Sheppey Cliffs, Kent

(TQ961 735)–(TR025 717)

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 century 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 ref erence 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 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 mudflows, 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/13 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-a-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, Bndash;2 and Bndash;3, the lower three of the 'Bracklesham Beds zones', of Bujak *et al.* (1980).

Conclusions

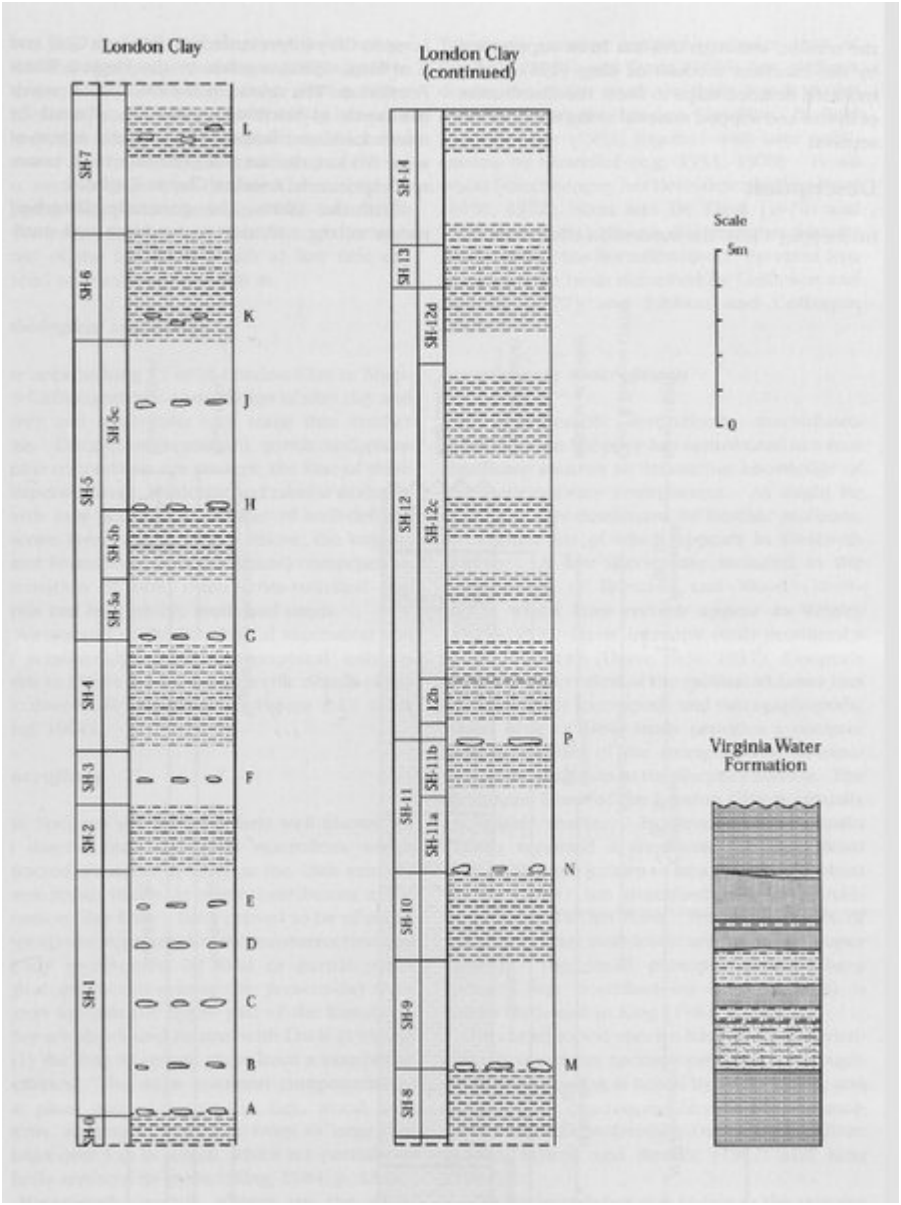
Sheppey Cliffs comprise the only extant cliff section of the upper part of the London Clay in the London Basin and are the most laterally extensive section of the formation in southern Britain. Their importance for ongoing and future work is therefore considerable.

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.

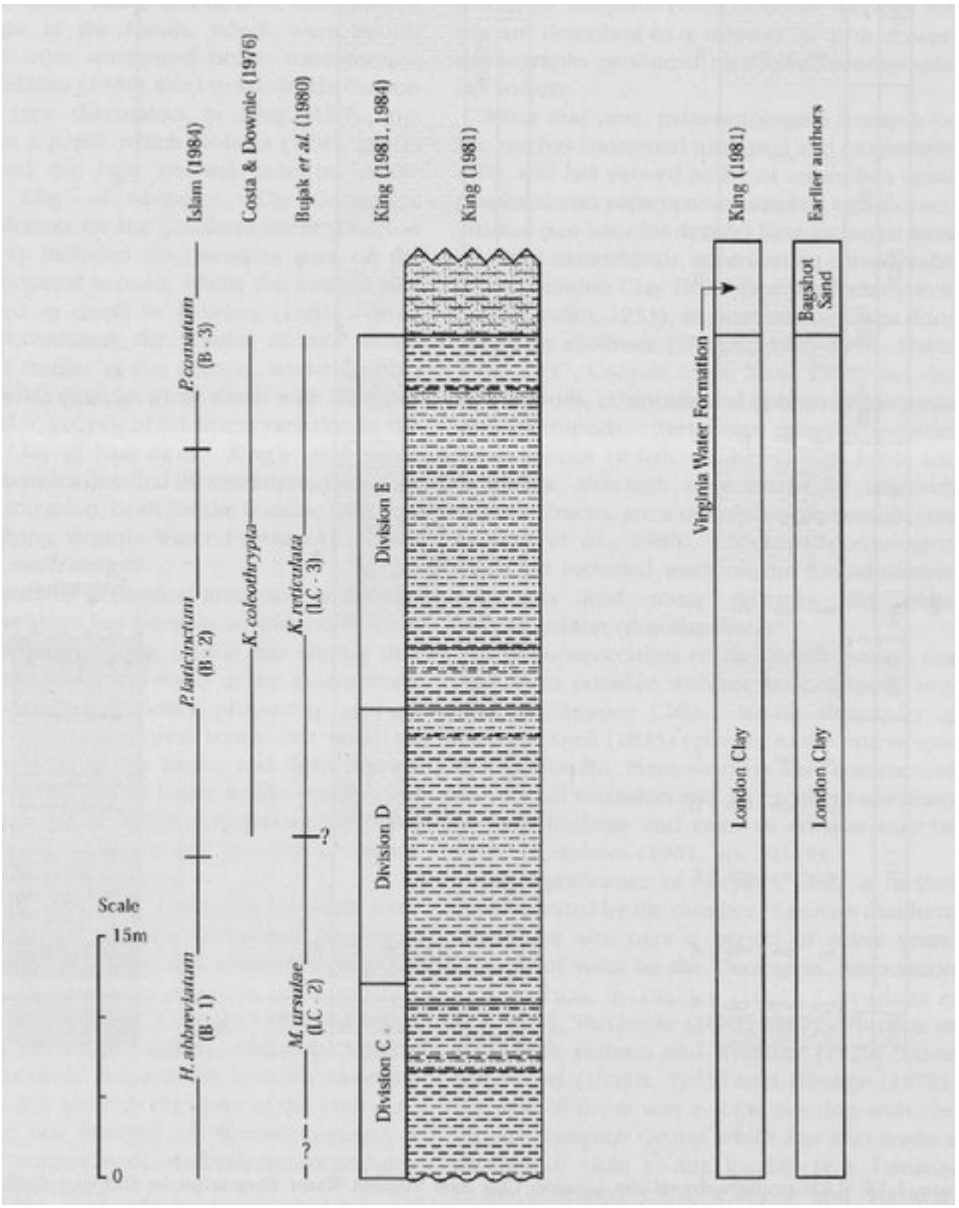
Many groups of fossils from Sheppey have proved to be valuable in helping with palaeoenvironmental and palaeogeographical interpretation. An example is that much of the knowledge we have of contemporary Eocene climate in the British area comes from the London Clay Flora and, of that, the bulk is from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

References

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



(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.



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