other parts of the sequence have however received greater attention, particularly the Lambeth Group (formerly the Woolwich and Reading Formation). In a broad study of the facies distribution of the latter, Ellison (1983) considered that of six major lithofacies, the 'Glauconitic sand' was best represented in the Herne Bay section. These sediments are the 'Bottom Bed' of Hester (1965), now the Upnor Formation, and were thought by Ellison (1983) to represent a littoral deposit in a barrier sand complex.

Detrital mineralogy

Mineralogical work on the section has been concerned with the glauconites (see earlier and also later discussion), sediment provenance and a search for evidence of contemporary ash falls. Amongst provenance studies were those of Blondeau and Pomerol (1962, 1968) and Weir and Catt (1969). The source of the Thanet Beds according to these workers was a garnet–epidote–amphibole terrain, and a northerly, Scottish Highland source seems possible (Morton, 1982a, p. 268).

Vertical mineralogical variation of the Thanet Sand Formation, reported by Blondeau and Pomerol (1968) (diminishing-upwards proportions of such minerals as epidote, sphene, etc.), was interpreted by Morton (1982a) as evidence for pre-Woolwich and Reading Formation weathering of the Thanet Beds. These minerals and others which he records as diminishing upwards (garnet, apatite, hornblende) are moderately to strongly etched towards the top of the Thanet sequence, the product, in his view, of a response to acidic groundwater circulation.

The mineralogy of the succeeding strata at Herne Bay is broadly similar to that of the Thanet Sand Formation. Weir and Catt (1969) stated that 'The mineral composition of the marine Woolwich Beds at Bishopstone Point is exactly the same as that of the underlying Thanet Beds'. However, from samples taken elsewhere, Morton (1982b) found that the Woolwich Bottom Bed has a mineralogy indicative of an Armorican or Ardennes–Rhenish massif source, unlike the remainder of the succession both stratigraphically above and below.

Contemporary vulcanism

The Herne Bay section has made an important contribution to our knowledge of early Palaeogene volcanic activity. At one time, the Herne Bay section was considered to contain no evidence of contemporaneous volcanic events. Knox and Harland (1979) found no trace of ash in the Woolwich and Reading Beds or the Oldhaven Beds, whilst Knox and Ellison (1979) found none in the 'London Clay'. Material from unweathered foreshore sections, however, subsequently enabled Knox (1983) to recognize well-preserved volcanic grains from the Oldhaven Beds, albeit comprising a small proportion (1–5%) of the sand fraction. This discovery was to have considerable stratigraphical significance (see next section).

Interpretation and evaluation

The Herne Bay section provides us with particular insight into the early Palaeogene history of south-eastern England. It comprises the best record of the upper part of the Thanet Sand Formation, 'Woolwich Beds' (now the Upnor Formation) which contrast markedly with much of the Lambeth Group sequence further west, and evidence from the Oldhaven Beds that clarifies stratigraphical relationships of the early Thames Group strata.

Comparison with other localities

The Thanet Sand Formation is best developed and thickest in north-eastern Kent (see isopachyte map in Hester, 1965). By contrast, the Woolwich and Reading Formation (the Lambeth Group) is thin in this area. Ellison (1983, p. 312) referred to a 5 m thickness compared to around 30 m near Chertsey and 20 m as a general rule elsewhere. The significance of the thin 'Woolwich Beds' sequence in Herne Bay is that it represents the remnant of a once thicker succession, which, in the eastern part of the London Basin, was uplifted and eroded prior to the deposition of the Thames Group. In the London Basin, the Oldhaven Beds is virtually confined to northern Kent and south Essex, and Herne Bay provides the only complete extant section. At one time regarded as older than the Harwich Member of the 'London Clay', it is now, on the basis of evidence from Herne Bay (see later discussion), thought to be its lateral equivalent (Ellison *et al.*, 1994).

Palaeoclimatology

There seems little doubt that the rich fossil assemblages at certain horizons will continue to make Herne Bay attractive to palaeontologists. That the section includes fossiliferous Thanet Beds renders it particularly interesting palaeoenvironmentally and palaeogeographically, albeit that the evidence is somewhat equivocal particularly regarding climatic implications. Gardner's (1878) view that the Thanet Beds represent a temperate climate was 'regarded with suspicion' by Chandler (1964), although Haynes (1956–1958) concluded from his work that the sea in which this formation accumulated was shallow and cool. Wrigley (1949) found both cold water (e.g. *Arctica*) and warm water elements in the molluscan fauna, but concluded that the indications 'point to a subtropical rather than a temperate or boreal climate'. This is compatible with White's (1931) reference to the occurrence of subtropical and tropical fish in these strata and Curry's (1965a) mention of calcareous algae in the highest Thanet Beds near Bishopstone Glen. Such apparent palaeoecological dissonance remains an interesting aspect of the section.

Chronostratigraphy

Herne Bay is significant internationally as the co-chronostratotype for the Thanetian Stage (Pomerol, 1982b). Its value is reiterated by Siesser *et al.* (1987) in their statement that 'Any correlation of rock sequences from elsewhere in the world to the Thanetian Stage depends on an accurate knowledge of the biozonation of the Thanetian stratotype and reference sections'. In a paper that contains an excellent and comprehensive discussion of the concept, history and usage of the Thanetian (and the Thanetien), these authors (p. 95) give the Thanet Formation, the Woolwich Bottom Bed and the Oldhaven Beds as the lithostratigraphical units comprising the Thanetian Stage in the type area. They further point out that since the youngest Thanet Formation strata here date as NP8 and the other two units are barren of nannofossils, Zone NP9 which is included in the Thanetian Stage elsewhere is not therefore proven to be present in the chronostratotype locality. Gamble (1983), in an earlier discussion of the Thanetian chronostratotype, pointed out that in fact the stratotype 'spans the smallest proportion of its intended chronostratigraphical time division application among all the eight principal (Palaeogene) stages' and suggests that 'either the Selandian or Landenian Stages more closely approximate to the ideal for a single late Palaeocene Stage division'.

The occurrence of glauconite at various horizons in Herne Bay led to its use for absolute age dating. Indeed, Fitch *et al.* (1978b) suggested that since the Thanet Formation was neither deeply buried nor more than gently warped, its glauconites should provide ideal samples for dating by the K–Ar method. Many workers followed Everden *et al.* (1961) in attempting to date the Thanet Beds and other horizons in Herne Bay, but with a considerable scatter of results (see Odin *et al.*, 1978, p. 489). The glauconite dating method in general is now much better understood and the techniques considerably refined (Fitch *et al.*, 1978a; Odin *et al.*, 1978), with material from Herne Bay making a considerable contribution to this end.

Palaeogeography

Whilst no detailed sedimentological study has been published on the section, aspects of the lithostratigraphy (e.g. Ellison, 1983; Ellison *et al.*, 1994) together with mineralogical and palaeomagnetic research have contributed greatly to our understanding of early Palaeogene correlation and palaeogeography. Morton's (1982a) findings (see earlier) regarding the provenance and contemporaneous weathering of the Thanet Sand Formation is an example.

The difference between the nature and thickness of the Woolwich and Reading Formation here and elsewhere at more western localities has attracted attention over many years. The fact that at Herne Bay the formation was a glauconite sand led early workers to conclude that, in the east Kent area, the whole of the Woolwich and Reading Formation was of marine origin. However, work by such authors as Hester (1965) and Ellison (1983) confirmed a view that it represents the 'Bottom Bed' of the formation, elsewhere comprising a transgressive sand sheet extending as far west as Dorset. The thinness of the glauconitic sands in Herne Bay simply reflects pre-Oldhaven Beds uplift and erosion. Ellison (1983, fig. 3) implied that they were originally thicker and succeeded in this area by other facies, possibly including lagoonal deposits. However, he also pointed out (p. 312) that the glauconitic sands reach 10 to 15 m in the east of the London Basin and suggested that this thicker occurrence represents a barrier sand complex to the west of which lagoonal 'Woolwich Beds' developed.

Solving the 'Oldhaven' problem

The stratigraphical affinities of the Oldhaven Beds were established by two separate yet complementary pieces of research on the Herne Bay section: one on its mineralogy and the other on its palaeomagnetic attributes. King (1981) regarded his Oldhaven Formation (Herne Bay Member) as older than his Harwich Member, which forms the base of the 'London Clay' elsewhere, partly on the basis of faunal differences. Knox and Harland (1979) concurred with this, since in the 'Oldhaven Formation', they found none of the volcanic ash present throughout the Harwich Member. However, volcanic material later found in the Oldhaven Beds of Herne Bay is closely comparable to that of the Harwich Member in comprising both partly glauconitized and unaltered volcanic grains (Knox, 1983).

The conclusion arising from such mineralogical work has facilitated the interpretation of palaeomagnetic data derived from the site. Townsend and Hailwood (1985) recognized strata with normal polarity both in all but the lowest Oldhaven Formation of Herne Bay and in the upper part of the Harwich Member at Wrabness and Harwich to the north. Both occurrences were confidently assigned to the Oldhaven Magnetozone, which would probably not have been the case had the Herne Bay succession been devoid of volcanic material. These complementary studies indicated that the Oldhaven Formation here is a lateral correlative of the earliest 'London Clay' to the north, now formally designated the Harwich Formation (Ellison *et al.*, 1994). It represents not a separate sedimentary cycle but a nearshore facies of the initial 'London Clay' transgression and is the equivalent in time to the 'Ash Marker' of the Balder Formation in the North Sea. The variations in fauna between the Oldhaven Formation and the 'London Clay' referred to by King (1981) are consequently now interpreted as a reflection of differences in facies (Knox *et al.*, 1983). Recent doubts cast on the reliability of the Oldhaven Magnetozone do not detract from the above, since other evidence remains uncompromisd by such a view.

Conclusions

Herne Bay is stratigraphically the major Palaeogene site in the London Basin. Furthermore, it is the most important Palaeocene site of the British onshore succession, since both the Thanet Sand Formation and the Lambeth Group are exposed here.

The site is lithostratigraphically, chronostratigraphically and magnetostratigraphically significant, in that it provides the type sections for the Thanet Sand Formation, the internationally important Thanetian Stage and the Oldhaven Magnetozone.

The site provides insights into a number of aspects of Palaeogene history and palaeoenvironments. A considerable contribution to our understanding of Thanetian times in southern England comes from this locality and that in Pegwell Bay. The Upnor Formation of the Lambeth Group is well developed here and the thinness of the formation as a whole is testament to a period of uplift and erosion leading to an unconformable relationship with the overlying Thames Group. Mineralogical and palaeomagnetic work on the Herne Bay succession has established that the Oldhaven Beds represent a nearshore facies equivalent to the offshore former Harwich Member elsewhere. Furthermore, since it contains similar volcanic material to the latter, it has been correlated with the 'Ash Marker' of the North Sea succession.

Palaeontologically, the site continues to maintain the significance which became apparent early in the 19th century, with various horizons such as the *C. regulbiensis* Bed, having more prolific faunas in their Herne Bay development than elsewhere. Recent years have seen the considerable amount of micropalaeontological work on the section contribute to establishing a sound correlation of Palaeogene strata both locally and beyond the British area.

SHEPPEY CLIFFS, KENT (TQ961735–TR025717)

POTENTIAL GCR SITE

Highlights

The 'London Clay' of Sheppey Cliffs has been studied geologically since the 18th century and has been the subject of more publications than any other British Palaeogene site. Its main attraction is its rich fauna and flora which has provided considerable insight into the depositional environment and climate of younger London Clay times. It is particularly renowned as the prime source of the fossil 'London Clay Flora'.

Introduction

This is one of the classic Palaeogene sites. It has been the subject of geological interest for approaching three hundred years and has a vast literature, much of which reflects a persistent interest in the variety and significance of its fossils. This site was also independently selected for its fossil plant and fossil fish content, more detailed accounts of which can be found elsewhere in the GCR series (*Mesozoic to Tertiary Palaeobotany of Great Britain* (Cleal and Thomas, in prep); *Fossil Fishes of Great Britain* (Dineley and Metcalf, 1999)).

The section includes cliff and foreshore exposures (Figure 3.11) which extend for about 6.5 km from Scraps Gate to Warden Bay. Most of the section comprises London Clay, capped by Pleistocene material except between East End and Cliff Farm where the cliff intersects an outlier of the Virginia Water Formation.

The exposures of the London Clay along the northern coast of the Isle of Sheppey are renowned for their fossil flora and fauna. Both the fossils and other aspects of the geology have been studied scientifically since the 18th century. Numerous papers reflect this longstanding interest in the site that persists up to the present. A valuable bibliography listing over 250 references was produced by Cooper *et al.* (1984). A detailed and useful summary of previous work also appears in the Memoir for the Faversham Sheet (Holmes, 1981). King's (1984) account, the most comprehensive modern paper on the site, is drawn upon considerably as a source of information for this present site description.

The Sheppey sections were identified as 'London Clay' at the beginning of the 19th cen-

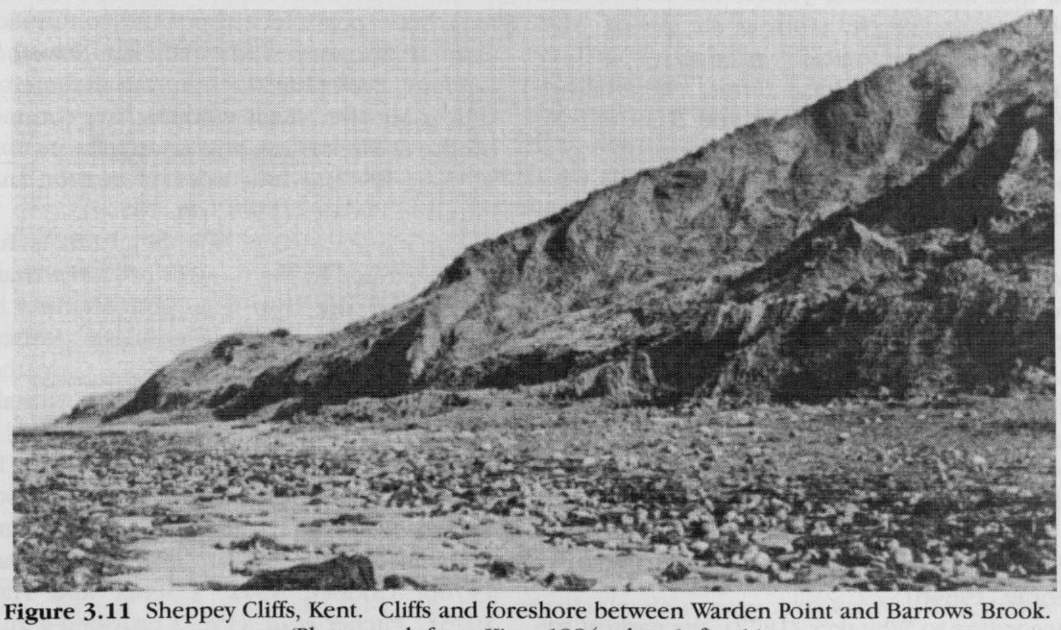

Figure 3.11 Sheppey Cliffs, Kent. Cliffs and foreshore between Warden Point and Barrows Brook. (Photograph from King, 1984, plate 1, fig. 1.)

tury at a time when the term was used *sensu lato* to include most of the early Tertiary deposits in this part of England. Prestwich (1847a) recognized the similarity of the Sheppey fossils to those of the London area and later (1854b) attempted to relate the Sheppey exposures to others of the 'London Clay' in the latter area. The memoir by Whitaker (1872) referred to Sheppey but gave no stratigraphical details. The disturbed and generally slipped nature of the cliffs frustrated many attempts at determining the origin of the fossils, which were mainly obtained from winnowed beach concentrates, although Davis (1936) tried to subdivide the succession (see discussion in King, 1984, pp. 122–3) in a paper which Holmes (1981, p. 44) considered the best general account of the 'London Clay' of Sheppey. The Geological Survey Memoir for the Chatham Sheet (Dines *et al.*, 1954) includes the western part of the Sheppey coastal section, whilst the eastern part is covered in detail in Holmes (1981). King (1981) introduced the results of new stratigraphical studies of the section, whilst Gamble (1981, 1984) dealt in some detail with Sheppey in his wider analysis of thickness variation in the London Clay of East Kent. King's later paper (1984) provides detailed lithostratigraphical logs for the succession, both for the London Clay and the overlying Virginia Water Formation (Figure 3.12).

The essential geological attraction of the site over many years has been its considerable fossil flora and fauna. King (1984) has shown that prolonged and careful study of the in-situ strata can be palaeontologically productive and of value in biostratigraphical terms, but much of our knowledge of the fauna and flora derives from the collection of loose fossils mainly preserved in pyrite or within concretions that have been naturally concentrated by wave action on the present-day foreshore.

Much of the early collecting of such winnowed material was for economic purposes. W.N. Edwards (1936, p. 22) referred to the collection of pyrite for the copperas industry since Elizabethan times (see George, 1984a for more details of this former usage), whilst the argillaceous limestone concretions became commercially valuable towards the close of the 18th centre as the raw material of 'Roman cement', a hydraulic cement made from calcareous nodules (George, 1984b).

According to Whitaker (1872), the earliest reference to the fossils of Sheppey is the 'Fossillae Sheppeianae Catalogus' of 1709 (Anon), followed by Parsons (1757) and Jacobs (1777). Early 19th century accounts include those of Crow (1810) and Hunter (1836). Prestwich (1854b) published what he implied was the first 'complete' fossil list for Sheppey, whilst Whitaker (1872) also contains a long list of fossils from this locality. An interesting account of early fossil collecting from Sheppey was produced by Bingham (1861). Many Sheppey fossils are described in a number of 19th century monographs produced by the Palaeontographical Society.

Since that time, palaeontological research on the site has continued unabated and enthusiastically, and has proved to be of enormous stratigraphical and palaeoenvironmental significance. Studies (see later for details) have included work on plant macrofossils, contributing considerably to the 'London Clay Flora' (see particularly Reid and Chandler, 1933), an invertebrate fauna dominated by molluscs (Wrigley, 1925–1953; Davis, 1936, 1937; Cooper, 1984; King, 1984) but also brachiopods, echinoids and ophiuroids, bryozoa and arthropods. Vertebrate material includes many species of fish, whilst reptiles, birds and mammals, although represented by relatively rare specimens, are a significant component (see Hooker *et al.*, 1980). Micropalaeontological work has included work on the foraminiferids, ostracods and most recently the plant microplankton (dinoflagellates).

The concentration of the fossils would not have been possible without the continued erosion of Sheppey Cliffs. In his *Principles of Geology*, Lyell (1833) referred to the rate of erosion at Minster. Many workers have commented on the cliff recession and an excellent summary of their findings and rates of erosion may be found in Holmes (1981, pp. 101–9).

The significance of Sheppey Cliffs is further demonstrated by the number of parties that have visited the site over a period of many years. Reports of visits by the Geologists' Association include those by Highley (1861), Carruthers *et al.* (1875), Shrubsole (1881, 1887), Whitaker *et al.* (1898), Holmes and Whitaker (1910), Davis and Elliott (1951b, 1955) and Hooker (1978). The last of these was a joint meeting with the Tertiary Research Group which has also made a number of visits to the locality (e.g. Daniels, 1970b; Cooper, 1972; Cooper and Hackett, 1975). Pitcher *et al.* (1967) provided a guide to

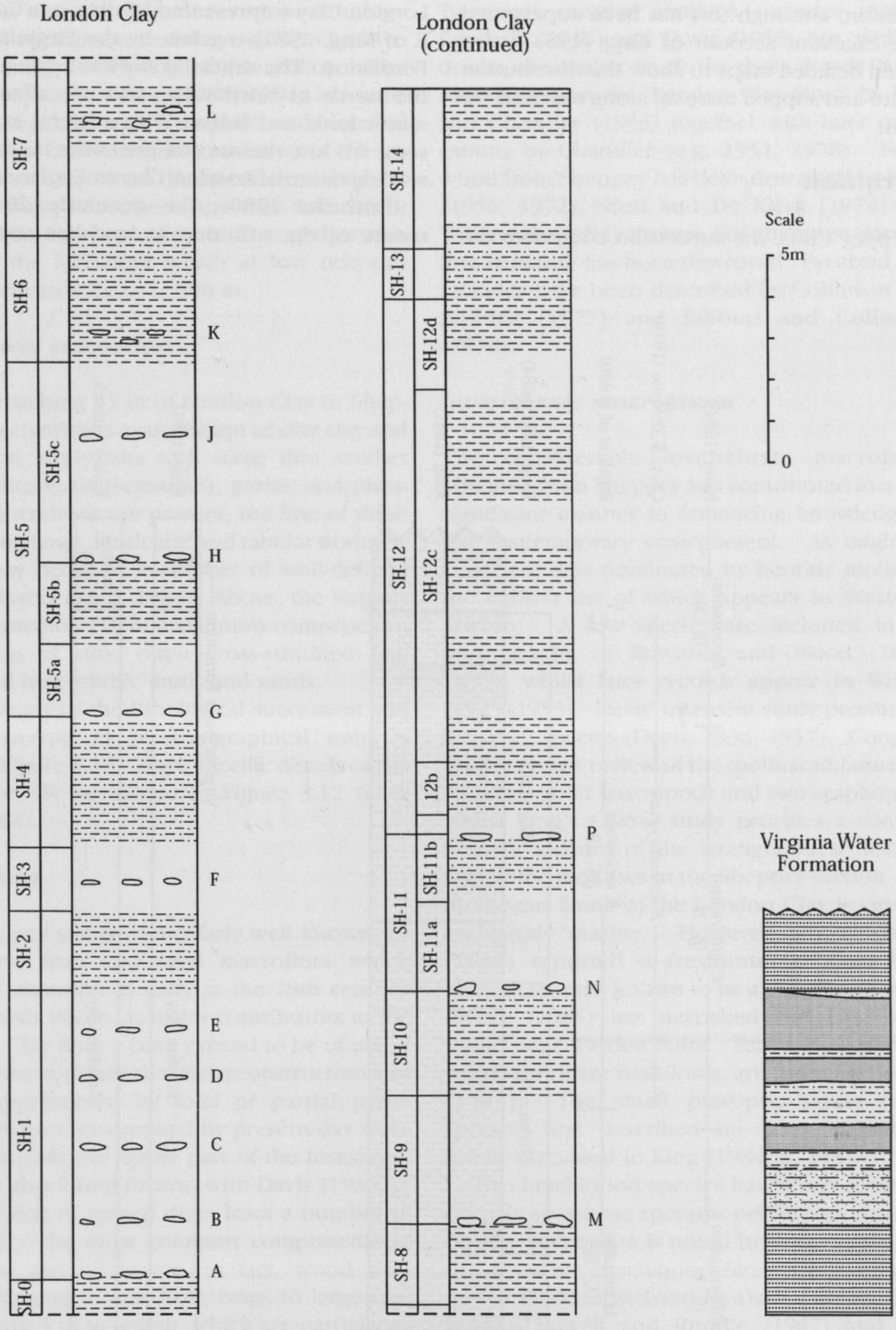

Figure 3.12 Lithostratigraphy of the London Clay and Virginia Water Formation in Sheppey Cliffs, Kent. London Clay bed numbers labelled SH-1, etc., and septarian nodule layers A to P (after King, 1984). See Figure 2.7 for key to lithologies.

the section, although this has been superseded by the excellent account of King (1984), who included detailed maps to show the distribution of in-situ and slipped material along much of the section.

Description

In Sheppey Cliffs, the succession comprises the London Clay (represented by divisions C, D and E of King, 1981) overlain by the Virginia Water Formation. The strata dip at a low angle towards the north to north-west, and are affected by minor folds and faults. With a lateral extent of some 6.5 km, the site comprises the most extensive exposure of London Clay in England.

Until the 1980s, the generally disturbed nature of the site, due to landslips and mud-

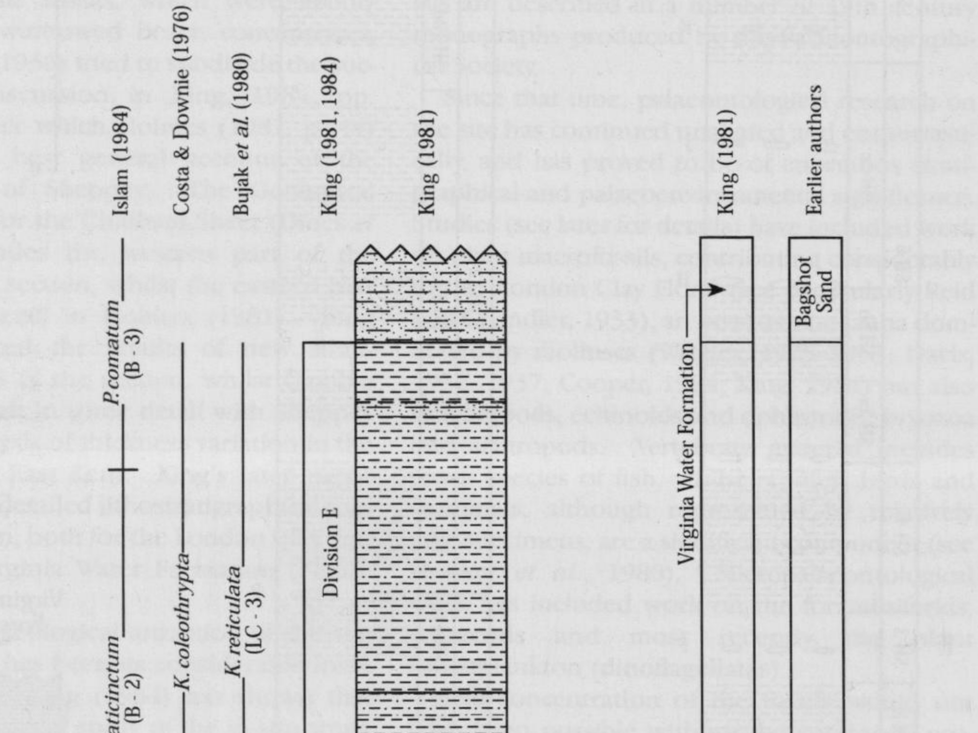

Figure 3.13 Generalized succession of the London Clay in Sheppey Cliffs, to show the relationship between lithostratigraphy and biostratigraphy.

flows, and the relatively monotonous lithology frustrated attempts at deriving a comprehensive stratigraphical description of the section. The meticulous work of King (1981, 1984) has now, however, established a complete and detailed account that facilitates the correlation of the in-situ sections separated by areas disturbed by slipping. Many of the best exposures occur within the lowest 6 m or so of the cliffs, together with those of the foreshore which at low tide can extend seawards for over 300 m.

Lithological succession

The approaching 55 m of London Clay in Sheppey Cliffs comprises a succession of silty clay and clayey and sandy silts with some thin sandier beds. Calcareous (septarian), pyritic and phosphatic concretions are present, the first of these comprising large, lenticular and tabular nodules, which may occur in a number of well-defined discrete layers (King, 1984). Above, the Virginia Water Formation (10 m maximum) comprises an alternation of silts, often cross-stratified fine sands and heterolithic muds and sands.

A summary of the lithological succession and its relationship to biostratigraphical units is given in Figure 3.13. More specific details of the succession are contained in Figure 3.12 (after King, 1984).

Macroflora

The Sheppey site is particularly well known for its diverse fruit and seed macroflora which attracted attention as early as the 18th century. These fossils which, as major contributors to the 'London Clay flora', have proved to be of major importance in palaeoclimatic reconstruction, are mostly represented by total or partial pyrite replacements concentrated by present-day wave action towards the upper part of the foreshore. They are also found *in situ*, with Davis (1936, p. 341) the first to record them from a number of localities. The most common components of the plant macroflora are, in fact, wood fragments, ranging in size from twigs to large tree trunks over 5 m in length, which are partially or wholly replaced by pyrite (King, 1984, p. 134).

Nineteenth century papers on the plant macrofossils include those of Brown (1837), Bowerbank (1840a), Carruthers (1875), von Ettinghausen (1879), Gardner and von Ettinghausen (1879) and Gardner (1881). Twentieth century research includes that of Edwards (1936) and Davis (1936) but, without doubt, the major work on these fossils is the monograph on the 'London Clay Flora' by Reid and Chandler (1933) together with later publications by Chandler (e.g. 1951, 1978). Fossil wood from Sheppey has been described by Brett (1956, 1972), Scott and De Klerk (1974) and Wilkinson (1984) though, for the most part, its fine structure has been destroyed. Pyritized fern rachides have been described by Collinson and Ribbins (1977) and Ribbins and Collinson (1978).

Invertebrate macrofauna

The considerable invertebrate macrofauna obtained from Sheppey has contributed in a very significant manner to enhancing knowledge of the contemporary environment. As might be expected, it is dominated by benthic molluscs, the earliest list of which appears in Prestwich (1854b). A few species are included in the monographs of Edwards and Wood (1849–1877), whilst later records appear in Wrigley (1925–1953). Davis' intensive study produced a list of 79 species (Davis, 1936, 1937). Cooper's (1984) recent review of the molluscan fauna lists 35 bivalves, 71 gastropods and two scaphopods, whilst King's (1984) study provides a comprehensive account of the stratigraphical distribution of the molluscs in the Sheppey section. The molluscan fauna of the London Clay is virtually exclusively marine. However, Godwin-Austin (1882) reported a freshwater mollusc from Sheerness (now known to be a pteropod), whilst Preece (1984) has described two land snails found near Warden Point. Ten cephalopods, of which seven are nautiloids, are listed by Cooper (1984). The small pteropod fauna (three species) first described by Curry (1965b) is briefly discussed in King (1984, p. 143).

Two brachiopod species have been recorded: *Lingula* sp. whose sporadic occurrence throughout the succession is noted by King (1984), and the articulate brachiopod *Terebratulina wardenensis* Elliott, discussed by Davis (1936), Elliott (1938), Rowell and Rundle (1967) and King (1984).

Echinoderm debris was sparse in the samples studied by King (1984) except in shelly drifts associated with logs and in King's unit 12c in which echinoid and ophiuroid debris is common. Earlier records include those in the monograph by Forbes (1852), and Davis (1936, 1937). Except for the echinoids, three species of which were recorded by Davis (1936), echinoderm records from Sheppey have been revised and updated by Rasmussen (1972). The most striking forms are large asteroids, which are usually pyritized (King, 1984).

Three species of Bryozoa were recorded by Gregory (1893) whilst Davis (1936) listed 13 species. King (1984, p. 13) briefly discussed the environmental implications of morphological groups in Davis' list. Other macroinvertebrates referred to by King (1984) include the serpulid *Rotularia bognoriensis*. Corals are represented mainly by the solitary coral *Paracyathus caryophyllus* whilst *Platycyathus brevis* and calcareous rods of the octocoral *Graphularia wetherelli* also occur.

Amongst the members of the Arthropoda, crabs and lobsters have frequently been found at Sheppey. They almost always occur in small phosphate nodules, although crushed carapaces and claws are sometimes found unphosphatized (King, 1984). Early studies include those of Bell (1858), who described a variety of crabs from Sheppey, M'Coy (1849) and Carter (1898). Twentieth century records include those in Woods (1924–1931), Glaessner and Withers (1931), Collins (1961) and Quayle (1984). According to King (1984), *Hoploparia* and *Zanthopsis* are the most common genera found at Sheppey. Cirripede valves occur in some of the shelly 'drifts' associated with logs (see Davis, 1936) whilst Sheppey material is referred to in Wither's (1953) *Catalogue of Fossil Cirripedia*. Insect remains are very rare (King, 1984).

Vertebrate remains

Vertebrate material includes many species of fish, whilst reptiles, birds and mammals, although represented by relatively rare specimens, are a very important part of the fauna (see Hooker *et al*., 1980).

Four types of fish remains occur at Sheppey: isolated teleost bone and scale fragments; isolated teeth, spines and tooth plates of teleosts, sharks and rays; teleost skulls and chondrichthian skeletal debris preserved in phosphatic nodules; and teleost otoliths.

The fish fauna was first seriously studied by Agassiz in a series of papers on the fishes of the 'London Clay', followed by work by Woodward later in the 19th century (see Cooper *et al*., 1984 for references). In an extensive work, Casier (1966) described a large teleost fauna whilst in an appendix to this monograph and in subsequent papers, Stinton described the teleost otolith fauna (Stinton, 1966). A considerable fauna of teeth, spines and toothplates has been obtained by sieving and concentrating the foreshore residues (Hooker *et al*., 1980; Ward, 1980).

A large number of papers on vertebrate material from Sheppey were published by Owen between 1840 and 1880 (see Cooper *et al*., 1984 for details). The reptilian fauna includes snakes, crocodiles and turtles (see particularly Owen, 1850; Owen and Bell, 1849–1850) whilst their distribution in the British Palaeogene is referred to in a broader context in a paper by Moody (1980). Fossil birds have been obtained from Sheppey: see, for example, Andrews (1899), Bowerbank (1854) and various papers by Owen. Work by Harrison and Walker includes references to the Sheppey avifauna (see Walker, 1980 for further details).

Mammalian fossils have also been obtained from Sheppey since the 19th century (see various papers by Owen). They are relatively uncommon, here as they are throughout much of the 'London Clay' (see Hooker and Insole, 1980), although relatively recent discoveries have been made by enthusiastic local collectors.

Microfauna

Sheppey has produced a considerable microfauna. Chapman and Sherborn (1889) listed 42 foraminiferid species, to which a further seven were added by Davis (1936). A few samples were studied by Bowen (1954) who recorded 20 species, whilst Curry (in Bronniman *et al*., 1968) recorded three species of planktonic foraminiferids from Minster. Williams (1971) recorded 42 species from a series of samples collected at Warden Point, whilst King (1984) recorded approximately 50 species. Ostracods are much less abundant than foraminiferids and a total of 13 species were identified by King (1984). The stratigraphical distribution of the foraminiferid and ostracod microfaunas is given in King (1984, fig. 9, p. 136).

Microflora

Plant microfossils from Sheppey have been collected since the 19th century although the last

20 years have witnessed a rise in interest as their value for dating and correlation has become apparent. Diatoms were recorded by Shrubsole (1879–1880) from borehole material. Costa and Downie (1976) included Sheppey in their broader study of the dinoflagellate *Wetzeliella* in the Palaeogene of northern Europe and recognized a distinctive assemblage towards the top of the London Clay here which is unrepresented in the London Clay (*sensu* King, 1981) elsewhere. Bujak *et al.* (1980) later assigned this part of the sequence to their *Kisselovia reticulata* Assemblage Zone (LC-3) for which Sheppey Cliffs is the type section. Later work on the dinoflagellate stratigraphy and palaeoenvironmental significance was undertaken by Islam (1981, 1984).

No comprehensive work on the pollen and spores has been undertaken, although samples from Sheppey have been studied by several authors (see references in King, 1981).

Magnetostratigraphy

Sheppey was apparently not investigated in any systematic way by Aubry (1986; Aubry *et al.*, 1986). Townsend and Hailwood (1985) did not include Sheppey in their work on the magnetostratigraphy of the Palaeogene strata of the London and Hampshire Basins, although a comprehensive investigation of the magnetostratigraphy of the Sheppey section has recently been completed as part of a broader study by Ali *et al.* (1993). Three normal-polarity magnetozones were identified at Sheppey. The upper part of the central magnetozone (Shep-2) was identified at Warden Point, with its top 8 m below the division C/D junction. It represents a record of Chron C24N. At Paddy's Point the base of magnetozone Shep-3 is positioned 3.35 m below the division D/E boundary (just above the level indicated by Islam (1983b) for the base of the *K. coleothrypta* dinoglagellate zone) and continues up into the Virginia Water Formation. Ali *et al.* (1993) placed Shep-3 at a similar stratigraphical position to the Wittering Magnetozone and proposed a correlation with Chron C23N.

Sedimentology

Sedimentological aspects of the succession at Sheppey have received little attention from earlier workers. Partially, this has reflected the rather monotonous nature of the London Clay and the extensive bioturbation, which at most horizons has obliterated or seriously disturbed primary depositional structures. King (1984) has now looked at various aspects of sedimentation and diagenesis including the biogenic structures (trace fossils), but almost without exception, earlier attempts at palaeoenvironmental interpretation were based on palaeontological criteria.

Interpretation and evaluation

Of all the Palaeogene sites in Britain, Sheppey has encouraged the greatest production of geological papers. Furthermore, it has almost certainly the longest history of documented geological interest, which extends back to the beginning of the 18th century. The site is of major importance for the contribution that it has made to our knowledge of a wide variety of organisms that lived in or on the land areas adjacent to the 'London Clay' sea and their palaeoenvironmental and palaeogeographical significance.

Plant fossils and palaeoclimatology

The site is particularly well known as the source of much of the London Clay Flora (Reid and Chandler, 1933), although King (1984) has emphasized that there is no evidence to suggest any unusual concentration of seeds, fruits or logs in the London Clay of Sheppey. Most 'London Clay' localities in the central and eastern London Basin yield a macroflora and the relative abundance at Sheppey is largely or entirely a function of the very extensive exposures and the reworking of the fruits and seeds into 'concentrates' on the foreshore.

In addition to its purely botanical importance (which will be described in the *Mesozoic to Tertiary Palaeobotany* GCR volume, Cleal and Thomas, in prep.), the flora from this site has a considerable significance for the interpretation of the early Eocene climate in the British area. Reid and Chandler (1933) concluded that it represented humid tropical rainforest conditions although this has been challenged (e.g. Daley, 1972a; Flenley, 1979, p. 23).

Invertebrate palaeontology

The attraction of the macroinvertebrate fossils endowed the site with considerable importance for over two centuries. Some groups uncommon at other 'London Clay' localities have been found here and, as well as having an inherent palaeontological value, have contributed to our overall understanding of contemporary environments. Brachiopods present include *Lingula,* which occurs sporadically throughout the sequence, whilst *Terebratulina wardensis* (Davis, 1936; Elliott, 1938; Rowell and Rundle, 1967), for which Sheppey Cliffs is the type locality, is concentrated in (and restricted to) two horizons – the 'lower *Terebratulina* horizon' and the 'upper *Terebratulina* horizon'. In the former, the presence of slightly disturbed colonies has proved of considerable palaeoecological interest.

Perhaps not surprisingly, numerous molluscs have been listed from the site, although King (1984, p. 143) refers to their general scarcity throughout much of the sequence. This he attributes to the availability of a restricted food supply, together with a generally uncompacted unstable mud bottom inhibiting shallow burrowers and bottom crawlers. A variety of different faunas are present at different horizons. King (1984) has attributed these to changes related to such things as current activity, bottom conditions, depth *vis-à-vis* the photic zone, etc. The much less common, pelagic pteropods have been recorded from the site and it is the type locality for two species, *Spiratella tutelina* and *Camptoceratops prisca* (Curry, 1965b).

Vertebrate palaeontology

The importance of the site for fish remains is emphasized by Casier's (1966) monograph. These include bone and scale fragments, teeth, spines, toothplates and otoliths, but most impressive of all an extensive fauna of teleost skulls occurring in large phosphatic nodules which must have formed before decomposition could be completed (King, 1984, p. 145). King's band D (Figure 3.12) is probably the main source of this material. (Early phosphatization (including soft parts) has also been recorded in crustaceans and molluscs from other stratigraphical horizons.)

Reptiles, birds and mammals are represented by relatively rare specimens, mainly found loose but with the larger ones probably from the phosphatic nodules from band D.

Stratigraphy

King (1984) considers that the Isle of Sheppey is a key section (sic) for the study of the early Eocene in England, but its potential has hitherto been neglected due to the difficulties in establishing its stratigraphy. This may explain for example why Townsend and Hailwood did not include it in their investigation of the magnetostratigraphical correlation of Palaeogene sediments in the London and Hampshire Basins (published 1985). Meticulous work by King (1984) has now clarified the stratigraphy; 14 lithostratigraphical units were defined by him, together with a series of septarian nodule layers (lettered A to P; see Figure 3.12) which have served as useful datum layers for other measurements.

Depositional environment

From his study of the section, King (1984) concluded that the London Clay exposed in the Sheppey Cliffs was laid down in a low-energy, well-oxygenated shelf environment, varying in water depth from about 20 to 100 m. He considered that the alternation of finer and coarser beds was due to minor sea level fluctuations, that the upper part of the sequence reflected progressive shallowing and that the succeeding Viginia Water Formation represents a tidally influenced sand body (an inner sub-littoral marginal marine environment according to Ali *et al.*, 1993).

Comparison with other localities

The Sheppey Cliffs section is now the only exposure in the London Clay where the higher part of the London Clay may be examined. That the site represents the upper part of the formation was recognized by Prestwich (1854b) and agreed by 20th century workers such as Davis (1936), Wrigley (1940) and Davis and Elliott (1957). King (1981, p. 52) correlated the section with his informal stratigraphical divisions D and E, with the base of the exposed section believed to be just above the base of division D, but later stated (King, 1984, p. 155) that the top of division C is represented.

In his 1981 paper, King had correlated Sheppey with the 'standard' sequence in the London area, but later (1984) recognized the need for modification, in part since the basal junctions of the divisions although well defined in the London area, were difficult to identify at Sheppey. King (1984) in fact found that it was to some extent easier to establish correlation with the London area on a biostratigraphical basis (see King, 1984, pp. 154–5 for further details).

Age and correlation

In terms of formal zonation, King (1981) noted that an absence of diagnostic taxa prevents the identification of calcareous nannoplankton or planktonic foraminiferid zones at Sheppey. In summarizing the microfossil zones recognizable at Sheppey, King (1984, p. 152) assigned the sediments between +15 and +51 m above the base of the succession to Keen's (1978) *Echinocythereis reticulatissima* Ostracod Zone, whilst his units 9 to 14 he assigns to the pteropod zone of *Spiratella tutelina*.

With regard to dinoflagellate zones, both *Wetzeliella varielongituda* and *Kisselovia (W.) coleothrypta* Zones have been identified within division D (King, 1981, p. 116). In the dinoflagellate scheme of Bujak *et al.* (1980) the Sheppey section represents the upper two of their three 'London Clay' Zones and Sheppey is the type section for the uppermost zone, the *K. reticulata* Assemblage Zone. Since the latter is coeval with the lowermost part of the *K. coleothrypta* Zone which, according to Costa and Downie (1976), includes all the Bracklesham Beds of Whitecliff and Alum Bays, it is clear that the uppermost part of the London Clay at Sheppey is equivalent to part of this unit in the Isle of Wight. This had been suggested by Eaton (1976), reiterated by Costa and Downie (1976, see particularly their fig. 4) and was later confirmed by the detailed work of Islam (1984). According to this last author, King's divisions D, E and the Virginia Water Formation are represented by Assemblage Zones B-1, B-2 and B-3, the lower three of the 'Bracklesham Beds zones', of Bujak *et al.* (1980).

Conclusions

Sheppey Cliffs comprise the only extant cliff section of the upper part of the London Clay in the London Basin and are the most laterally extensive section of the formation in southern Britain. Their importance for ongoing and future work is therefore considerable.

Of all the Palaeogene sites in Britain, it is the one that can claim to have received the greatest attention, both as regards the length of time its geology has attracted serious interest and also in terms of the volume of publications referring to it. Such attention is predominantly a reflection of the variety of fossils, which have been and continue to be obtained from the site, and their contribution to our knowledge and understanding of many different palaeontological taxa and their stratigraphical significance.

Many groups of fossils from Sheppey have proved to be valuable in helping with palaeoenvironmental and palaeogeographical interpretation. An example is that much of the knowledge we have of contemporary Eocene climate in the British area comes from the London Clay Flora and, of that, the bulk is from Sheppey Cliffs.

LOWER UPNOR SAND PIT, KENT (TQ 759711)

Highlights

The site is one of the very few to show a complete succession of the Lambeth Group and the Oldhaven Beds. It is an important comparative section for the first of these units (formerly called the Woolwich and Reading Formation) and has helped geologists to understand its complicated stratigraphy.

Introduction

This large sand pit lies on the north bank of the River Medway, just north of Chatham, at grid reference TQ 759711. Here, the strata exposed range from the upper part of the Thanet Sand Formation to the lower part of the 'London Clay'.

Interest in the site extends back for over 150 years. The early description by Morris (1837) was followed by others published by Prestwich (1854a) and Whitaker (1872) who both produced faunal lists. It also featured in a number of 19th century papers concerned with stratigraphical definition and nomenclature (Morris, 1837; Whitaker, 1862; Harris, 1887). Early palaeoenvironmental interpretations include that of Whitaker (1889) who alluded to the abundant yet low diversity fauna of the Woolwich Beds at Upnor compared with other localities around London including Charlton and Erith. Monckton (1904) referred to Upnor as providing examples of estuarine (Woolwich

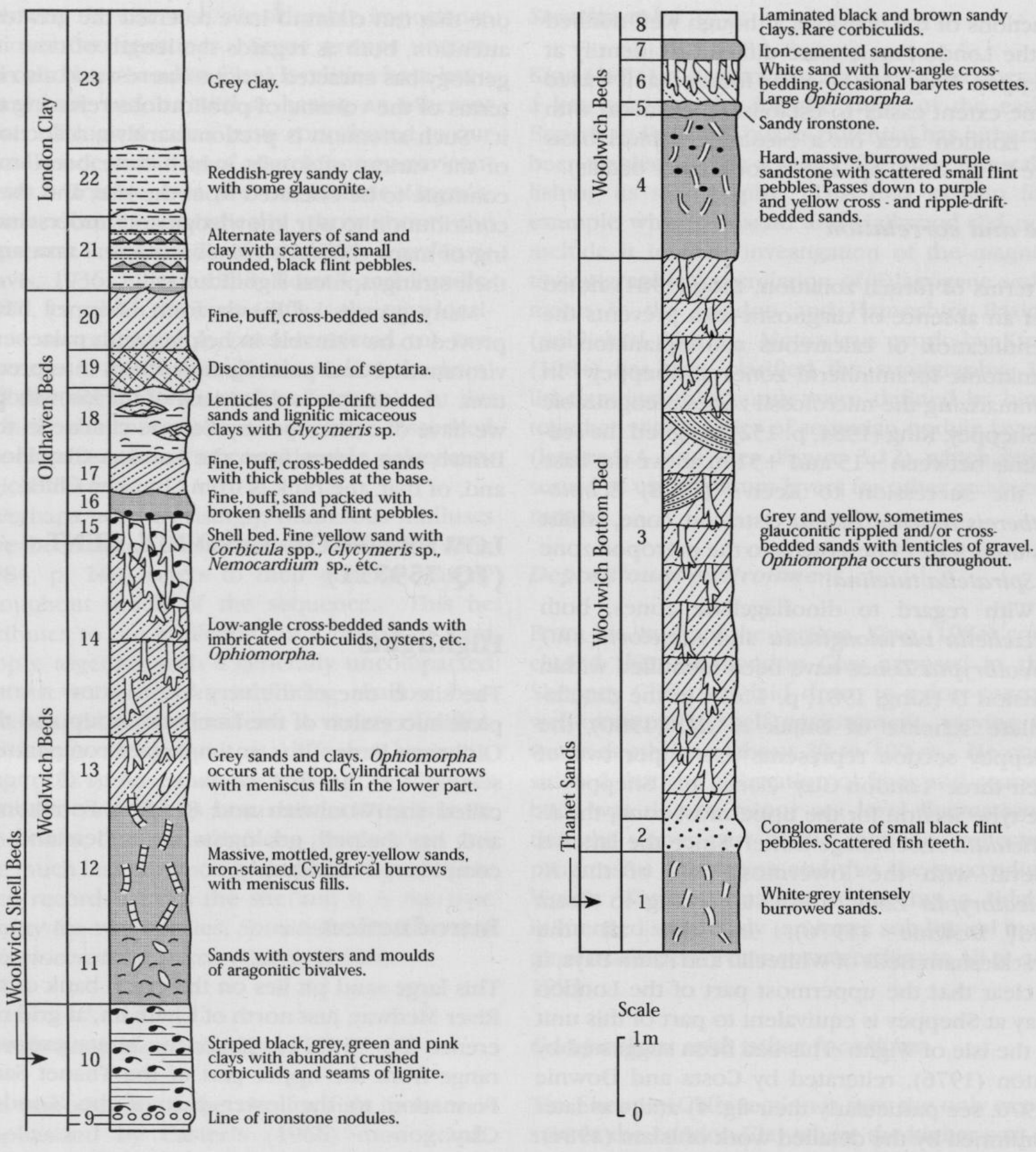

Figure 3.14 Lithostratigraphical succession of the Thanet Formation to London Clay strata in Lower Upnor Sand Pit, Kent (after Kennedy and Sellwood, 1970, fig. 1).

Beds), shallow marine (Oldhaven Beds) and relatively deep marine (Thanet Beds) deposits.

Visits to Upnor by the Geologists' Association have been recorded by Berdinner and Hutchings (1925), Searle (1947) and Stinton (1965a). The last of these authors included a detailed section, as did Kennedy and Sellwood (1970; see Figure 3.14) in their paper on the trace fossil *Ophiomorpha* which is particularly well developed in the Woolwich Beds at this locality.

Relatively brief descriptions of the strata present appear in the Sheet Memoir for the Chatham area (Dines *et al.*, 1954), together with combined faunal lists for this and other sections. References to the locality are also made in the reviews of the Woolwich and Reading Formation by Hester (1965) and Ellison (1983), both of whom alluded to the contribution that it makes to our understanding of the stratigraphy and depositional environments of this part of the

Figure 3.15 Lower Upnor Sand Pit, Kent. The face comprises sands of the Upnor Formation capped at the top by the thinner strata of the Woolwich Formation including the Woolwich Shell Beds. (Photograph: courtesy R.A. Ellison.)

Palaeogene succession. Recently, Ellison *et al.* (1994) have introduced lithostratigraphical nomenclatural changes as part of a wider study.

Description

Lower Upnor Sand Pit (Figure 3.15) is one of the very few localities where a continuous section from the Thanet Sand Formation through complete sequences of the Lambeth Group (formerly the Woolwich and Reading Formation) and the Oldhaven Beds to the 'London Clay' is exposed. The geographical location of the pit facilitates a comparison of what is known to occur to the west (e.g. at Charlton Sand Pit), with the succession of the more easterly exposures in the cliff sections of Pegwell Bay and Herne Bay.

Lithological succession

Below the London Clay, the succession comprises something in excess of 23 m of mainly unlithified sands. The shelly clays of the Woolwich Shell Bed occur towards the centre of the Lambeth group and below this unit, some beds are lithified. Kennedy and Sellwood (1970, fig. 1) recorded the London Clay at about 4 m but King (pers. comm.) has indicated that it exceeds 15 m in thickness. The succession is summarized in Figure 3.16, whilst additional bed-by-bed details are given in Figure 3.14 (after Kennedy and Sellwood, 1970).

Biostratigraphy

Recent work by Powell *et al.* (1996, p. 172) recognized five dinoflagellate cyst 'sequences' at Lower Upnor and that they can contribute to the recognition of breaks in the succession.

Thanet Sand Formation

Although only the upper part of the Thanet Sand Formation is visible here, the locality is located where this unit begins to approach its maximum thickness (see isopachyte map in Hester (1965, p. 130). The basal strata, including the Bullhead Bed are, however, exposed nearby and were sampled by Weir and Catt (1969) in their mineralogical study of the Palaeogene sediments of north-eastern Kent.

Lambeth Group

A complete sequence of the 'Woolwich Beds' of the Woolwich and Reading Formation of Ellison (1983) occurs in the pit. Of the six lithofacies into which he divided this formation, three are

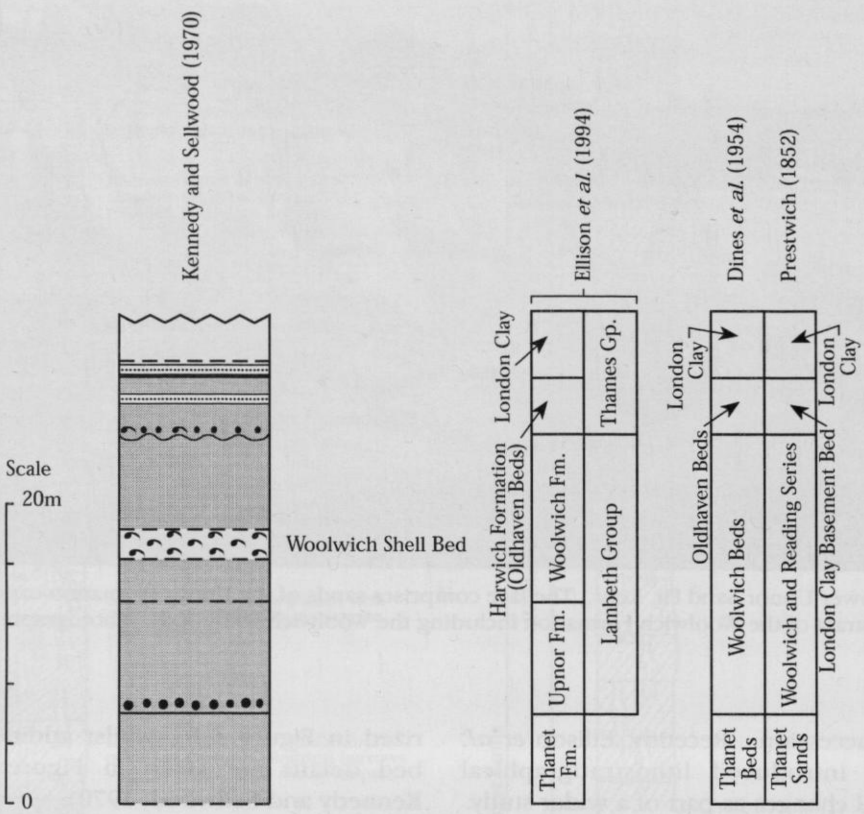

Figure 3.16 Generalized succession at Lower Upnor Sand Pit, Kent, including current and earlier lithostratigraphical terminology.

represented: the 'Glauconite sand', mainly near the bottom of the sequence; the 'Shelly clay' towards the centre (Woolwich Shell Beds of Kennedy and Sellwood (1970) and other authors); and below this, the 'Ferruginous sand' (see Beds 4 and 5, Figure 3.14). Ellison (1983, p. 315) considered that Lower Upnor Sand Pit contains the best extant exposure of the last of these three lithofacies. The sands contain a variety of sedimentary structures in addition to the well-developed *Ophiomorpha* burrows.

Recent changes to the lithostratigraphical subdivision of this part of the Palaeogene succession by Ellison *et al.* (1994) have introduced new nomenclature. The glauconitic sand which Kennedy and Sellwood (1970) called the 'Woolwich Bottom Bed' is now part of the Upnor Formation, and Lower Upnor has been designated the type locality for this formation. Up to the base of the Oldhaven Beds, the remainder of the Lambeth Group is assigned to the Woolwich Formation, whilst the Oldhaven Beds themselves are a component of the Harwich Formation.

Thames Group

The erosive relationship of the overlying Oldhaven Beds (Harwich Formation) with the underlying unit is clearly seen. This unit is thinner than further east. It has a basal shell bed (Bed 15, Figure 3.14) with *Corbicula* (disarticulated and reworked according to King, pers. comm.), *Glycymeris* and *Nemocardium*, whilst according to Stinton (1965a), lenses occurring higher up contain numerous ophiuroids. The succeeding 'London Clay' has a clearly erosive relationship with the underlying Oldhaven Beds.

Interpretation and evaluation

As a result of the dramatic facies changes which characterize the pre-'London Clay' 'Lower

London Tertiaries', any exposure contributes to a better understanding and interpretation of Palaeocene times in this part of the British area. Lower Upnor Sand Pit is particularly important, for it provides a section including the whole of the critical Lambeth Group and Oldhaven Beds and is the only suitable extant exposure 'linking' what is known from the London area with more easterly developments represented by Pegwell Bay and, more particularly, Herne Bay.

Stratigraphical significance

This was first recognized in the 19th century. Morris (1837) grouped the Thanet, Woolwich and Oldhaven beds found here as part of his 'Woolwich and Upnor Strata', whilst Whitaker (1866) recognized Upnor as a key locality in his definition of a new formation, the Oldhaven Beds, in a review of the stratigraphical nomenclature of the 'Lower London Tertiaries' of Kent. Later, Harris (1887) made numerous references to Upnor in a review of the increasingly complex Tertiary nomenclature of the London Basin.

Depositional environments and palaeogeography

Interest in the site has particularly centred on the 'Woolwich and Reading Formation' (now the Lambeth Group) and the Oldhaven Beds. The former, as Whitaker (1872, p. 98) said, is 'as constant in its presence as it is changeful in its structure' and displays marked facies changes throughout its outcrop. Its succession here makes a major contribution to our understanding of these changes. The glauconitic 'Bottom Bed' (now the Upnor Formation) occurs here, as elsewhere, at the base. Further west in the London area, the 'Woolwich Beds' contain plant material and, above the 'Woolwich Shell Bed', comprise muds and sands representing a back barrier lagoon (Ellison, 1983, p. 314). At Lower Upnor, the greater development of sands is thought to represent a barrier sand complex (Ellison, 1983 p. 312). However, the fauna is still of low diversity, suggesting that salinities were less than fully marine. Furthermore, whilst the commonly occurring *Ophiomorpha* has been considered as a marine indicator (Kennedy and Sellwood, 1970), there is evidence that this ichnogenus also develops in brackish or even fresh water environments (Stewart, 1978).

The 'Ferruginous sand' facies, now best exposed at this locality, equates to ferruginous sandstone doggers, informally known as the 'Winterbourne Ironstone', and formerly visible at Winterbourne Sand Pit (grid reference TR 065571) (Gamble, 1972). This facies is considered by Ellison (1983) to represent the culmination of the mid-Woolwich and Reading Formation regression when the barrier sands were modified following emergence or a lowering of the water table. Furthermore, he has speculated that this 'event' may be represented to the west in the 'Mottled clay' (typically 'Reading Beds') facies by a prominent soil profile.

The difference between the Lambeth Group succession here and that at Herne Bay mainly reflects the pre-Oldhaven Beds unconformity, for the latter is markedly erosive and in general lies on progressively lower horizons of the 'Woolwich Beds' (Lambeth Group) from west to east (Hester, 1965, fig. 6). Whilst the Lambeth Group is thinner at Herne Bay than at this locality, the opposite applies to the Oldhaven Beds. The fossiliferous nature of the latter is unusual, since in most inland sections, it has been decalcified (Ward, 1978, p. 6). The Oldhaven Beds contains a mixed fauna, including brackish elements, suggesting an inshore situation, and are now agreed by Ellison *et al.* (1994) to be a proximal or nearshore facies of the Harwich Formation.

Conclusions

Lower Upnor Sand Pit is one of the very few remaining sections where a complete section of the Lambeth Group (formerly the Woolwich and Reading Formation) and Oldhaven Beds (Harwich Formation), together with the top of the Thanet Sand Formation and the lower part of the 'London Clay' may be examined. As a geographically intermediate exposure between sites such as Charlton Sand Pit in the London area and the coastal localities of Pegwell Bay and Herne Bay, it is especially significant.

For the Lambeth Group in particular, it has proved to be an important comparative section that has facilitated our understanding of its complex stratigraphy and hence an appreciation of the contemporary palaeogeography. The best stratigraphical 'marker' in the formation (the 'Woolwich Shell Beds') and the underlying 'Ferruginous' sand is clearly seen here, whilst the barrier sand facies is also well developed.

The relationship with the overlying Oldhaven

Beds here, together with that apparent at localities such as Herne Bay, clearly demonstrates the development of intra-Palaeocene tectonism towards the eastern end of what is now the London Basin, when uplift was followed by differential erosion of the Lambeth Group, an event now represented by the sub-Oldhaven Beds unconformity.

CHARLTON SAND PIT (GILBERT'S PIT), KENT (TQ 419786)

Highlights

Charlton Sand Pit is the best remaining section in the Lambeth Group strata in the London area. Here, Palaeocene sediments rest unconformably on the Chalk. Various facies of the Thanet Sand Formation and the Woolwich Formation are exposed whilst the presence of the Blackheath Beds, now rarely seen elsewhere, further enhances the value of the site.

Introduction

Charlton Sand Pit (grid reference TQ 419786), known also as Gilbert's Sand Pit, in Maryon Park, Greenwich, comprises a long disused sand pit in which a succession of Palaeogene strata comprising the Thanet Sand Formation, the Upnor Formation and the Woolwich Formation (both formerly considered as the Woolwich Beds) and the 'Blackheath Beds' occur above an unconformable contact with the Upper Cretaceous Chalk.

The exposures, widely recognized as the finest of their type in the London area, have attracted the attention of geologists since the middle of the 19th century. Following an early section of the pit produced by Prestwich (1854a), Lavis (1876) compared the 'Lower London Tertiaries' exposed at Charlton with those at Lewisham and made some perceptive observations on both the conditions of deposition and sources of sediment. Charlton has been visited on many occasions by the Geologists' Association, whose earliest recorded excursion was documented by Lobley (1881). Subsequent visits by the Association are recorded in a number of field meeting reports (Holmes, 1895; Leach, 1908, 1915, 1920, 1930, 1939; Pitcher, 1948; Epps, 1950, 1956). Later work on the site was undertaken by the Tertiary Research Group and recorded by Rundle (1970b, 1972), whose later paper includes a comprehensive review of the literature. References to the site are made also in Gamble (1982) and in Ellison (1983), who referred to the locality as a classical Tertiary exposure. The reference to Charlton Brickpit in Costa and

Figure 3.17 Charlton Sand Pit, Maryon Park, Greenwich, Kent. The 'Woolwich Shell Bed' (Woolwich Formation). (Photograph: B. Daley.)

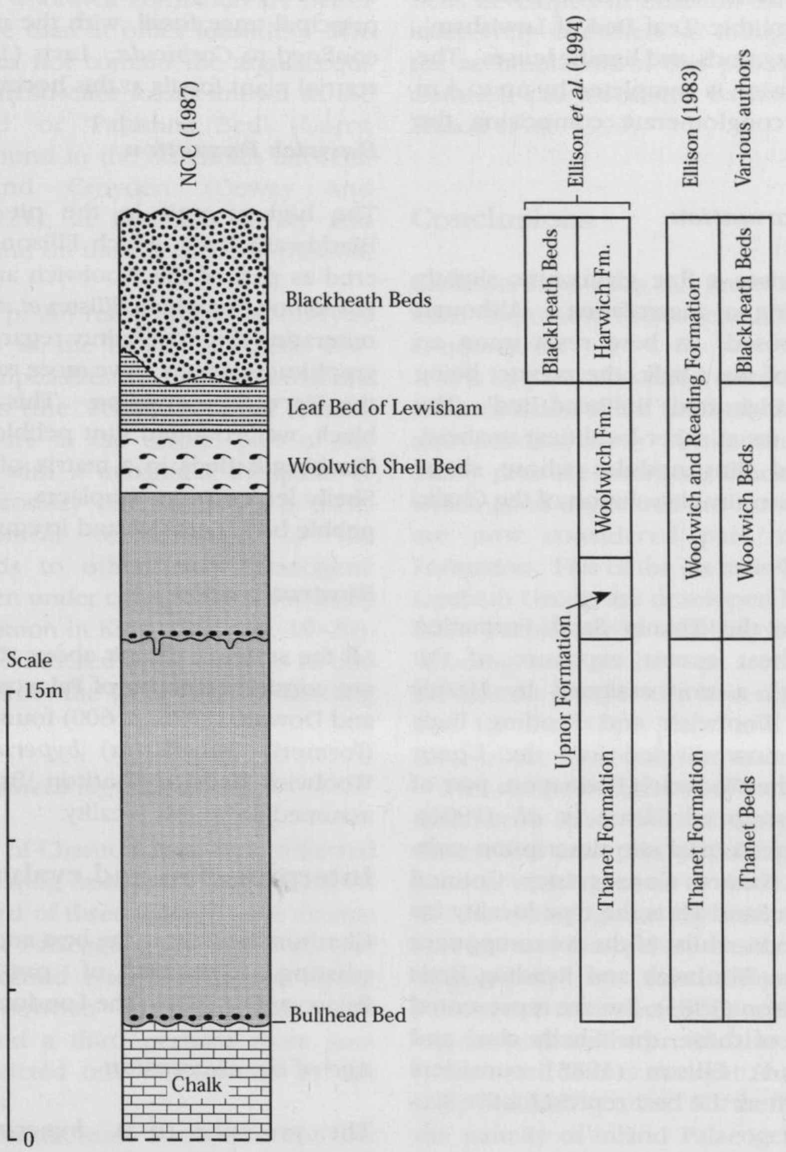

Figure 3.18 Lithostratigraphical succession of the Thanet Formation, Upnor Group and Blackheath Beds (Harwich Formation) at Charlton Sand Pit, Kent (after Nature Conservancy Council, 1987 and other authors). (Currently the contact with the Chalk is not exposed.)

Downie (1976) is thought to refer to this locality.

Description

The lower part of the Palaeogene succession in the pit, including the contact with the Chalk, is presently obscured but it provides the best outcrop at this stratigraphical level in the area where the formerly named Woolwich Beds were originally defined (Figure 3.17).

Lithological succession

The succession (Figure 3.18) comprises less than 20 m of sediments. The Thanet Sand Formation comprises somewhat glauconitic sands. The Lambeth Group (now the Upnor Formation and the Woolwich Formation) are some 10.4 m in thickness. This unit commences with sands, glauconitic below but brown and yellowish-weathered above. Next, comes the mud with numerous shells of the 'Woolwich Shell Bed' and above, the heterolithic 'Leaf Bed of Lewisham', comprising sands, muds and lignitic lenses. The top of the succession is completed by up to 3 m of flint-pebble conglomerate comprising the Blackheath Beds.

Thanet Sand Formation

This unit comprises a fine glauconitic slightly silty sand lacking a macrofauna. Although presently unexposed, its base rests upon an eroded surface of the Chalk, the contact being marked by the celebrated 'Bullhead Bed'. The latter comprises (as at other localities) unabraded, green-coated flint nodules whose shape probably reflects in-situ dissolution of the Chalk.

Lambeth Group

The beds above the Thanet Sand Formation comprise the best extant exposure of the 'Woolwich Beds', a unit assigned by Hester (1965) to the Woolwich and Reading Beds Formation but now divided into the Upnor Formation and the Woolwich Formation, part of the Lambeth Group of Ellison *et al.* (1994). According to a geological site description published by the Nature Conservancy Council (1987), Charlton Sand Pit is the type locality for the Woolwich Beds, whilst of the six component lithofacies of the Woolwich and Reading Beds described by Ellison (1983), five are represented here. For two of these, the 'Shelly clay' and 'Laminated sand', Ellison (1983) considers Charlton Sand Pit as the best representative section.

Stratigraphically, the Lambeth Group at Charlton may be considered to consist of four units. The lowest comprises the 'Woolwich Bottom Bed', glauconitic sands, with well-rounded flint pebbles at their base, now called the Upnor Formation. The remaining three units above comprise part of the Woolwich Formation, for which the pit is the type section (Ellison *et al.*, 1994). The first comprises sands, brown and yellow-weathered above. This is followed by the Woolwich Shell Bed ('Shelly clay' of Ellison, 1983) which contains a restricted fauna of molluscs, particularly *Brotia*, *Corbicula*, *Ostrea* and *Tympanotonus*. Above, is the Leaf Bed of Lewisham ('Laminated sand' of Ellison, 1983), comprising wavy and lenticular bedded fine sands and silty clay. Bioturbated thicker beds also occur. *Ophiomorpha* is the principal trace fossil, with the molluscan fauna confined to *Corbicula*. Lavis (1876) found terrestrial plant fossils at this horizon.

Harwich Formation

The highest unit in the pit comprises the Blackheath Beds, which Ellison (1983) considered as part of the Woolwich and Reading Bed Formation but which Ellison *et al.* (1994), whilst reiterating the uncertainty regarding their stratigraphical relations, have more recently placed in the Harwich Formation. This unit comprises black, well-rounded flint pebbles typical of the Blackheath Beds in a matrix of silty fine sand. Shelly lenses occur in places. The base of this pebble bed is erosive and irregular.

Biostratigraphy

All the strata in the pit above the unconformity are considered to be of Palaeocene age. Costa and Downie (1976, p. 600) found *Apectodinium* (formerly *Wetzeliella*) *hyperacantha* in the Woolwich Beds of Charlton 'Brickpit', which is assumed to be this locality.

Interpretation and evaluation

Charlton Sand Pit is the best and most complete existing exposure of pre-'London Clay' Palaeogene rocks in the London area.

Age of the succession

The presence of *A. hyperacantha* in the Woolwich Beds confirms an Upper Palaeocene age for the sequence and allows their correlation with the Landenian, the Lower Sparnacian and the upper part of the German Paläozän. Proximity to the top of the Palaeocene is emphasized by the fact that in Herne Bay and Whitecliff Bay, the top of the *A. hyperacantha* Zone lies in the basal few metres of the 'London Clay'.

Comparison with other localities

A comparison of the section with the sequence in other pits and selected boreholes is given in Ellison (1983, fig. 2). The Thanet Sand Formation is thinner and less well-exposed than at localities further east (e.g. Herne Bay), although the 'Shelly clay' and 'Laminated sand' of the overlying Woolwich Formation are better represented here than at other localities. The 'Shelly clay' does not contain the argillaceous limestone with freshwater fossils known as the 'freshwater bed' or 'Paludina Bed' (Curry, 1958b, p. 64) found in the boreholes between Rotherhithe and Croyden (Dewey and Bromehead, 1921), at Peckham (Berry and Cooper, 1977) and on the Isle of Dogs (Ellison, 1983).

King's (1981, p. 20) reference to the rarity of good exposures of the Blackheath Beds elsewhere further emphasizes the importance of this site. This facies (the 'Pebble Beds' of Ellison, 1983) only occurs in the central part of the London Basin, with a maximum thickness of 24 m around Bromley (Ellison, 1983, p. 315). The stratigraphical relationships of the Blackheath Beds to other early Palaeogene deposits has been under consideration for many years (see discussion in King, 1981, pp. 19–20). Ellison (1983) considered these deposits as one of his six facies from the Woolwich and Reading Beds.

Palaeogeographical significance

The importance of Charlton Sand Pit is reflected by an interest dating from the 19th century. It provides a record of three transgressive events: the earliest of the Palaeogene transgressions (the Thanetian), a second evidenced by the Upnor Formation (Woolwich Bottom Bed) (the 'Landenian'), and a third perhaps more geographically restricted one represented by the Blackheath Beds.

Whilst the Thanet Sand Formation and the Upnor Formation are clearly marine in origin (see discussion elsewhere), the Woolwich Formation represents less saline waters. The 'Woolwich Shell Bed' consists almost entirely of brackish water shells whilst the overlying 'Leaf Bed of Lewisham' indicates a closeness to land. Lavis (1876) noted that whilst an aquatic flora occurred at Lewisham, terrestrial plants were present here. Ellison (1983, p. 314) saw this unit as representing a back barrier lagoon. Also, it may be that at some stage, freshwater conditions were established here, for King (pers. comm.) has pointed out that the freshwater 'Paludina Bed' is from a higher level in the formation and that its absence at Charlton reflects erosion in pre-Blackheath times.

The erosional relationship of the Blackheath Beds developed in Charlton Sand Pit and more extensively elsewhere is thought to represent the accumulation of this pebbly facies in tidal channels and associated barrier complexes (cf. Ellison *et al.*, 1994).

Conclusions

Charlton Sand Pit is the finest and scientifically most important Palaeogene site in the south London area.

It is of particular value since it contains a varied succession of the Lambeth Group (Woolwich and Reading Beds Formation *sensu* Hester, 1965) plus the overlying Blackheath Beds, for which good exposures are now rare and which are now considered part of the Harwich Formation. Five of the six main lithofacies in the Lambeth Group are developed here. Whilst the often purple to red mottled clays typical of the 'Reading Beds' to the west are absent, the pit is thought to provide the best representative section for the 'Shelly clay' and the 'Laminated sand' of the Woolwich Formation.

The site provides one of the finest records of Palaeocene times in south-eastern England and the earliest examples of the transgressive cyclic pattern, which goes on to characterize the whole of the Palaeogene succession in both the London and Hampshire basins. It provides an opportunity for continuing research into Palaeocene environments, including palaeontological work on the prolific though taxonomically restricted faunas thought to represent essentially brackish waters. Furthermore, in view of the paucity of inland Palaeogene exposures in the London area, its potential for educational purposes should not be underestimated.

ELMSTEAD ROCK PIT, CHISLEHURST, KENT (TQ 423706)

Highlights

This small site comprises a good section in cemented and fossiliferous Blackheath Beds, examples of which are now rare. The succession, with its diverse marine and brackish water fauna, is considered to be a good representative of tidal channel bar facies.

Introduction

The site referred to here as Elmstead Rock Pit is located in the back garden of 41 Elmstead Lane, Chislehurst (TQ 423706) and is a former quarry face comprising fossiliferous pebbly sands attributed to the 'Blackheath Beds'.

Prestwich (1854a) made an early reference to this area of Kent in his comprehensive study of the Woolwich and Reading Beds. He noted that in the vicinity of Sundridge Hill, the pebbly sands ('Blackheath Beds') overlying the Woolwich Beds were unusual in having a strong calcite cement and contained abundant shelly fossils. At Sundridge (Elmstead), these beds showed a 'strong stratification dipping up to 22° north'.

The area of Elmstead Woods and Sundridge Park has in earlier years been visited many times by the Geologists' Association, interest being in the 'Rock Pit' in Sundridge Park and in the railway tunnel and cutting at Elmstead Hill (TQ 422707). There are numerous references to the area dating back to the 19th century (Ilott and Coles-Child, 1872; Lobley, 1876; Whitaker and Holmes, 1897; Holmes, 1900, 1901; Holmes and Osman, 1902a,b; Stamp, 1920; Wrigley, 1945). As was pointed out, however, by James and George (1970) in a report on the current site, the past literature contains many vague location details, and clearly more than one site was involved. However, the present site is probably that described by Wrigley (1945) as being 'in an enclosed copse hard by the station', i.e. Elmstead Station.

On the 1910 6-inch geological map (Kent VIII SW), the area is inscribed 'Fossiliferous sands with pebbles' and the site of the Rock Pit is marked 'Sand and pebbles with conglomerate bands. 20ft. Many fossils'. This map also shows the area containing the Rock Pit as Rockpit Wood, a name the later 6-inch maps use for the area south of the railway. The most recent description of the site is the brief account given by James and George (1970) who referred to earlier descriptions by Stamp (1920) and Wrigley (1945) who produced faunal lists, as did Prestwich (1854).

Description

The rock pit at 41 Elmstead Lane is a fine section, comprising some 6 m exposure of Blackheath Beds. These consist of fine quartz sands containing abundant, very well-rounded flint pebbles up to 8 cm in diameter, concentrated into bands some centimetres to decimetres in thickness. The beds have an apparent dip of up to 25° NE, but this is a syndepositional inclination rather than one of tectonic origin.

The sands, for the most part, are strongly cemented by calcite which has facilitated their remaining particularly fossiliferous. Amongst the most common fossils recorded by Wrigley (1945) are *Corbicula cuneiformis*, *C. cordata*, *Ostrea bellovacina*, *Lentidium antiquum* and *Aloidis arnouldi*. James and George (1970) recorded *Nerita semilugubris* and a teredinid tube, both of which were new records for the locality, together with *Barbatia modioliformis*, rare in Britain, and a variety of fish teeth and bones.

Interpretation and evaluation

As King (1981) pointed out, good exposures of the Blackheath Beds nowadays are rare. Although formerly well-exposed at Blackheath (grid reference TQ 395765), there are no longer good exposures there.

Opinions have differed regarding the stratigraphical relationships and status of the Blackheath Beds (see discussion in King, 1981). Although at one time thought to be the lateral equivalent of the Oldhaven Beds, a later consensus suggested that they are a facies of the Woolwich and Reading Beds (King, 1981; Ellison, 1983). King (1992, pers. comm.) subsequently postulated that they may be younger than this, a view recently supported by Ellison *et al.* (1994) who placed the Blackheath Beds in their Harwich Formation.

A particularly unusual and significant aspect of Elmstead Rock Pit is the preservation of a diverse fauna including brackish as well as fully marine species. Wrigley (1945) considered that the former were derived from the underlying Woolwich Beds, although Curry (1965a, p. 159) felt that derivation from the latter could only account for a proportion of what he called the 'estuarine element' of the fauna of the Blackheath Beds. Ellison's (1983) conclusions are compatible with this view. Elmstead represents a western brackish facies of his 'Pebble Beds' (synonymous with Blackheath Beds) which contrasts with their marine development further east.

Although the bottom of the Blackheath Beds is not visible in the Elmstead Rock Pit, it is apparent from Elmstead Hill that they have a markedly erosional base and, in Elmstead railway Tunnel, truncate various divisions in the underlying Woolwich Beds (Whitaker, 1889). In outliers, near Caterham, the Blackheath Beds are reported to actually cut down into the Chalk but this may be due to late Tertiary reworking, followed by the formation of solution hollows (King, 1981 and pers. comm.).

Curry (1965a) suggested a tidal channel origin for the Blackheath Beds, whilst Ellison (1983) concluded that those parts of the sequence with steep syndepositional dips are best interpreted as bars within such channels (see also Ellison *et al.*, 1994). Elmstead Rock Pit therefore appears to provide a rare exposure of the latter and one representing brackish influences someway westward from the seaward end of the tidal channels.

The presence of well-rounded flint pebbles is indicative of high energy, although rounding may reflect a polycyclic history. The presence of flints in large numbers may shed light on the palaeogeography of the area, although open to various interpretations. Was the Chalk locally exposed; were the flints derived from earlier gravels; or were they, as Curry (1965a) suggested (following Leach, 1910), derived from the erosion of the Chalk subaqueously in deep channels?

Conclusions

Elmstead Rock Pit comprises a good exposure of the Blackheath Beds of which exposures are nowadays rare. It consists of a fine example of what is considered to be tidal channel bar facies within this unit and unusually contains a diverse fauna, comprising abundant shelly fossils of brackish as well as marine affinities.

The presence of large numbers of well-rounded flints indicates that a considerable amount of Chalk had been eroded by the time the Blackheath Beds accumulated. However, whether they were derived from subaerial exposures of Chalk, subaqueously, in deeply incised channels, or polycyclically via earlier flint gravels remains unclear.

HARWICH, ESSEX (TM 263316–TM 263323)

POTENTIAL GCR SITE

Highlights

This locality is particularly important as the best exposure of the 'Harwich Stone Band', the most distinctive of the ash bands in the Harwich Formation (formerly the Harwich Member of the 'London Clay') which are now known to correlate with volcanic horizons in the North Sea Palaeogene succession.

Introduction

To the eastern side of the Harwich promontory, between grid references TM 263316 and TM 263323, a conspicuous hard bed, the 'Harwich Stone Band', is well exposed on the upper foreshore. This represents the best lithified and most easily identifiable example of in excess of 30 ash bands within the Harwich Formation (Ellison *et al.*, 1994), formerly the Harwich Member of the 'London Clay'. Both the Harwich Formation and the London Clay belong to the Thames Group of King (1981).

Harwich Cliff was first described by Dale in 1704 and in more detail in a later account in 1730, well before the construction in the 19th century of a protective breakwater and concrete 'promenade' which led to the cessation of active erosion (Elliott, 1971a).

The 'stone band' at Harwich was recognized as significant many years ago: the streets of Harwich had been originally paved with it and, indeed, the very existence of Harwich may reflect its resistant nature (Greensmith *et al.*, 1973, p. 10). Its presence had been noted by workers such as Whitaker (1918) and Davis and Elliott (1951a), although its geological significance was not fully recognized prior to Elliott's (1971a, b) discovery that it provided evidence for contemporaneous Eocene vulcanicity.

References to fossils from the 'Harwich Stone Band' and the adjacent muds within the Harwich Formation include Elliott (1971a) and Daniels (1971), whilst its magnetostratigraphical character was investigated by Townsend and Hailwood (1985, p. 972).

This site is a confirmed GCR site for its fossil plant content, a more detailed account will be published in the GCR Series volume *Mesozoic to*

Tertiary Palaeobotany of Great Britain (Cleal and Thomas, in prep.).

Description

No natural cliff exposures have occurred at Harwich since the construction of the 'promenade'. Elliott (1971a), however, referred to the exposure on the foreshore of the lowest 7 m of the 'London Clay', with the 'basement-bed' not seen but known from dredged material. This succession, later assigned to the Harwich Member by King (1981), occurs within the Harwich Formation of Ellison *et al.* (1994).

The Harwich Stone Band

At the time of writing, foreshore exposures are poor, except for the 'Harwich Stone Band' which is well exposed on the upper foreshore. This comprises an apparently tabular, very well lithified band around 20 cm in thickness that rests sharply on underlying soft muds. A.C. Bishop (in Elliott, 1971a) referred to its having an ash content comprising angular, brown glass shards, some of which are streaky and resemble pumice, crystal fragments (often plagioclase) and lithic fragments full of opaque granules containing minute elongate feldspar crystals. Elliott (1971b) reported that the ash content varies rapidly laterally.

Palaeontology

Elliott (1971b) referred to the common occurrence of fossils within the 'Harwich Stone Band', including sparse bivalves and gastropods, microcoprolites, siliceous diatoms and pyritized radiolaria. Fossils from this band were also recorded by Daniels (1971), including a seed *Jenkinsella apocynoides*. In places, there is evidence of bioturbation (Elliott, 1971a).

Whilst the muds both above and below the 'Harwich Stone Band' are currently poorly exposed, they are known to be fossiliferous. From the foreshore muds below this horizon, Elliott (1971a) reported numerous fish teeth, a small fruit flora (some ten genera according to K.I.M. Chesters in Elliott, 1971a) and a microbiota of diatoms (including *Coscinodiscus*), hystrichospheres, the foram *Astrorhiza* and Chalk-derived sponge spicules and foraminifera. Similar microfossils also occur in the muds above the Harwich Stone Band, together with woody material. Elliott's (1971a) account clearly implies that the fossil material noted was at least in part redistributed by present-day foreshore processing. Daniels (1971) referred to the presence of pyrite concentrates on the foreshore, which include pyritized wood or 'platimore', to use an old local term (Greensmith *et al.*, 1973).

Magnetostratigraphy

Magnetostratigraphical results determined from material from the Harwich Stone Band and the underlying mud by Townsend and Hailwood (1985) indicate deposition during a period of reverse polarity magnetization.

Interpretation and evaluation

The 'Harwich Stone Band', with its tough, well-lithified character, is lithologically quite unique in the context of the Thames Group. It was not, however, until the early 1970s (Elliott, 1971a, b) that its stratigraphical and palaeogeographical importance was fully appreciated; namely that it provides clear evidence that the range of ash-fall deposits of early Eocene age extended into the area of onshore Britain. The Harwich site clearly, therefore, has not just a scientific but an historical significance in the development of our understanding of Palaeogene times.

The Harwich Stone Band is the thickest of the ash layers known from the Harwich Formation and its lateral persistence in eastern Essex and South Suffolk makes it an important marker horizon. It occurs, for example, in 'Ferry Cliff' near Woodbridge, Suffolk (grid reference TM 278486) (George and Vincent, 1977, p. 25) and at Wrabness, where younger ashes are also present. Further discussions of the ashes and the significance of the magnetostratigraphical data are considered in the account of the Wrabness site.

As well as being of stratigraphical importance, the Harwich site has been notified for its palaeobotanical significance. The site apparently yields the only fossil flora attributable with certainty to division A1 (the former Harwich Member) of King (1981). Hence, whilst floristic details will be considered elsewhere in the *Mesozoic to Tertiary Palaeobotany* GCR volume, the fossil plants may also provide data to enhance understanding of both palaeoenvironmental and palaeoclimatological aspects of early Thames Group times.

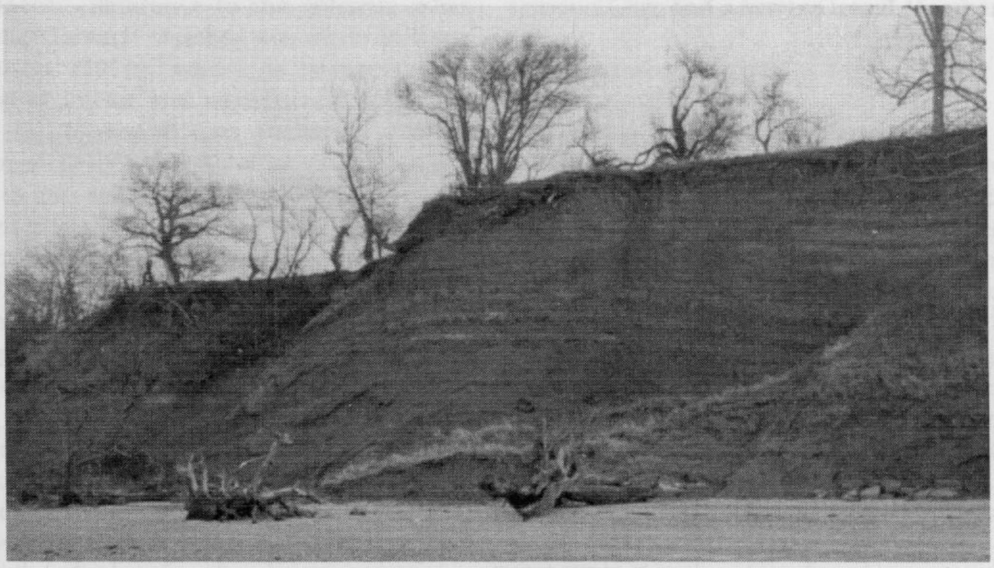

Figure 3.19 Wrabness, Essex. Cliff section showing parallel ash bands (light-coloured) in the Harwich Formation. (Photograph: B.Daley.)

Conclusions

This site provides the best exposure of the Harwich Stone Band, the thickest and most distinctive of the ash bands that comprise a significant component of the Harwich Formation in this area and are correlatable with volcanic horizons in the North Sea succession. Furthermore, the site is historically important, since it was from here that evidence for Eocene volcanism was first discovered in the onshore sediments of the London Basin.

Harwich has a restricted fossil biota, but the macroflora (considerably older than that of Sheppey) has some potential for clarifying palaeoenvironmental and palaeoclimatological aspects of earliest Thames Group times in the British area.

WRABNESS, ESSEX (TM 171323–TM 174324)

POTENTIAL GCR SITE

Highlights

The cliffs at Wrabness comprise the major volcanic ash-bearing exposure of the Harwich Formation, with around 34 ash bands present. Its importance stratigraphically is recognized by its designation as one of the two type sections for the distal facies of the Harwich Formation. Of the fossils present in the succession, the macroflora is of particular importance.

Introduction

Exposures of Thames Group strata occur in the banks of a number of rivers in Essex and Suffolk (George and Vincent, 1977). Of these, the most stratigraphically significant is that at Wrabness on the southern side of the estuary of the River Stour, particularly the cliff between grid references TM 171323 and TM 174324 (Figure 3.19). Here, both the Harwich and Walton Members of the 'London Clay' of King (1981) are represented in the approximately 15 m high cliff, the former having now attained formational status as the Harwich Formation (Ellison *et al.*, 1994).

Whilst the cliff at Wrabness was known to early workers and was figured, for example, in Whitaker (1885), relatively recent years have seen a renewal of interest in the section. This mostly reflects the fact that it is the major volcanic ash-bearing site within the Thames Group, although both the cliff and the adjacent foreshore exposures are also of importance palaeontologically.

References to the fossils present include Daniels (1971) and a brief note in George and Vincent (1977). Figure 3.24 (after King, 1981) shows the stratigraphical relationship of the Wrabness section with those at Ferry Cliff (near Woodbridge, Suffolk) and Walton-on-the-Naze and the Shotley Gate borehole (grid reference

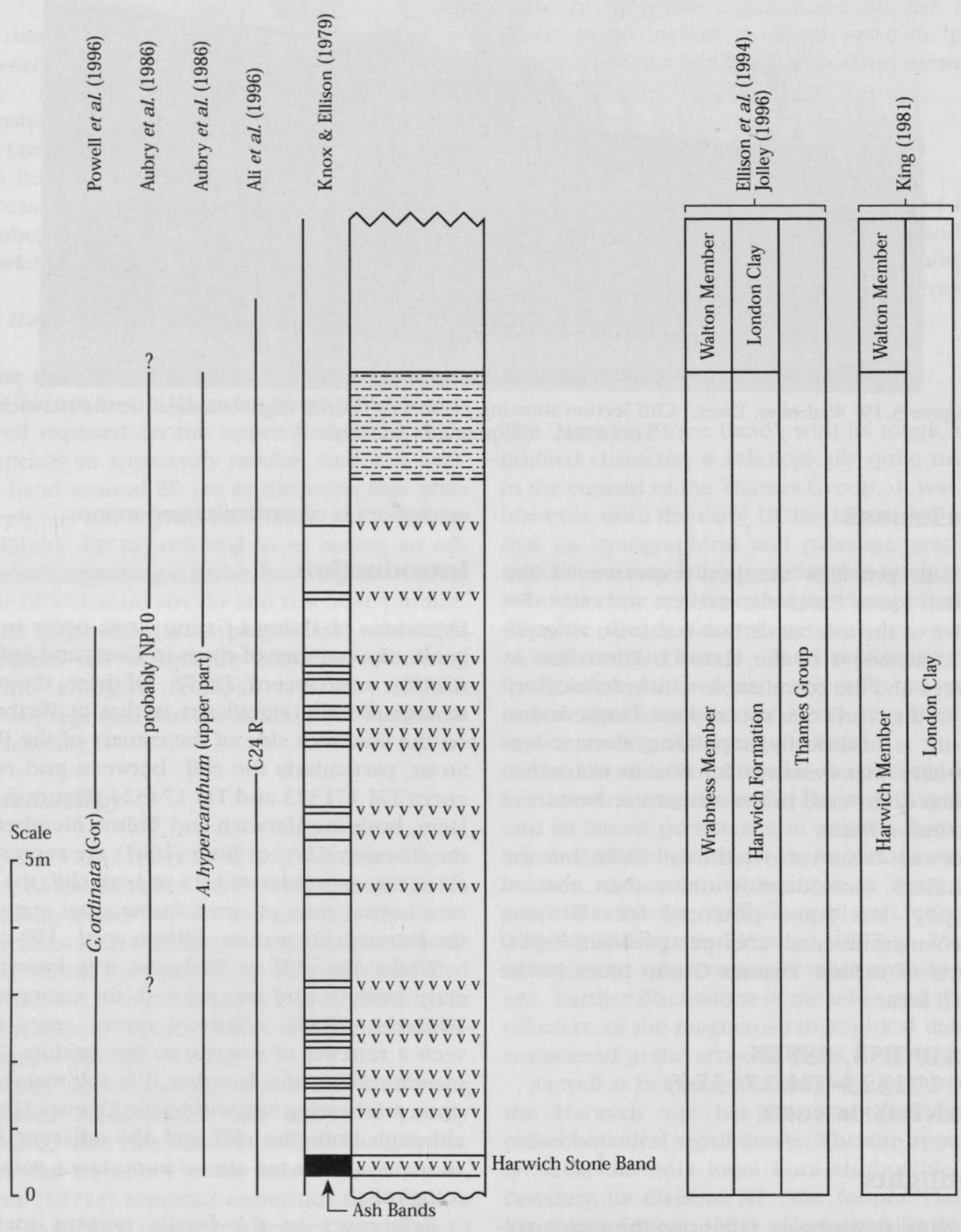

Figure 3.20 Lithostratigraphical, biostratigraphical and magnetostratigraphical succession of the Harwich Formation and London Clay at Wrabness, Essex (after various authors).

TM 244346). Reference to the volcanic ashes within the Harwich Member was made in Knox and Ellison (1979), whilst its magnetostratigraphical character and significance were considered by Townsend and Hailwood (1985), Aubry *et al.* (1986) and Ali *et al.* (1996). A reference to the section was made in Jolley and Spinner (1991), who sampled it as part of their study of spore-pollen associations from the lower 'London Clay'. More recently, its dinoflagellate assemblages were studied by Powell *et al.* (1996; see particularly their log: fig. 5, p. 150). A recent log is also given in Jolley (1996, fig. 3, p. 223).

This site is a confirmed GCR site for its fossil plant content, a more detailed account will be published in the GCR series volume *Mesozoic to Tertiary Palaeobotany of Great Britain* (Cleal and Thomas, in prep.).

Descriptions

Exposures in the 15 m or so high cliff at Wrabness extend laterally for about 300 m, with parallel stratification indicating a weakly anticlinal structure.

Lithological succession

The succession (Figure 3.20) is something in excess of 16 m in thickness. Much of it comprises muds and silty muds which are concretionary in places. Jolley (1996, p. 253) refers to 10 m of tuffaceous siltstone (sic) containing 32 complete tephra layers (Figure 3.21). The distinctive Harwich Stone Band occurs near the base of the section. The upper part of the Harwich Formation comprises sandy silts and these are succeeded by muds of the London Clay.

Lithostratigraphy

King (1981) designated Wrabness as the stratotype for his Harwich Member ('London Clay'), now the Harwich Formation, for which the site is part of a composite stratotype (Ellison *et al.*, 1994, p. 194) and of which the top 10 m is exposed in the cliff. The uppermost part of the cliff is in the Walton Member of the London Clay. More recently, Jolley (1996, pp. 252–3) has split the Harwich Formation into two members: an upper Wrabness Member, to 'describe the tuffaceous siltstones [sic]' up to the base of the London Clay, and a lower Orwell Member.

Palaeontology

The cliff is poorly fossiliferous. King (1981) reported that, overall, the Harwich Member is decalcified at outcrop, except for calcareous nodules and occasionally shelly pockets (see account of Walton-on-the-Naze in this volume). At Wrabness, a restricted calcareous microfauna from just above the Harwich Stone Band yielded *Cytheridea unispinae* and poorly preserved polymorphinids. Fossils are, however, preserved in the 'stone-bands', including a few molluscan genera such as *Arctica* and *Mytilus* (Daniels, 1971).

Daniels (1971) referred to both unweathered 'London Clay' and pyrite concentrates on the foreshore, from which sharks' teeth, seeds, a cone and woody material were recovered. In addition to plant and fish fossils, George and Vincent (1977) reported the occurrence of beetle remains.

The site has now been designated as an SSSI for its palaeobotanical importance, yielding plants from both members. Small seeds and fruits are preserved in concretions, thereby complementing anatomical detail obtained from pyritized material at other localities.

Biostratigraphy

In work on the Wrabness section, Jolley and Spinner (1989,1991) assigned the Harwich Formation to the *A. hyperacanthum* dinoflagellate biozone (*sensu* Costa and Downie, 1976; Costa *et al.*, 1978) and restricted the succession above the Harwich Stone Band to the *D. oebisfeldensis* acme biozone. However, in more recent work by Powell *et al.* (1996), the whole of the sequence is placed in the *Glaphrocysta ordinata* chronozone (the 'Gor' biozone of Powell, 1992). Ali and Jolley (1996) placed the Harwich Formation tephras in the early Eocene NP10 nannoplankton zone and assigned it to the upper part of the *A. hypercanthum* zone (not *sensu* Powell, 1992). Figure 3.21 shows the distribution of palynomorph association sequences at Wrabness (after Jolley, 1996).

Magnetostratigraphy

It is not surprising that Wrabness, as the best section in the 'distal' facies of the Harwich

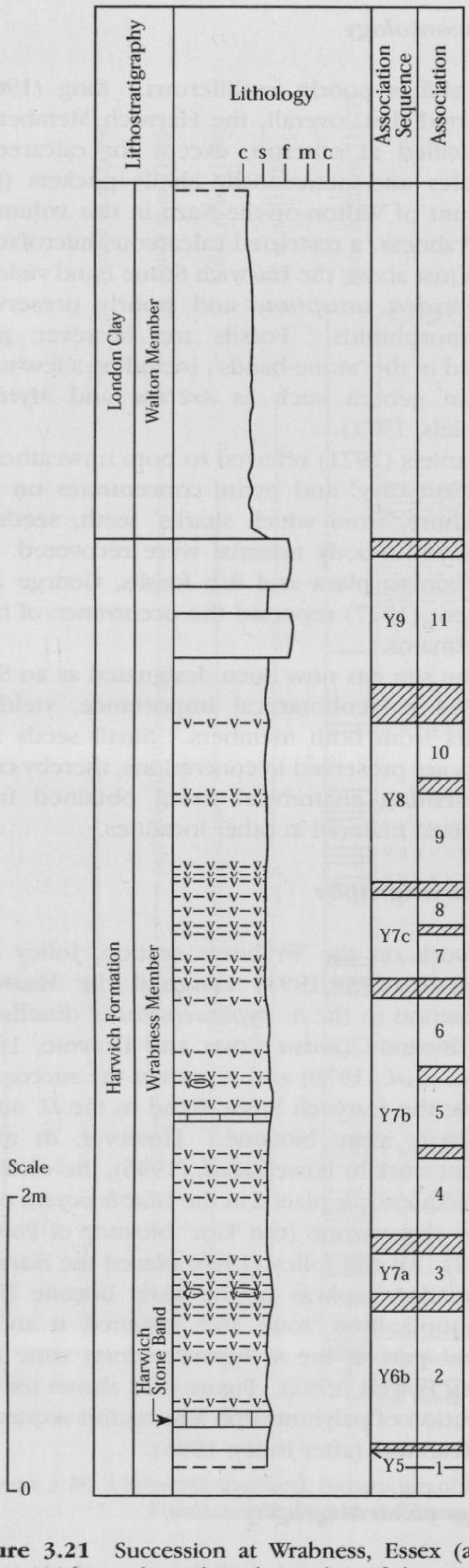

Figure 3.21 Succession at Wrabness, Essex (after Jolley, 1996), to show the relationship of the tephra-bearing lithostratigraphical succession to palynomorph association sequences.

Formation, has attracted the attention of magnetostratigraphers. Townsend and Hailwood (1985, pp. 971–2) found that here the lower third of what was then the Harwich Member (including the Harwich Stone Band) is characterized by reverse polarity and the remaining two thirds of the member by normal polarity, which they called the 'Oldhaven magnetozone'. Both stratigraphical levels sampled from the overlying Walton Member of the London Clay have a reverse polarity magnetization, suggesting that the top of the normal polarity magnetozone approximated to the junction between the two formations.

More recent work by Ali *et al.* (1996), however, indicates that the normal polarity is a recent overprint as a result of the weathering of the section. The whole of the section is therefore characterized by reverse polarity and has been correlated by Ali *et al.* (1996) with Chron C24R.

Contemporary vulcanism

The marked parallel stratification in the cliff represents laterally continuous ash layers. Including the Harwich Stone Band, somewhere around 32 to 34 ash bands are present, their distribution being represented (though not in any detail) in Knox and Ellison (1979, fig. 2) and recently in a more precise log by Jolley (1996, fig. 3, p. 223). The ash layers weather cream to brown but are blue-grey on fresh surfaces. The Harwich Stone Band was not visible during a visit to the site in 1994, but its position approximates to the junction of cliff and foreshore. Daniels (1971) referred to two 'stonebands' separated by 4.25 m of clay, the lower being the Harwich Stone Band (cf. King's 1981 text-fig. 14 representation of Wrabness).

Apart from the Harwich Stone Band, Knox and Ellison (1979) found the more uniform ashes to range from 10 to 80 mm in thickness, that they were mostly altered to bentonite and contained structures such as graded bedding and, more commonly, horizontal- or cross-lamination. Pyroclastic texture and composition are best preserved in the cemented tuffs such as the Harwich Stone Band and where tuffaceous material within concretions has been protected from weathering.

Interpretation and evaluation

Whilst the Wrabness site was recognized by King

(1981) to be important stratigraphically as the prime exposure of and type section for his Harwich Member of the London Clay, it is particularly significant on two other counts: firstly, with regard to what it tells us about the distribution of early Eocene pyroclastic deposits and secondly, for contributing to a better understanding of Palaeogene lithostratigraphical relationships and hence also of lateral palaeogeographical variation.

Contemporaneous vulcanism

In their review of the Lower Eocene ash sequence in south-east England, Knox and Ellison (1979) saw Wrabness as the largest and most complete of the onshore ash-bearing 'London Clay' sites. Together, the Shotley Gate Borehole and Wrabness provide a complete sequence of the ash beds. Knox and Ellison (1979) pointed out that most of the ashes above the Harwich Stone Band are laterally persistent (for over 6 km). Whilst the presence of cross-lamination indicates some reworking, such lateral persistence presumably reflects an accumulation in offshore waters below wave base. The better preserved ashes indicate a basic rather than an acid igneous origin.

That the ashes at Wrabness were related to those of the North Sea Palaeogene was accepted from the start, although Jacqué and Thouvenin (1975) considered the Harwich ash (then only known as an isolated occurrence) as a little younger than the 'main tuff zone' or 'ash marker' of the North Sea. Knox (1984) was later able to show that the East Anglian ashes could be assigned to subphase 2b of the second of two main phases of Palaeogene pyroclastic activity represented in the North Sea succession. The ashes of subphase 2b are the most widely represented in onshore areas around the North Sea and equate to the lower part of the Balder Formation (see Deegan and Scull (1977) for North Sea lithostratigraphical nomenclature).

Correlation with other Palaeogene strata

Early discussions centred in part around possible relationships between the former Harwich Member and other Palaeogene lithostratigraphical units further to the south. King (1981) and Knox and Harland (1979) considered the then Harwich Member to pre-date the ash-free 'London Clay' of Kent. As early as 1971, Daniels noted the similarity of the fish fauna at Wrabness to that of the Oldhaven Beds, but King (1981) considered that his Oldhaven Formation was older than the Harwich Member, whilst Knox and Harland (1979) argued that the absence of volcanic material in the former made any equivalence unlikely. Yet dinoflagellate data suggested that this could not be ruled out. At Herne Bay, the Oldhaven Formation of King (1981) was of *A. hyperacanthum* age (Knox *et al.*, 1983) whilst the Harwich Member had earlier been assigned to the upper part of this zone (characterized by the acme occurrence of *Deflandrea oebisfeldensis*).

With the discovery of ash in the Oldhaven strata by Knox (1983), a major objection to correlation was set aside, whilst (although now not considered valid) it then appeared to be reconfirmed by the assignment by Townsend and Hailwood (1985) of their normal polarity magnetozone at Wrabness to the Oldhaven Magnetozone. This part of the Wrabness section was thought by Aubry *et al.* (1986) to be of NP10 age and to represent a short-period normal polarity interval within the reversed polarity Chron C24R.

The age of the Harwich Formation at Wrabness and elsewhere and its relationship with the London Clay and adjacent strata is now much clearer (see Ellison *et al.*, 1994). Such a resolution illustrates how different types of data can be brought together to solve a problem. In this instance, mineralogy, biostratigraphy, magnetostratigraphy and an appreciation of facies variation complemented each other. Further clarification continues to arise from more detailed study and it is interesting to note that on the basis of dinoflagellate data, Powell *et al.* (1996, p. 179) recently concluded that the succession at Wrabness has no direct equivalent at Herne Bay.

Depositional environment

It is now accepted that the Harwich Formation at Wrabness represents a 'distal' offshore shelf environment coeval with the shallow shelf conditions represented by the sandier 'Oldhaven Beds' strata, found for example at Herne Bay, representing what Ellison *et al.* (1994) called the 'proximal' facies of the formation.

Conclusions

The upper part of the Harwich Formation and the lower few metres of the Walton Member of the London Clay are exposed at Wrabness. This site provides the best exposure of the Harwich Formation, for which it is one of the type sections.

A complete sequence of ash bands is present from the Harwich Stone Band to the top of the Harwich Formation. Something over 30 separate ash layers occur. It is therefore the most important site in southern England at which pyroclastic Palaeogene deposits may be found.

The Harwich Formation at Wrabness represents an offshore facies broadly equivalent to the shallow shelf Oldhaven Beds developed further to the south.

WALTON-ON-THE-NAZE, ESSEX (TM 264230–TM 267245)

POTENTIAL GCR SITE

Highlights

The succession here is the best exposed section in the Thames Group north of the River Thames. It is the type section for the Walton Member of the London Clay and is one of the type sections for the offshore facies of the Harwich Formation. It has also proved to be of importance palaeontologically and is particularly significant as regards its plant macrofossils and vertebrate remains.

Introduction

This site was also independently selected for its fossil plants and birds and Quaternary sediment content, more detailed accounts 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 Neogene geology of this site is discussed in Chapter 11.

From grid reference TM 264230 in the south to TM 267245 some 1.5 km further north, good sections occur in the cliffs and in the foreshore at low water. The Thames Group is exposed both in the foreshore and the cliffs (Figure 3.22) where, except at the northern end of the section, it is overlain unconformably by the shelly sands of the Red Crag.

George and Vincent's (1977) account of the Walton section mentions references to the geology of the site which date back to the 18th century. Much of the early attraction reflected a concern with the rate of cliff erosion (Defoe, 1724; Buckland, 1824; Cole, 1898; Dalton, 1902). An interest in this aspect of the section has continued in recent times. In the Geologists'

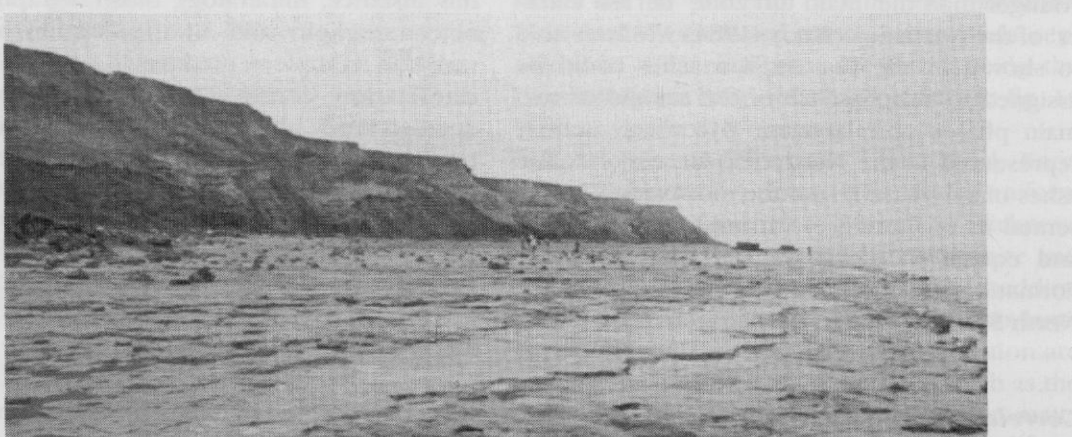

Figure 3.22 Walton-on-the-Naze, Essex. London Clay exposed on the foreshore at low water. In the cliffs behind, the London Clay is overlain unconformably by the Red Crag. (Photograph: P. Balson.)

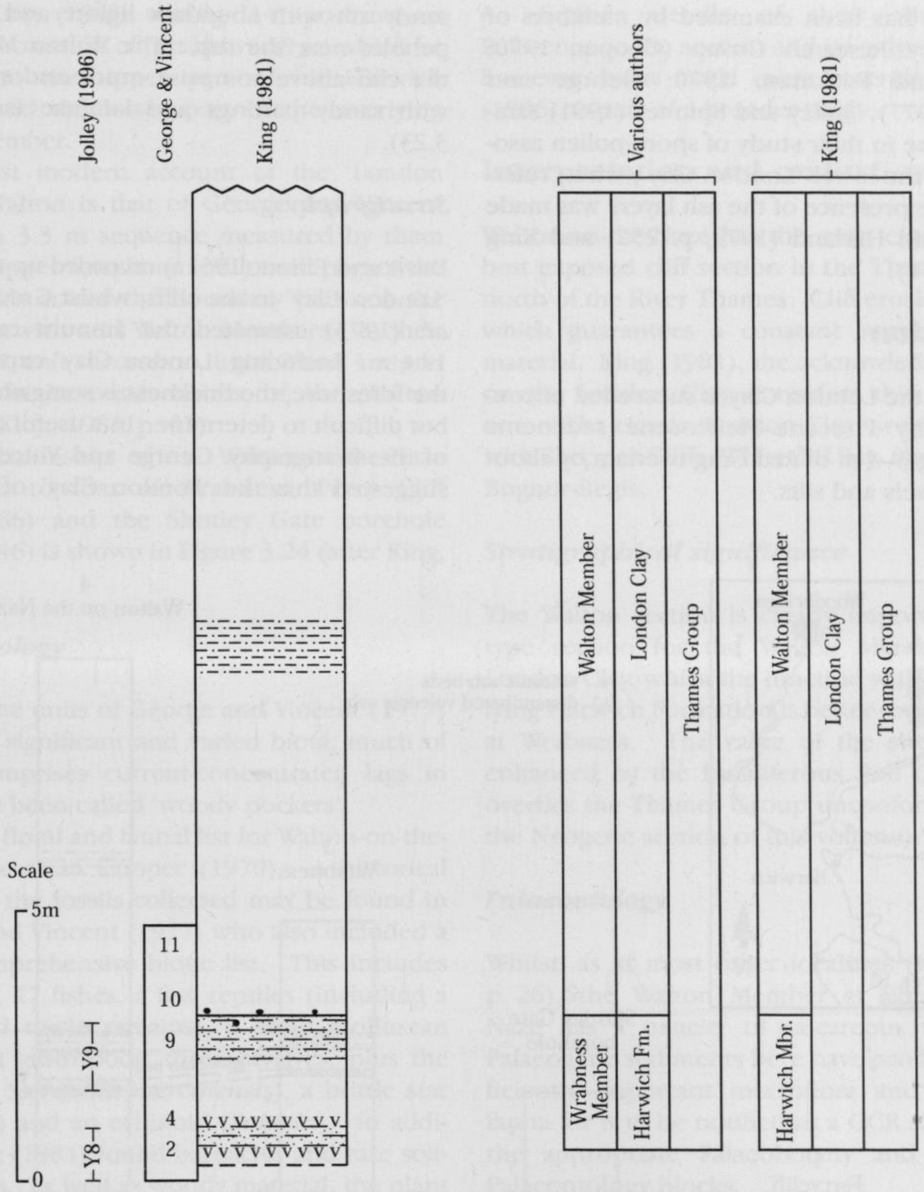

Figure 3.23 Succession in the Harwich Formation and London Clay at Walton-on-the-Naze, Essex (after various authors).

Association Guide, Greensmith *et al.* (1973) referred to the presence on the beach of a concrete World War II blockhouse which had been originally built back from the edge of the cliff. George and Vincent (1977) recommended the undergraduate dissertation of Rayner (1971) as a comprehensive source of information on erosion at Walton. Their paper also includes a useful summary and references for the local copperas and Roman Cement industries.

Early stratigraphical studies include those of Prestwich (1854b) and Whitaker (1877), whilst

19th century field meetings were reported by Holmes (1890, 1891). Earlier palaeontological work produced a limited list of fossils (e.g. Johnson, 1901; Davis, 1937). Following the account of the section by Davis and Elliott (1951a), it has been examined by members of the Tertiary Research Group (Cooper, 1970; George and Packman, 1970; George and Vincent, 1977). Jolley and Spinner (1991) sampled the site in their study of spore-pollen associations of the lower 'London Clay', whilst reference to the presence of the ash layers was made in Knox and Harland (1979, p. 252) and King (1981, p. 51).

Description

At Walton, the London Clay is succeeded unconformably by Pliocene–Pleistocene sediments comprising 3–4 m of Red Crag overlain by about 3 m of gravels and silts.

Lithological succession

King's section (1981, text-fig. 14) shows the Harwich Formation to comprise muds including two ash bands, with a glauconitic bioturbated sandy silt with abundant lignite and scattered pebbles near the top. The Walton Member in the cliff above comprise muds and silty muds with sandy partings and laminae (see Figure 3.23).

Stratigraphy

Davis and Elliott (1951a) recorded up to 12 m of 'London Clay' in the cliffs, whilst Greensmith *et al.* (1973) estimated the amount exposed at 14+ m. Including 'London Clay' exposures on the foreshore, the thickness is somewhat greater but difficult to determine. In a useful discussion of the stratigraphy, George and Vincent (1977) suggested that the 'London Clay' of the fore-

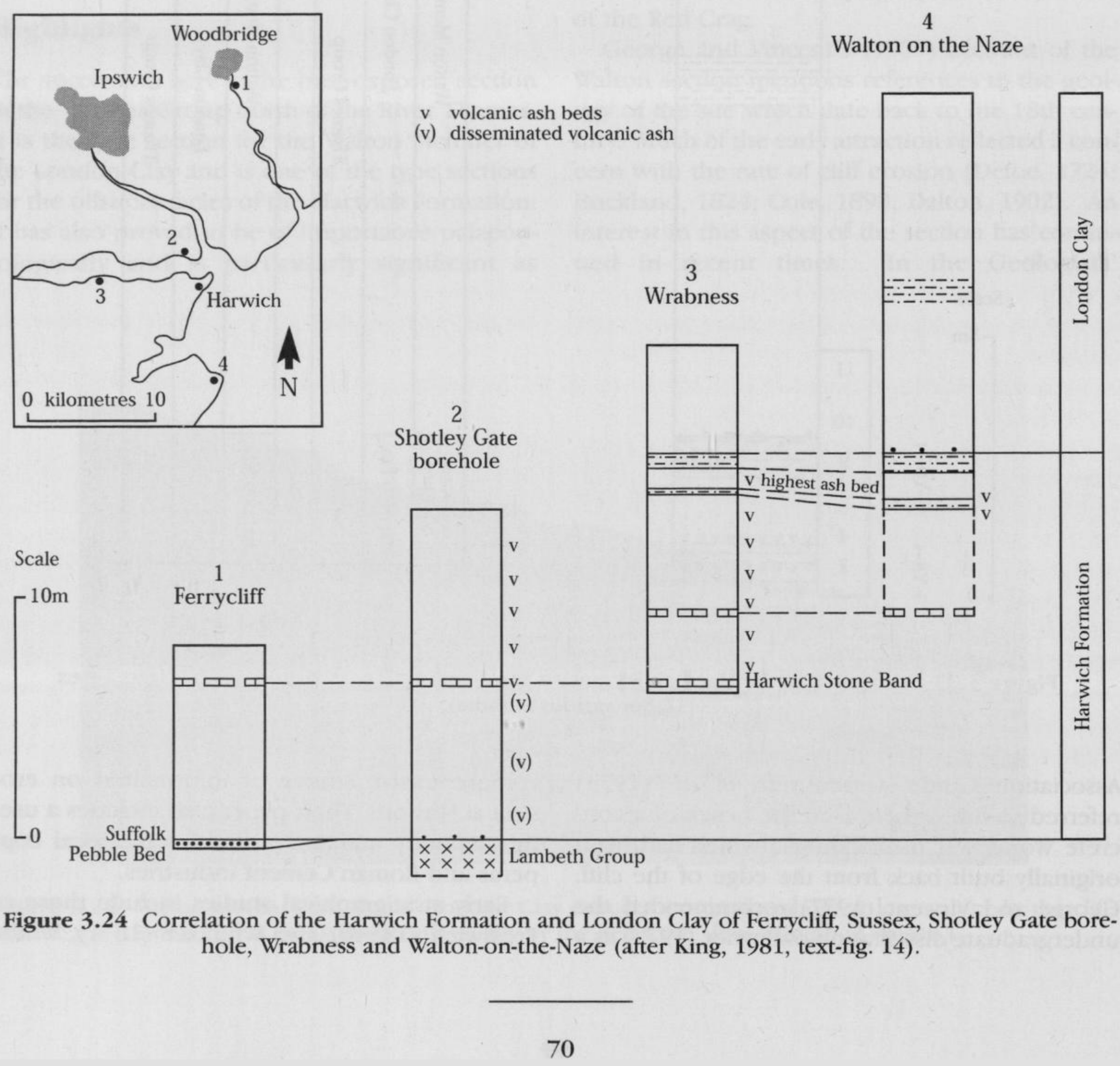

Figure 3.24 Correlation of the Harwich Formation and London Clay of Ferrycliff, Sussex, Shotley Gate borehole, Wrabness and Walton-on-the-Naze (after King, 1981, text-fig. 14).

shore is slightly greater than *c.* 21 m above the London Clay 'Basement Bed'. Davis and Elliott (1951a) estimated that from just above high watermark the latter was at a depth of *c.* 20.5 m, with the Harwich Stone Band at almost 19 m down. King (1981, text-fig. 14) portrays an exposed succession of just above 18 m, which he assigned to the upper part of his Harwich Member and the lower part of the overlying Walton Member.

The best modern account of the 'London Clay' at Walton is that of George and Vincent (1977). A 3.3 m sequence measured by them from the upper foreshore and lowest part of the cliff extends across the boundary between the former Harwich and Walton Members. In their detailed 11 unit succession, units 2 and 4 represent the highest ash bands of the Walton Member (King, 1981, p. 51).

The relationship of the Walton-on-the-Naze succession to that of Wrabness, Ferry Cliff (TM 278486) and the Shotley Gate borehole (TM 244346) is shown in Figure 3.24 (after King, 1981).

Palaeontology

Many of the units of George and Vincent (1977) contain a significant and varied biota, much of which comprises current-concentrated lags in what have been called 'woody pockets'.

A short floral and faunal list for Walton-on-the-Naze appears in Cooper (1970). A historical review of the fossils collected may be found in George and Vincent (1977) who also included a more comprehensive biotic list. This includes five birds, 17 fishes, a few reptiles (including a snake and turtle remains), a small molluscan fauna (six gastropods, three bivalves, plus the pteropod *Spiratella mercinensis*), a brittle star (*Ophiura*) and an echinoid (*Salenia*). In addition, King (1981) found barnacles and rare solitary corals. As well as woody material, the plant macrofossils present include fruit, seeds and leaves. George and Vincent (1977) listed 17 plant genera, some tentatively. The foraminifer *Astrorhiza* is present, whilst King (1981, p. 51) reported a restricted calcareous microfauna containing *Cytheretta aff. nerva* and *Cytheridea unispinae* close to the upper ash band.

Logs occur in the Walton Member (often in concretions; Cooper, 1970). There is no calcareous fauna but King (1981, p. 51) has recorded microfossils from the Walton Member including pyritized diatoms and small agglutinated foraminifera.

Jolley and Spinner (1991) collected spore-pollen samples from both the Harwich Formation and Walton Member here, but gave no further details of their distribution. Reference to the section and its palynoflora has, however, been made more recently by Jolley (1996) as part of a broader study.

Interpretation and evaluation

Walton-on-the-Naze has the most extensive and best exposed cliff section in the Thames Group north of the River Thames. Cliff erosion is rapid which guarantees a constant supply of fresh material. King (1981), the acknowledged expert on the London Clay, considers this section as one of the classic 'London Clay' sections, along with Sheppey Cliffs, Whitecliff Bay, Alum Bay and Bognor Regis.

Stratigraphical significance

The Walton section is clearly important as the type section for the Walton Member of the London Clay, whilst the junction with the underlying Harwich Formation is better seen here than at Wrabness. The value of the site is clearly enhanced by the fossiliferous Red Crag which overlies the Thames Group unconformably (see the Neogene section of this volume).

Palaeontology

Whilst, as at most other localities (King, 1981, p. 26), the Walton Member at Walton-on-the-Naze has a paucity of calcareous fossils, the Palaeogene sediments here have produced a sufficiently important macroflora and vertebrate fauna for it to be notified as a GCR site for both the appropriate Palaeobotany and Vertebrate Palaeontology blocks.

Walton-on-the-Naze is the only 'London Clay' locality to yield angiosperms in the form of carbonaceous compressions, invaluable for the study of small seed fossils, and is considered a key Tertiary palaeobotanical locality.

It is also described as an exceptional avifaunal site of considerable importance in the study of bird evolution. Indeed, Lucy (1989) quotes the NCC as saying that 'The London Clay at Walton-on-the-Naze contains the best preserved Tertiary bird fauna in the world'. Interestingly, an avifauna thought to be of similar age has been recorded from the Mo Clay of Denmark, a formation of upper *A. hypercanthum* age, and agreed to be a distant correlative of the Harwich Member (Knox and Harland, 1979).

Conclusions

Walton-on-the-Naze is a classic Thames Group site and provides the most extensive cliff section in the group north of the River Thames.

Both the Harwich Formation and the Walton Member of the London Clay are well exposed in the cliffs and foreshore at low tide. Parts of the succession have a flora and fauna offering considerable potential for research, from which a better understanding of contemporary environmental conditions will inevitably arise.