Fossil Fishes of Great Britain

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JOINT NATURE CONSERVATION COMMITTEE

Chapter 14

British Cenozoic fossil fishes sites

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INTRODUCTION: PALAEOGEOGRAPHY AND STRATIGRAPHY

The principal Tertiary (or Cenozoic) rocks of southern England occur in two broad basins – the Hampshire Basin and the London Basin. Elsewhere they form small isolated outcrops, e.g. basin infills at Bovey Tracy and Petrockstow, Devon. Originally a single basin, the two outcrops of the south-east are continued offshore into the Dieppe Basin and the North Sea Basin respectively. As early as 1814 the Hampshire succession and faunas were correlated to those of the Paris Basin, as described by Cuvier and Brongniart (1810) and Webster (1814). In this chapter we are concerned with the sites in the Palaeogene strata – the Palaeocene, Eocene and Oligocene (Daley, 1997). These rocks appear everywhere on land to overlie unconformably the Upper Chalk or older strata. A limited Neogene (Pliocene) sequence is present in Suffolk, and restricted Mio-Pliocene occurrences exist in Kent, Norfolk and Cornwall (Curry *et al.* 1978). Younger Cenozoic or Quaternary sediments (Pleistocene and Holocene) are more abundant, being distributed over much of the British Isles, and yielding fossil vertebrates espe-

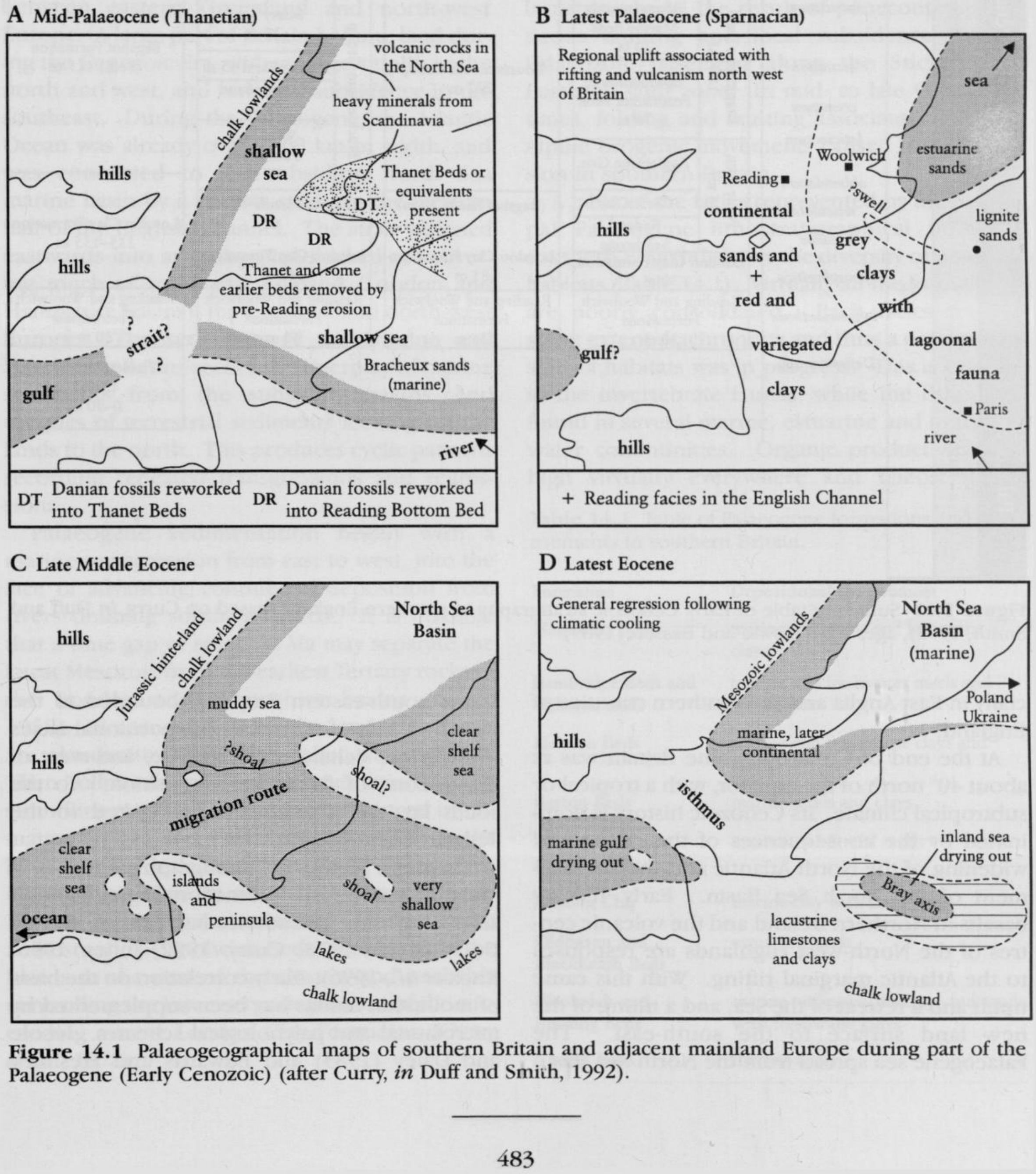


Figure 14.1 Palaeogeographical maps of southern Britain and adjacent mainland Europe during part of the Palaeogene (Early Cenozoic) (after Curry, *in* Duff and Smith, 1992).

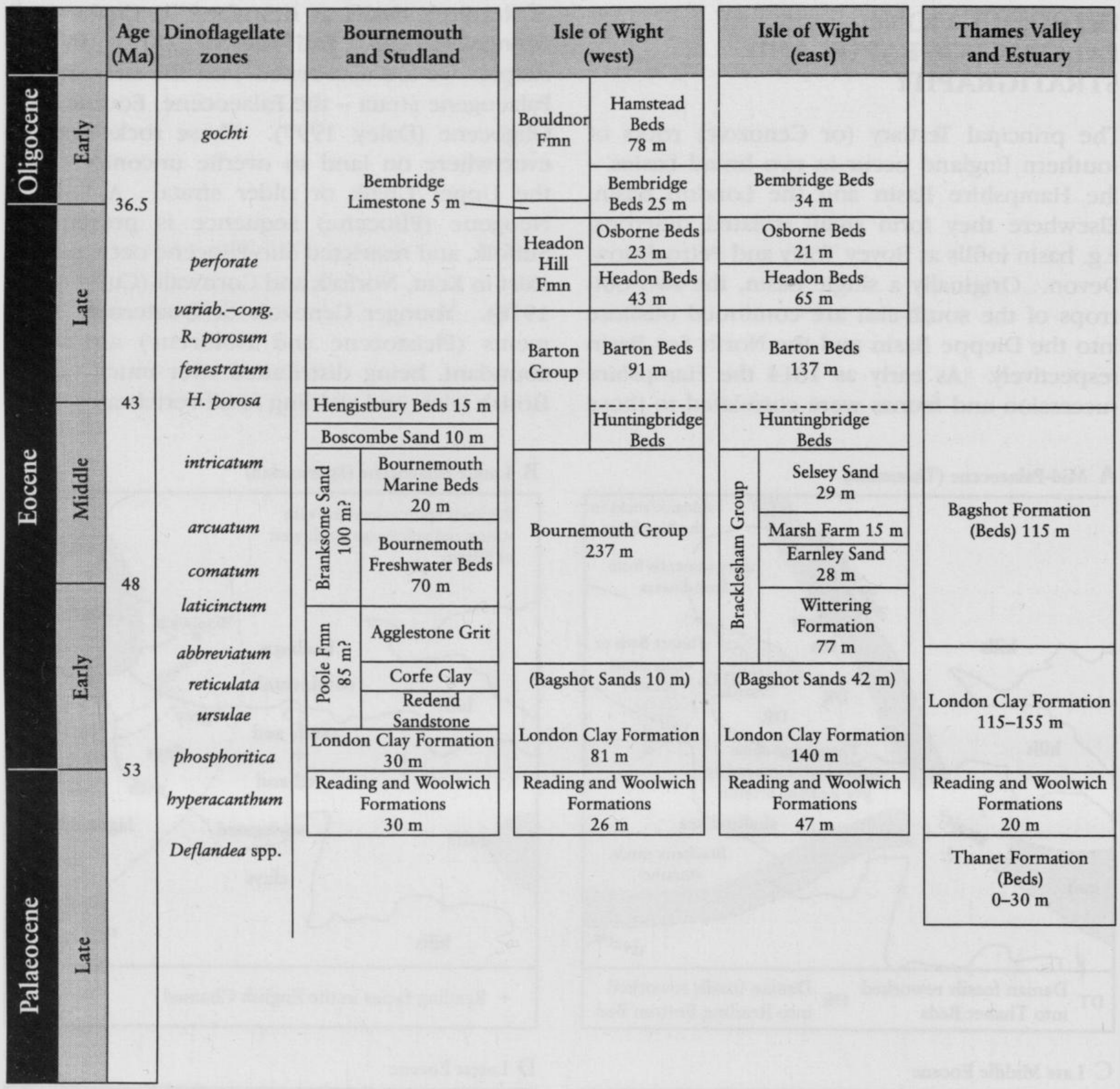


Figure 14.2 Summary table of Early Cenozoic stratigraphy in southern England (based on Curry, *in* Duff and Smith, 1992), ages from Cowie and Bassett (1989).

cially in East Anglia and the southern counties of England.

At the end of Cretaceous time Britain was at about 40° north of the equator, with a tropical or subtropical climate. Its Cenozoic history is dominated by the consequences of the rifting and widening of the North Atlantic and the development of the North Sea Basin. Early Tertiary basalts in Northern Ireland and the volcanic centres of the North-West Highlands are responses to the Atlantic marginal rifting. With this came uplift and a retreat of the sea, and a tilting of the new land surface to the south-east. The Palaeogene sea spread from the North Sea Basin across south-eastern England, bounded to the west by a belt of transitional depositional facies – estuarine, deltaic, and fluviatile, and west of that a zone of freshwater deposition. To the south lay the Aquitaine Basin, linked to the Tethyan Ocean (Figure 14.1).

There is a plethora of stratigraphical rock unit and time names, and international agreement on stage and other boundaries has been slow (see Curry *et al.*, 1978; Curry, 1992; Jolley, 1996; Knox *et al.*, 1996). Early correlation on the basis of molluscan faunas has been supplemented by microfaunal and palynological schemes. Insole and Daley (1985) and Edwards and Freshney

(1987) have provided syntheses of the formal stratigraphy of the Hampshire Basin (Figure 14.2). Daley and Balson (1997) have recently completed a GCR volume on Tertiary stratigraphy, and many of the Palaeogene sites overlap with fish localities reported here. Ellison *et al.* (1994) have reviewed the early Palaeogene lithostratigraphy of the London Basin.

ENVIRONMENTS

At the end of the Cretaceous, much of Britain lay beneath the Chalk sea, but uplift was taking place linked with the initiation of rifting and ocean-floor spreading in the North Atlantic between eastern Greenland and north-west Europe. A large part of Britain became land during the Cenozoic Era, with strongest uplift in the north and west, and renewed subsidence in the southeast. During the Palaeogene, the Atlantic Ocean was already over 1000 km in width, and was connected to the subsiding North Sea marine basin by a narrow strait via the western half of the English Channel. The strait widened eastwards into an almost landlocked sea covering much of south-east England (London and Hampshire Basins), the Channel, and north-west Europe. The sediments of the London and Hampshire Basins record the interplay of marine sediments from the subsiding basins, and tongues of terrestrial sediments feeding off the lands to the north. This produces cyclic patterns recording repeated transgressions and regressions.

Palaeogene sedimentation began with a marine transgression from east to west, into the face of advancing continental deposition from rivers draining south-eastwards. It is possible that a time gap of some 20 Ma may separate the latest Mesozoic from the earliest Tertiary rocks of the London and Hampshire basins (Cope, 1955). Almost everywhere the lowest Tertiaries are glauconitic sands with rolled flint pebbles. Then followed cycles of sedimentation as the strandline migrated to and fro, influenced by climatic changes and eustatic swings. The straits between the Atlantic Ocean and North Sea closed for a time in the Palaeocene and early Eocene, resulting in continental (Reading Beds) and estuarine (Woolwich Beds) sediments in the basins to the east of the closure and probably controlling the low-energy deposition of the succeeding marine London Clay Formation (Curry *et al.*, 1978).

In the late Eocene, a brief marine trangression in south-east England was followed in latest Eocene and early Oligocene times by another fall in sea level. During the Palaeogene climatic cooling continued; marine regressions appear to correlate with phases of ocean cooling and regional drought, and it seems that polar glaciation may have been responsible for the sea-level fall in the Oligocene. Deposits of this age are rare in the southern basins, but include freshwater limestones and marls, although there was continuous sedimentation in the North Sea Basin (Curry *et al.*, 1978). In south-west England the Oligocene basins of Bovey and Petrockstow contain fluvially deposited and lacustrine beds; the result of penecontemporaneous faulting and local subsidence in the Palaeozoic basement along the Sticklepath–Lustleigh fault zone. In mid- to late Oligocene times, folding and faulting associated with the Alpine orogenic movements caused basin inversion in southern Britain.

A table of the facies represented by the principal Palaeogene lithostratigraphical units of southern England shows the diversity of possible habitats (Table 14.1). Virtually all the formations are poorly consolidated. Each facies was to some extent diachronous and thus a continuous shift of habitats was in progress. This is evident in the invertebrate faunas, while the fishes are found in several marine, estuarine and brackish-water communities. Organic productivity was high virtually everywhere and teleost fishes

Table 14.1 Table of Palaeogene formations and environments in southern Britain.

Formation	Depositional environment
Hamstead Beds	marine, estuarine and lacustrine clays
Bembridge Beds and Osborne Beds	marine and freshwater marls and limestones
Headon Beds	marine and freshwater clays and sands
Barton Beds	marine sands and clays
Bracklesham and Bagshot Beds	marine and fluvial sands
London Clay	marine clay with basal sand
Oldhaven and Blackheath Beds	estuarine sands
Woolwich and Reading Beds	marine and estuarine clays and sands with freshwater clays
Thanet Beds	marine sands

occupied their ecological niches in much the same way as at present.

During Neogene time, the North Sea Basin continued to subside, and sediments accumulated during the Miocene and Pliocene. The Miocene and Pliocene are largely absent from onshore sites. The notable exceptions are the Coralline Crag and the Red Crag, a combined sequence of about 70 m which spans the Pliocene and Early Pleistocene. These are stratified cross-bedded sands containing marine invertebrate fossils which seem to have been deposited in shallow seas by tidal currents, and they indicate a cooling of the climate. During Pleistocene times, as is well known, the British Isles experienced a number of cooling and warming episodes. There were as many as six cold phases during the past 2 Ma, with associated glaciation extending, at its maximum, southwards to a line roughly from London to Bristol. Pleistocene vertebrates have been found in cave deposits, and in water-laid and glacial deposits.

FISH FAUNAS

The great explosion of fish numbers and types during the Cenozoic Era is one of the most impressive happenings in evolution. It is, moreover, almost entirely confined to the teleost fishes. They constitute about 90% of all known extant fish species. The remainder include fishes that have retained the essential characteristics of their Mesozoic (or older) ancestors – the sharks, the coelacanth, the lungfishes, paddlefishes, sturgeons and hagfishes being excellent examples. They have adapted to particular niches where in general there may not be such intense competition for living space.

The end of the Mesozoic Era witnessed mass mortality amongst many groups of animals, but it is difficult to correlate changes in the record of the fishes with this spate of events. By the time that the Chalk was being deposited in the latter half of the Cretaceous Period the teleosts had begun to achieve their ascendancy as most of the non-teleostean neopterygians disappeared. Teleost success then gathered pace with adaptation to efficient swimming, greater speed and manoeuvrability. The homocercal tail now prevailed, freeing the paired fins from the necessity of counteracting negative pitch induced by the earlier heterocercal tail. These basic improvements to the locomotive ability of the teleosts allowed these fishes to adopt many additional specializations, enabling them to invade every part of the oceans, seas and inland waters. Notable changes in the mechanism of the jaws and orobranchial anatomy took place. Many familiar extant teleosts in European waters first made their appearance early in the Cenozoic, others were introduced with climatic (principally cooling) changes. Chondrichthyans were plentiful early in the Cenozoic (Glückman, 1964a, 1964b); later their numbers diminished as the shallow sea waters grew cooler. European freshwaters, too, were inhabited by many of the familiar species of today; the ancient chondrosteans (sturgeons) were, however, more widespread than at present.

Although all parts of the Cenozoic succession in southern England are locally highly fossiliferous, the fishes are perhaps most common in the lower half. The earliest Palaeogene fish remains have recently been obtained from glauconitic sands and silty clays within the Thanet Formation of Kent (Ward, 1977, 1979). Early Eocene fishes are well represented in the estuarine mud and sand communities of the pre-London Clay Tertiaries and in particular the London Clay Formation of the London Basin, where the fauna is dominated by marine forms.

The Late Eocene marine mud, shallow-marine clay and sublittoral sandy clay beds above the London Clay in the Hampshire Basin are also rich in fossil fishes (Hooker and Ward, 1980). Later communities probably existed in water not more than 50 m deep, with sea temperatures of about 16–18°C. Palaeogene brackish-water and freshwater communities are much more restricted in number and extent, as in the Osborne and Headon Beds. The latest Palaeogene fish assemblages, those of the Bembridge Marl Member and Hamstead Member of the Bouldnor Formation (Lower and Middle Oligocene respectively) on the Isle of Wight have produced a fauna dominated by freshwater forms (Daley, 1973; Hooker and Ward, 1980).

Neogene and Pleistocene fish localities are sparse and it was hard to determine particular locations that had assessable potential for future finds. Hence, none were selected for the GCR 'fishes' review.

A feature of studies of some Cenozoic fish faunas has been the work on otoliths. These fossils are the 'ear stones' of certain teleosts – small (even microscopic) ossifications from within the sacculus of the inner ear. They are extremely numerous in some deposits, even where other skeletal remains are lacking. A very large number of otoliths has now been described from the English Cenozoic formations (see Stinton, 1965–1973; Nolf, 1985), including those that have little other evidence of fossil fishes. Otoliths taxa are not listed in the following reports since their significance is obscure compared to that of the other remains.

PRE-LONDON CLAY TERTIARIES OF THE LONDON BASIN

The earliest transgressive beds, of Late Palaeocene age (*c.* 58 Ma; Daley and Balson, 1999), occur in eastern Kent (Thanet Formation), and these marine units extended ever farther westwards through Berkshire and into Wiltshire during the Late Palaeocene (Woolwich and Reading beds) and Eocene (Thames Group: Blackheath and Oldhaven Formation, London Clay Formation). These trangressive units are bioturbated glauconitic sands, containing reworked flint pebbles derived from the underlying Chalk and tend to pass upwards into thicker regressive sand units and clays (Ellison, 1983). The Woolwich and Reading Formation (Late Palaeocene) in the west is represented by non-marine, red, mottled, kaolinitic clays and sands of fluvial, lagoonal and tidal mudflat origin that have yielded plant and insect fossils (Reading Beds), as well as a marine horizon towards the base (Ellison, 1983; Bone, 1986). In the east the Woolwich Beds comprise thick marginal marine and estuarine sand and clay units (Curry, 1965; Ellison, 1983).

A major unconformity consistently separates the Woolwich and Reading Formation from the younger strata of the Thames Group (whether they be Blackheath Beds, Oldhaven Beds or London Clay). Most current theories of the position of the Palaeocene–Eocene boundary (e.g. Knox, 1990), place it approximately at this unconformity. However, in terms of fossil fish diversity, the major faunal turnover took place with the onset of true London Clay marine deposition, and so in this report the Blackheath and Oldhaven Formation assemblages are recorded with those from the Palaeocene 'Lower London Tertiaries'. Those of the London Clay Formation are dealt with in the next section.

Fishes within the pre-London Clay Tertiaries are not uncommon, and occur within all of the early Tertiary transgressive units in southern England. Most finds are tiny fish teeth, scales and teleost otoliths, and are usually recovered by bulk sampling of the unconsolidated sediments. Hence, although some sampling was done as early as the 1920s and 1930s (Stamp and Priest, 1920; Brown, 1924; White, 1931), most of the literature has been written in the past 30 years, and includes important references by Gurr (1963), Stinton (1965a, 1965c, 1975–1980), Ward (1972, 1976, 1977, 1979), George and Vincent (1976) and Cooper (1976a).

Collections of Palaeocene and early Eocene fossil fish from the London Basin are housed in the NHM.

FISH SITES

Sporadic fish material has been recovered from many localities throughout the whole outcrop of pre-London Clay Tertiaries in the London Basin. However, most of these sites have only yielded fragmentary remains of one or two fish species and thus only the more significant are listed below by county from the south-west to north-east (taken mainly from Hooker and Ward, 1980):

WILTSHIRE: Clarendon road cutting (glauconitic shelly sand 3 m above the Reading Beds, Woolwich and Reading Formation; SU 183284; six species; Hooker and Ward, 1980).

KENT: Pegwell Bay sea cliffs (Thanet Formation, Base Bed Member, 'Cliffs End Greensand Bed'; TR 354643; nine species, see report; Ward, 1977); Herne Bay sea cliffs and foreshore exposures (Thanet Formation, Reculver Silts Member–London Clay Division B; TR 198688–TR 217691 55 species, including one type specimen, see report; Ward, 1979); Swanscombe quarries (Woolwich and Reading Formation, Woolwich Shell Beds; TQ 5973; four species; Stamp and Priest; 1920, Brown and Priest, 1924); Shelford disused quarry (Blackheath and Oldhaven Formation, Oldhaven Beds (Units 5–8 of Ward, 1972); TR 160600; nine species; Gamble, 1968, Ward, 1972); Upnor sand pit (Woolwich and Reading Formation, Woolwich Beds; Blackheath and Oldhaven Formation, Oldhaven Beds; TQ 757712; 21 species, including three type specimens, see report; White, 1931).

GREATER LONDON: Abbey Wood temporary excavation (Blackheath and Oldhaven Formation, 'Blackheath Shell Bed'; TQ 480786;

23 species, including 16 type specimens, see report; White, 1931).

MIDDLESEX: Harefield quarry (Harefield Beds (Units 2–7 of Cooper, 1976a); TQ 048911; two species; Cooper, 1976a).

HERTFORDSHIRE: Bignell's Corner road cutting (Harefield Beds (Unit 2 of Ward, 1976); TL 227007; eight species; Ward, 1976).

ESSEX: Harwich Harbour (Suffolk Pebble Beds; TM 2632; three species; Thompson, 1911).

SUFFOLK: Ferry Cliff river exposure (Suffolk Pebble Beds; TM 278486; six species of fish, one species of salamander; George and Vincent, 1976; Milner, 1986).

Four sites are selected as GCR sites on the basis of their important Palaeocene and Early Eocene fish faunas:

1. Pegwell Bay, Kent (TR 348640–TR 363642). Late Palaeocene–Early Eocene (?Upper Thanet Formation).
2. Herne Bay, Kent (TR 217691 – TR 205687). Late Palaeocene–Early Eocene, Upper Thanet Formation (Reculver Silts Member)–London Clay Formation (Division B).
3. Upnor sand pit, Kent (TQ 757712). Late Palaeocene–Early Eocene, Woolwich and Reading Formation–Blackheath and Oldhaven Formation (Oldhaven Beds).
4. Abbey Wood, Greater London (TQ 480786). Early Eocene, Blackheath and Oldhaven Formation ('Blackheath Shell Bed').

PEGWELL BAY (TR 348640–TR 363642)

Highlights

This site in Kent reveals a 40 cm shell bed containing quantities of disarticulated fish debris. It is a fauna rich in shark species and an assemblage of benthonic forms. No other site of comparable wealth in species and individuals of this age (Thanetian) is known in western Europe.

Introduction

Pegwell Bay has long been known for the presence of shark teeth in the Thanet Sands. The section formerly exposed on the northern side of the bay was in Palaeocene Thanet (Sands) Formation has been interrupted by road construction, resulting in smaller sections. At the eastern locality (Cliffs End Section; Ward, 1977) some 7.5 m of the Thanet Formation rests unconformably on Chalk; the western occurrence is now obscured by drift.

Pegwell Bay geology was first described by Prestwich (1852), who coined the term Thanet Sands for the succession of yellowish and pinkish sands, and underlying clayey glauconitic greensands. At the base is a thin layer of green-stained flints (the Bull Head Bed). Whitaker (1866, 1872) preferred the term Thanet Beds on account of the range of lithologies. Other contributions were made by Gardner (1883), Burrows and Holland (1896), White (1928) and by Ward (1977) who summarized the earlier work on the section. The highly fossiliferous character of the beds has attracted attention from Haynes (foraminifera; 1955, 1956–1958; Haynes and El Naggar, 1964), Downie *et al.* (palynomorphs; 1971), Aubrey (nannoplankton; 1983), and others have studied the vertebrates (Stinton, 1965a; Ward, 1977).

The age of these beds, the oldest of the Cenozoic rocks of south-east England, has been determined by isotopic dating of the glauconites (Fitch *et al.*, 1978; see below). Mineralogical work on the Thanet Formation has been carried out by Blondeau and Pomerol, 1968; Brown *et al.*, 1969; Weir and Catt, 1969; Knox, 1979; Wheatley, *in* Shephard-Thorn, 1988.

Description

The succession at Pegwell Bay is some 24 m of poorly consolidated strata, resting unconformably upon Santonian Chalk (see Ward, 1977; Shephard-Thorn, 1988). There has been some discussion as to the age of the Thanet Formation relative to the Herne Bay (q.v.) outcrop. General agreement has it that the Pegwell Bay strata are older than those at Herne Bay, though there may be some overlap; it certainly represents the onset of the Palaeocene marine transgression. Isotopic ages from glauconite in the basal beds at Pegwell Bay have been calculated as 59.5 ± 0.9 Ma (Fitch *et al.*, 1978). Palaeomagnetic data lead to the normal polarity magnetozone of NP6–NP7 and Chron 26N (Aubrey *et al.*, 1986).

Mineralogical investigation of the Pegwell Bay

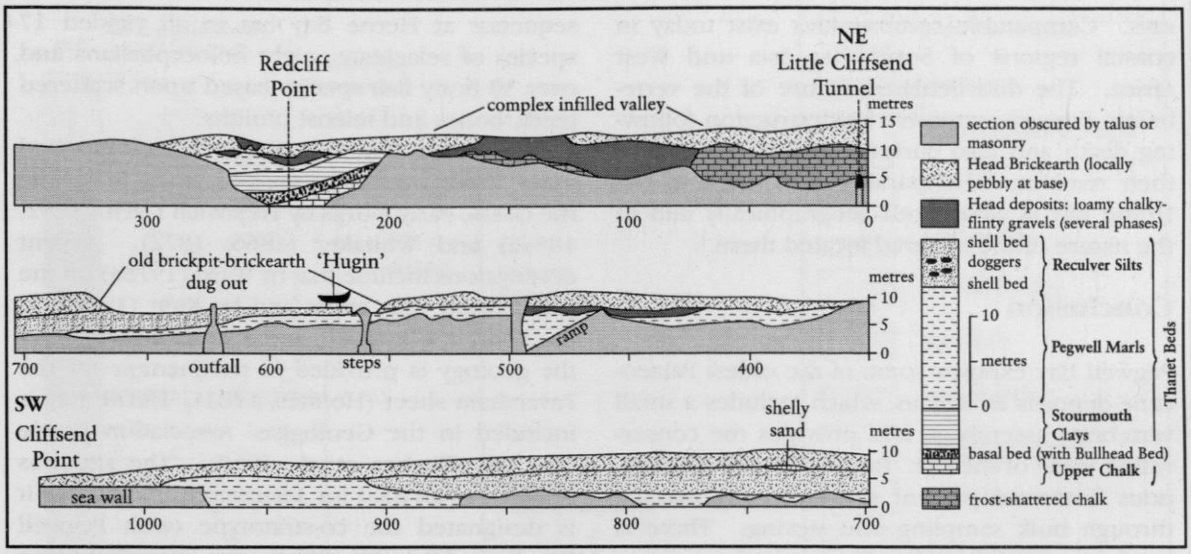


Figure 14.3 The section of Thanet Beds overlying eroded Chalk exposed in the Pegwell Bay cliffs (after Shephard-Thorn, 1988).

Palaeocene has revealed a component of volcanic materials which are comparable to those in contemporaneous ash falls within the North Sea Basin and the Hebrides (Knox, 1979). This volcanism was probably a strong influence upon the local ecology of the day.

The macrofossil content of these beds is most conspicuous at the horizons indicated in the section (Figure 14.3) and include over 70 species of marine invertebrates, mostly molluscs of boreal aspect. Taylor (*in* McKerrow, 1978) has described the marine sand community which is so widely represented in the Thanet Formation. Water depth was generally less than 50 m and sediment input was from the south and west. There is also a heavy mineral input that suggests a Scottish or Scandanavian source.

The teeth and bones of fishes have long been known from these beds; invariably they are disarticulated, indicating current activity as well as organic deprivation. The fossils are relatively easily recovered from weathered sediment or by bulk sampling techniques.

Fauna

Chondrichthyes: Elasmobranchii: Neoselachii: Squalomorphii

Squalus minor Leriche, 1902

Chondrichthyes: Elasmobranchii: Neolselachii: Galeomorphii

'*Lamna*' *inflata* Leriche, 1936

Otodus obliquus Agassiz, 1843

Otodus sp.

Palaeohypotodus rutoti (Winkler, 1874)

Synodontaspis teretidens (White, 1931)

Striatolamna striata (Winkler, 1874)

Chondrichthyes: Holocephali: Chimaeriformes: Chimaeroidei

indeterminate chimaeroid

Osteichthyes: Neopterygii: Teleostei

indeterminate teeth and bones

Otoliths

Interpretation

The Cenozoic deposits in this corner of south-east England were laid down on the edge of a marine basin with a broad cyclic regime of sedimentation. Each cycle began with a marine transgression that was followed by a gradual transition to a fluvial or non-marine phase. In Kent, which lay at the margin of the basin, the sequence is thinner than near the basin centre and there were numerous breaks in sedimentation. The Pegwell Bay section appears to indicate sediment accumulation after a relatively short break following the formation of the Chalk. The Palaeocene semi-consolidated terrigenous clastics (Thanet Beds) here contain both body and trace fossils from marine mollusc-dominated invertebrate communities. The Oldhaven and Blackheath Beds show a swing to estuarine and mudflat shallows environments with very abundant benthonic molluscs and high populations of fishes, particularly sharks and rays. Comparable communities exist today in coastal regions of South-east Asia and West Africa. The disarticulated nature of the vertebrates suggests extensive biodestruction following death and also current or tidal working of their remains. Comparable sites are few, but Herne Bay is close both geographically and in the nature of the material located there.

Conclusion

Pegwell Bay exposes some of the oldest Palaeocene deposits in Britain, which includes a small vertebrate assembage and provides the conservation value of the site. Both bony and cartilaginous fishes are present and collecting may be through bulk sampling and sieving. There is much potential for collecting to continue.

HERNE BAY (TR 217691–TR 205687)

Highlights

At Herne Bay in Kent an almost continuous sequence through the Palaeocene and Lower Eocene strata is exposed along the foreshore and cliff outcrop, and fossil fishes have been found in most units in the pre-London Clay Tertiaries and basal London Clay Formation. The 'Beltinge Fish Bed' (Woolwich Bottom Bed) which occurs near the base of the section, has yielded an exceptionally rich fossil fish fauna, with three species that only occur at this locality.

Introduction

Cliff and foreshore exposures extending from the east side of Herne Bay town north-eastwards to Reculver Point (TR 224693) give a continuous section from the Upper Thanet Formation to the London Clay. It is considered to be one of the best Lower Eocene fish-bearing localities in the British Isles and has yielded abundant material from nearly all levels in the sequence. The Beltinge Fish Bed (of the Woolwich Bottom Bed) near the base of the section is particularly important, as it yields well-preserved chimaeroid toothplates of at least seven species, three of which are known only from Herne Bay, in conjunction with a diverse shark fauna. Other important fish-bearing horizons occur within the Thanet Formation, the Oldhaven Formation and the basal beds of the London Clay. The sequence at Herne Bay has in all yielded 17 species of selachians, eight holocephalians and over 30 bony fish species based upon scattered teeth, bones and teleost otoliths.

The Herne Bay section has been described many times over the past 140 years, including the classic early works by Prestwich (1850, 1852, 1854a) and Whitaker (1866, 1872). Recent descriptions include that by Ward (1978a) on the pre-London Clay strata and by King (1981) on the London Clay itself, and a general account of the geology is provided in the memoir for the Faversham sheet (Holmes, 1981). Herne Bay is included in the Geologists' Association Guide No. 30B (Pitcher *et al.*, 1967). The site was selected as an SSSI for Tertiary stratigraphy, as it is designated the co-stratotype (with Pegwell Bay, Kent; TR 34986429) for the Thanetian Stage of the Palaeocene by Pomerol (1982), and is described by Daley (*in* Daley and Balson, 1999). The site is also the type locality for King's (1981) definitions of the Oldhaven Formation, and Herne Bay Member of this formation. The fish fossils have been recorded by Gurr (1963), Ward (1975, 1978a) and Gamble (1979). As an important Tertiary fish and stratigraphical site, Herne Bay used to be one of the most visited sites in the pre-London Clay Tertiaries and was the venue for several fieldtrips by the Geologists' Association (Brown, 1936; Gamble, 1968; Hutchinson, 1968) and the Tertiary Research Group (e.g. Rundle, 1970). However, in the past 20 years this activity has declined as coastal defence schemes have left the cliff sections poorly exposed.

Description

The section between Herne Bay town and Reculver village comprises a series of Palaeogene beds which dip gently towards the west. The oldest strata present, the 'Lower London Tertiaries', is made up of the upper part of the Thanet Formation and the overlying 'Woolwich Beds' of Ellison's (1983, p. 312) Woolwich and Reading Formation. These are succeeded unconformably by the Thames Group (King, 1981), i.e. the Oldhaven Beds of the Blackheath and Oldhaven Formation and the London Clay Formation (Figure 14.4). However, the London Clay succession at Herne Bay is now poorly exposed along the cliff sections, although King (1981) referred to cliff exposures of this unit as up to 30 m in thickness and the thickest preser-

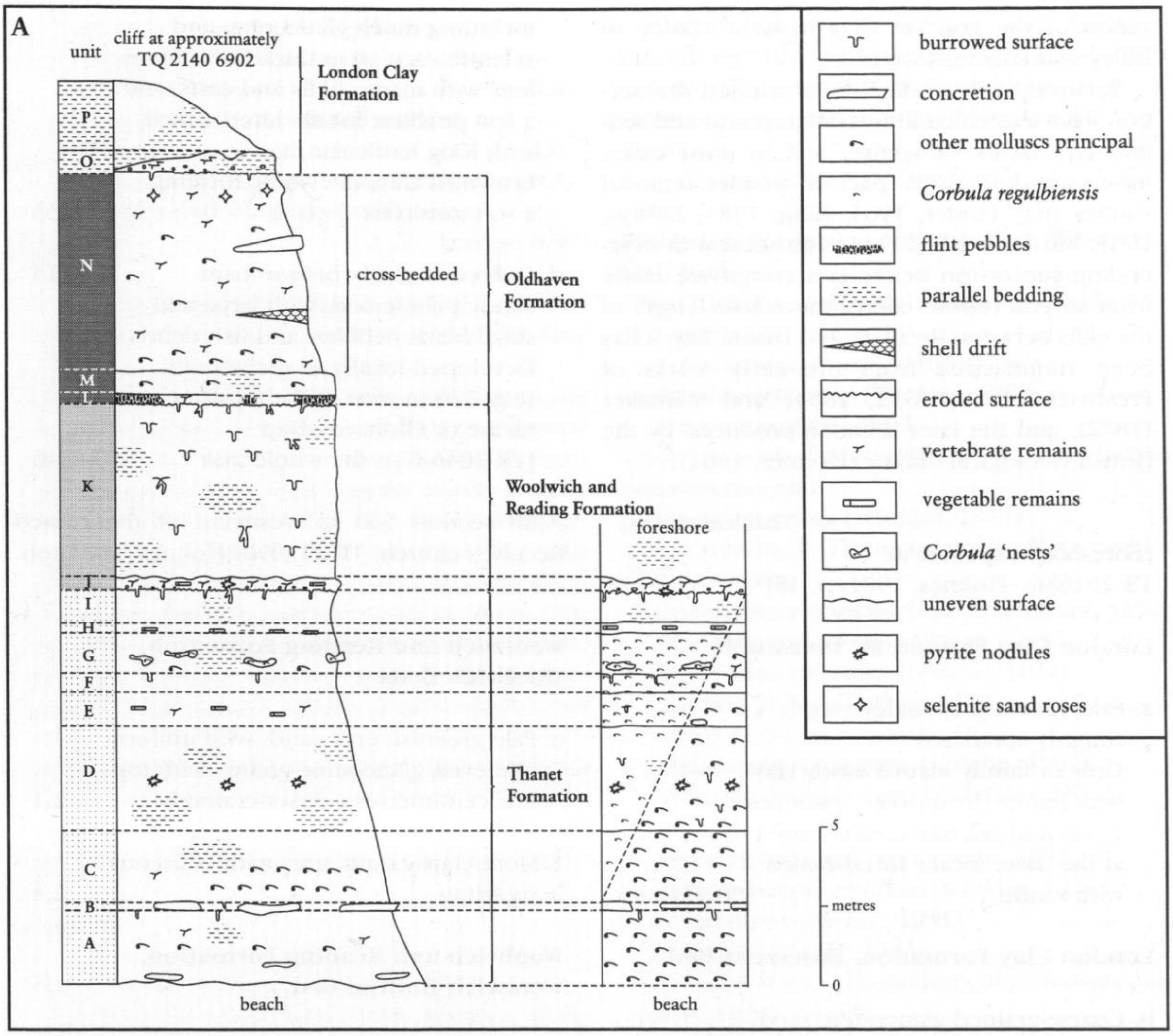
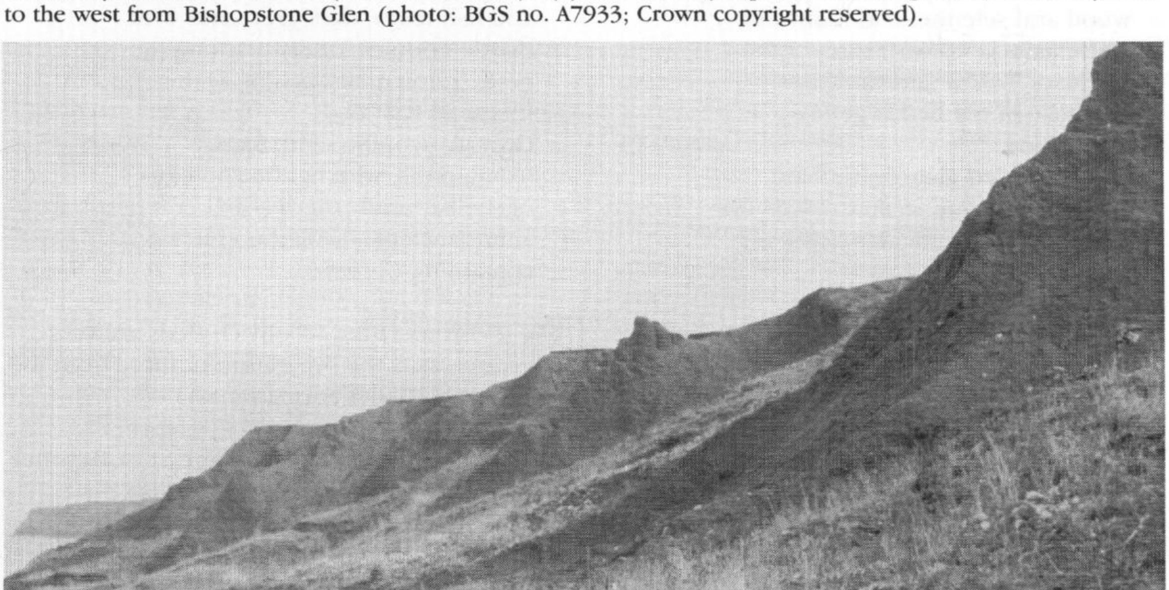


Figure 14.4 (A) Sedimentary log of a generalized vertical section of the Palaeocene and Lower Eocene in the Herne Bay Cliffs and foreshore (after Ward, 1978a). (B) London Clay exposed in Beltinge Cliff, Herne Bay, view to the west from Bishopstone Glen (photo: BGS no. A7933; Crown copyright reserved).



vation of the London Clay in Kent (Daley *in* Daley and Balson, 1999).

Relatively few workers have studied the section from a detailed lithostratigraphical and sedimentary facies viewpoint, and in most cases, have only done so as part of broader regional studies (e.g. Hester, 1965; King, 1981; Ellison, 1983; Ellison *et al.*, 1994). The section in descending succession below is a composite made from several reports along the whole length of the cliffs between Reculver and Herne Bay, it has been summarized from the early works of Prestwich (1850, 1852, 1854) and Whitaker (1872), and the later sections produced by the British Geological Survey (Holmes, 1981):

Thickness (m)

[Foreshore exposure at TR 201686: Holmes, 1981, p. 48]

London Clay Formation, Division B

a. Pale, bluish grey shaley clay, roughly laminated –
Grey or faintly mauve sandy clay with lignite, iron pyrite, pyritized wood and selenite concentrated at the base; locally interbedded with sand: 0.23–0.46

London Clay Formation, Basement Bed

b. Coarse-grained glauconitic sand, locally ferruginous with a few black flint pebbles, lignite, pyrite, pyritized wood and selenite; and many fish teeth, associated with casts of the molluscs *Natica* and *Cardium*. The base of the bed is gently undulating up to 0.15
Finely bedded glauconitic sand interbedded with shale towards the base, forming lenticular masses; few small flint pebbles 0–0.46

[Cliffs 1400 m west of ruined church at Reculver, TR 214690; Holmes, 1981, p. 41; a–b, London Clay as above; with 0.6 m of basal beds]

Blackheath and Oldhaven Formation, Oldhaven Beds

c. Fine-grained, pale, cross-bedded sand with lines of larger grains, including much glauconite, and selenite. A 0.10 m thick ferruginous lens with many shells and casts, and a few pebbles; locally interbedded with long lenticular masses of brownish clay; the whole forming a soft sandrock 5.33

d. Ochreous sandy, brown loam 0.15
Sandy pebble bed, with large and small black pebbles, and fish debris. Developed locally as shelly units (e.g. 320 m west of Bishopstone ravine or Oldhaven Gap [TR 204687]); the whole unit 0–0.46

[Cliff section 550 m westward of the ruined Reculver church, TR 214690; Holmes, 1981, pp. 29, 37]

Woolwich and Reading Formation, Woolwich Beds

e. Pale greenish grey sand, with uniform and even glauconitic grains; with top few centimetres coarser-grained 2.1

f. More clayey sand, grey with ochreous mottling 2.4

Woolwich and Reading Formation, Woolwich Bottom Bed

g. Pale grey sand, mostly coarser with dark grains and a few small pebbles and fish teeth; dark grey sand with pyritic nodules locally marking the base. Known hereabouts as the 'Beltinge Fish Bed' 0.6–2.7
Grey glauconitic sand, locally ferruginous, with lignite and casts of shells; locally there is an abundance of silicified nodules containing *Corbula* 0.5–1.0

The divisions of the Woolwich Beds are very indistinct, as is the separation of these from the underlying Thanet Formation

h. **Thanet Formation, Reculver Silts Member**
Fine sand, slightly clayey, brownish grey at top, and with very few flint pebbles. For most part a very pale greenish grey 3.7

Layer of concretionary blocks ('doggers') of calcareous indurated sandstone	0.3
Pale grey sandstone with abundant shells	2.6
Layer of calcareous sandstone doggers	0.3
Bedded, clayey buff sand with many shells	seen to 0.9

Prestwich (1852, p. 263) reported the Chalk beneath sands 'at a depth of about 70 feet [21 m], in a deep well at Reculver'.

The lenticular and locally discontinuous nature of some of the beds, and the general poor quality of the section, were discussed by Holmes (1981) and in the GCR volume report on the Tertiary deposits of Herne Bay (Daley *in* Daley and Balson, 1999). The latter author also recorded the biostratigraphy and mineralogy of the units exposed along the coast at Herne Bay, including the chronostratigraphical scheme based upon microfossils and employed successfully by Costa *et al.* (1976) at this locality, the magneto-stratigraphical work carried out by Townsend and Hailwood (1985) and the radiometric ages given by Odin *et al.* (1978), Odin and Curry (1985) and Fitch *et al.* (1978) for glauconite-bearing units within the succession.

Fauna

Fish fossils have been recovered from most levels in the sequence (Ward, 1980; Holmes, 1981) and are listed below bed by bed, otolith taxa are not included (Figure 14.5):

Thanet Formation, Reculver Silts Member (Units A–G of Ward, 1979)

Chondrichthyes: Elasmobranchii: Neoselachii: Squalomorphii
Squalus orpiensis (Winkler, 1874)
S. minor Leriche, 1902
Chondrichthyes: Elasmobranchii: Neoselachii: Squatinomorphii
Squatina prima (Winkler, 1874)
Chondrichthyes: Elasmobranchii: Neoselachii: Galeomorphii
Heterodontus lerichei Casier, 1943
Hypotodus robustus (Leriche, 1921)
'Lamna' inflata Leriche, 1936
Palaeogaleus vincenti (Leriche, 1902)
Palaeohypotodus rutoti (Winkler, 1874)
Otodus obliquus Agassiz 1836–1843
Synodontaspis striatus (Winkler, 1874)
S. teretidens (White, 1931)
Chondrichthyes: Holocephali: Chimaeriformes
Callorhinchus newtoni Ward, 1973
Osteichthyes: Actinopterygii: Neopterygii: Euteleosti
Ardiodus marriotti White, 1931

Woolwich Formation Bottom Bed, 'Beltinge Fish Bed'

Chondrichthyes: Elasmobranchii: Neoselachii: Squalomorphii
Notidanodon loozi (Vincent, 1876)
Squalus orpiensis (Winkler, 1874)
S. minor Leriche, 1902
Chondrichthyes: Elasmobranchii: Neoselachii: Squatinomorphii
Squatina prima (Winkler, 1874)
Chondrichthyes: Elasmobranchii: Neoselachii: Galeomorphii
Galeorhinus gomphorhiza Arambourg, 1952
Heterodontus lerichei Casier, 1943
Hypotodus robustus (Leriche, 1921)
'Lamna' inflata Leriche, 1936
Otodus obliquus Agassiz, 1836
Palaeogaleus vincenti (Leriche, 1902)
Palaeohypotodus rutoti (Winkler, 1874)
Scyliorhinus gilberti Casier, 1946
Synechodus eocaenus Leriche, 1902
Synodontaspis striatus (Winkler, 1874)
S. teretidens (White, 1931)
S. hopei (Agassiz, 1843)
Chondrichthyes: Elasmobranchii: Neoselachii: Batomorphii
'Hypolophus' sylvestris White, 1931
Myliobatis dixoni Agassiz, 1843
Myliobatis sp.
Chondrichthyes: Holocephali: Chimaeriformes
Callorhinchus regulbiensis Gurr, 1963
Chimaera eophantasma Ward, 1973
Edaphodon bucklandi Agassiz, 1843
E. minor Ward, 1973
Elasmodus hunteri Egerton, 1843
Ischyodus dolloi Leriche, 1902
Osteichthyes: Actinopterygii: Neopterygii: Halecostomi
Pycnodus sp.
Osteichthyes: Actinopterygii: Neopterygii: Euteleosti
Ardoides marriotti White, 1931
Egertonia sp.

Oldhaven Beds

Chondrichthyes: Elasmobranchii: Neoselachii: Squatinomorphii

Squatina prima (Winkler, 1874)
Chondrichthyes: Elasmobranchii: Neoselachii: Galeomorphii
Otodus obliquus Agassiz, 1836
Palaeohypotodus rutoti (Winkler, 1874)
Synodontaspis macrotus (Agassiz, 1843)
S. teretidens (White, 1931)
S. hopei (Agassiz, 1843)
Chondrichthyes: Elasmobranchii: Neoselachii: Batomorphii
Hypolophodon ('*Hypolophus*') *sylvestris* (White, 1931)
Chondrichthyes: Holocephali: Chimaeriformes
Amylodon eocenica (Woodward and White, 1930)
Undifferentiated osteichthyan bones, teeth, scales and vertebrae

London Clay Formation, Basement Bed
Chondrichthyes: Elasmobranchii: Neoselachii: Squatinomorphii
Squatina prima (Winkler, 1874)
Chondrichthyes: Elasmobranchii: Neoselachii: Galeomorphii
Otodus obliquus Agassiz, 1836
Palaeohypotodus rutoti (Winkler, 1874)
Synodontaspis macrotus (Agassiz, 1843)
S. teretidens (White, 1931)
S. hopei (Agassiz, 1843)
Chondrichthyes: Elasmobranchii: Neoselachii: Batomorphii
Hypolophodon ('*Hypolophus*') *sylvestris* (White, 1931)
Chondrichthyes: Holocephali: Chimaeriformes
Amylodon eocenica (Woodward and White, 1930)

London Clay Formation, Division B
Chondrichthyes: Elasmobranchii: Neoselachii: Squalomorphii
Notorhynchus serratissimus (Agassiz, 1844)
Isistius trituratus (Winkler, 1874)
Chondrichthyes: Elasmobranchii: Neoselachii: Galeomorphii
Carcharias hopei (Agassiz, 1843) (includes species labelled as *Hypotodus robustus* (Leriche, 1921) and *H. verticalis* (Agassiz, 1843))
Isurolamna affinis (Casier, 1946)
Jaekelotodus trigonalis (Jaekel, 1895)
'*Lamna*' *lerichei* Casier, 1946
Palaeohypotodus rutoti (Winkler, 1874)
Synodontaspis macrotus (Agassiz, 1843)
S. teretidens (White, 1931)
S. hopei (Agassiz, 1843)
Chondrichthyes: Holocephali: Chimaeriformes
Elasmodus hunteri Egerton, 1843
Osteichthyes: Actinopterygii: Neopterygii: Euteleostei
Ardiodus marriotti White, 1931
Cylindracanthus rectus (Dixon, 1850)

Interpretation

Several models for the deposition of the Thanet Formation at Herne Bay have been attempted, because of the rich fossil assemblage recovered from these beds. Although the depositional environment seems to have been within shallow marine conditions, with a maximum sea depth of about 50 m (Curry, 1965), the evidence is somewhat equivocal regarding climatic implications. For instance, Wrigley (1949) found both warm- and cold-water species of molluscs, and concluded that the evidence pointed to a subtropical regime, which seems to be compatible with the subtropical and tropical fish fauna (White, 1931) and Curry's (1965) reference to calcareous algae occurring in the highest beds of the Thanet Formation near Bishopstone Glen.

The beds of the Woolwich Formation are extremely thin at Herne Bay, in comparison to exposures in other parts of the London Basin, suggesting that uplift and erosion of a thicker sequence took place in the eastern part of the basin before the deposition of the overlying Thames Group. The glauconitic sands of the Woolwich Bottom Bed may represent a littoral deposit in a barrier sand complex and are suggestive of a transgressive sand sheet that extended across much of southern England (Ellison, 1983). The overlying Woolwich Formation is considered to be lagoonal or fully marine.

The mineralogy of some units in the Herne Bay section, has revealed early Palaeogene sediment provenance details (see Blondeau and Pomerol, 1968; Weir and Catt, 1968; Morton, 1982) and evidence of ash falls from contemporary volcanism within the Oldhaven Formation (Knox, 1979). Recent studies of palaeomagnetic and mineralogical data from the Oldhaven Formation by Townsend and Hailwood (1985) show this unit is laterally equivalent to the basal London Clay in Norfolk, and represents deposition in a nearshore environment within the initial London Clay Formation transgression. The variations in faunal composition between the Oldhaven Formation and overlying London Clay

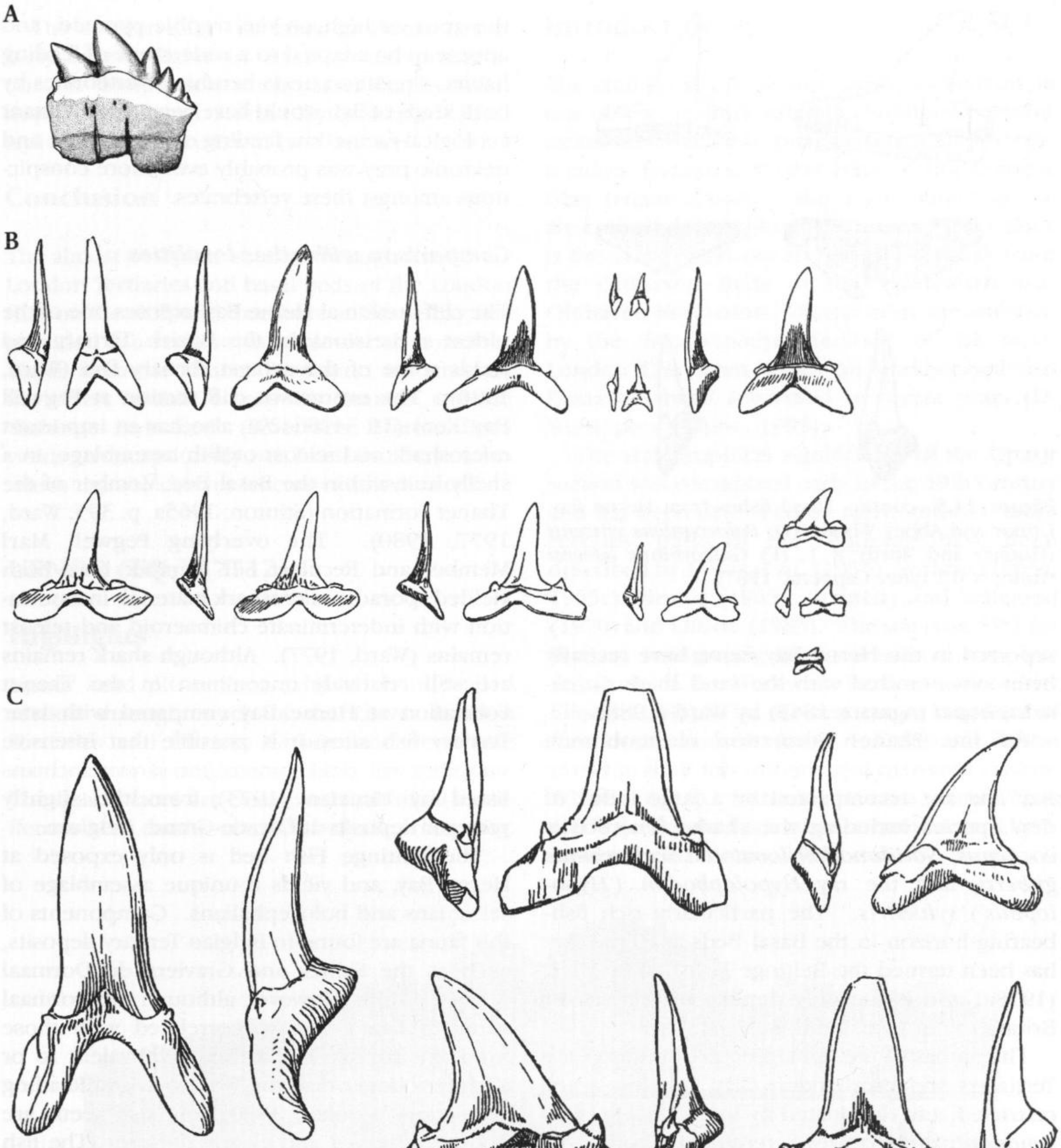


Figure 14.5 Fossil fishes from Herne Bay, Upnor and Abbey Wood. (A) *Notidanodon* sp., lingual view of lower anterior tooth, × 0.65, Herne Bay (from Cappetta, 1987); (B) elasmobranch teeth from Abbey Wood, *Odontaspis* (*Synodontaspis*) *macrota* (Agassiz) × 1.3; (C) *O. striata* (Winkler) (after White, 1931) × 2. (Continued on page 496.)

at Herne Bay (referred to by King, 1981) are now known to be a reflection of the differences in depositional environments (Knox *et al.*, 1983).

Fish material has been found throughout the sequence at Herne Bay and is in all beds dominated by the abundance of small sharks teeth (Cooper, 1977; Figure 14.5). The sand sharks *Synodontaspis striatus* and *S. teretidens* are common in the sandy uppermost horizons of the Thanet Formation at Herne Bay, whilst the dogfishes *Squalus minor* and *Palaeogaleus vincenti* occur in the more argillaceous facies (Ward, 1980). The species *Hypotodus verticalis* (Agassiz, 1843) and *H. robustus* Leriche, 1921

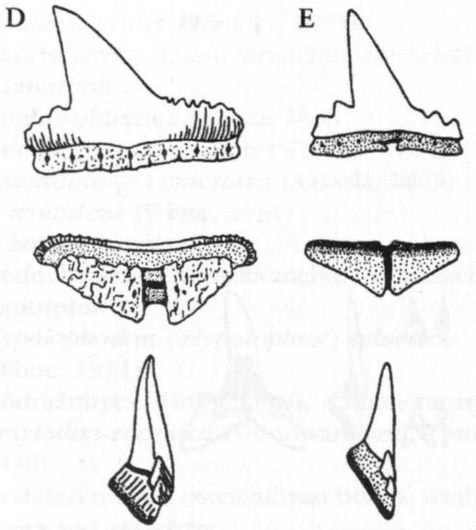


Figure 14.5 *–contd.* Fossil fishes from Herne Bay, Upnor and Abbey Wood. (D) *Palaeogaleus vincenti* (Hooker and Ward) × 1; (E) *Galeorhinus lefevrei* Gunn, × 0.1 (after Cappetta, 1987).

reported in the Herne Bay fauna have recently been synonomized with the sand shark *Carcharias hopei* (Agassiz, 1843) by Ward (1988).

All the Thanet Formation elasmobranch species range up into the Bottom Beds at Herne Bay and are accompanied by a large influx of new species including the sharks *Synechodus eocaenus*, *Notidanodon loozi* and *Scyliorhinus gilberti*, and the ray *Hypolophodon* ('*Hypolophus*') *sylvestris*. The particularly rich fish-bearing horizon in the Basal Beds at Herne Bay has been termed the Beltinge Fish Bed by Ward (1978a) and is the only deposit of this age in Britain to have yielded this assemblage.

The faunas of the remaining pre-London Clay Tertiaries and the London Clay Division A are restricted, and dominated by the coastal species *Synodontaspis striatus*, *S. teretidens* (both sand sharks), the monkfish *Squatina prima* and the ray *Hypolophodon* ('*Hypolophus*') *sylvestris'*. They yield only two new species: the shark '*Scyliorhinus*' *biauriculatus* and the giant stingray *Dasyatis wochadunensis*, which are not recorded at Herne Bay (Ward, 1980).

The various faunal communities identified within the British Palaeogene include many molluscan species, and it is clear that in the wide variety of depositional environments present, organic productivity was generally very high (Taylor, *in* McKerrow, 1978). Vertebrates figure in all but the marine sand communities. The teleosts and the elasmobranchs were clearly at the apex or high on the trophic pyramid, and appear to be adapted to a wide range of feeding habits. Predation upon benthic invertebrates by both kinds of fish would have been an important ecological factor, but feeding on planktonic and nektonic prey was probably even more conspicuous amongst these vertebrates.

Comparison with other localities

The cliff section at Herne Bay exposes one of the oldest successions in the British Tertiary and yields some of the earliest Tertiary fish (Ward, 1980). The overgrown cliff section at Pegwell Bay, Kent (TR 34986429), also has an important microshark and teleost otolith assemblage, in a shelly unit within the Basal Bed Member of the Thanet Formation (Stinton, 1965a, p. 395; Ward, 1977, 1980). The overlying Pegwell Marl Member and Reculver Silt Member have both yielded sporadic microshark material, in association with indeterminate chimaeroid and teleost remains (Ward, 1977). Although shark remains are still relatively uncommon in the Thanet Formation at Herne Bay compared with later Tertiary fish sites, it is possible that intensive sampling will yield some of the rarer selachians listed by Herman (1973) from the slightly younger deposits at Orp-de-Grand, Belgium.

The Beltinge Fish Bed is only exposed at Herne Bay, and yields a unique assemblage of selachians and holocephalians. Components of this fauna are found in Belgian Tertiary deposits, such as the Sables and Graviers de Dormaal (Casier, 1967). However, although the Dormaal mammal fauna can be correlated with those from the Suffolk Pebble Bed (equivalent to or slightly younger than the Woolwich and Reading Formation; Hooker, 1980), the fish teeth are poorly preserved and clearly derived. The fish remains clearly come from a different deposit than the mammal teeth, but Ward (1980) considered it impossible to differentiate which fauna was the older, as the same shark faunas persisted up to the lower part of the Argile d'Ypres (approximately equivalent to the London Clay) in Belgium.

The Woolwich Shell Beds in eastern Kent commonly yield isolated shark teeth and other fish remains, and localities include Upnor (q.v.) and Swanscombe quarries (TQ 5973; Stamp and Priest, 1920; Brown and Priest, 1924). Farther west, the contemporary Reading Beds also yield fish remains.

The London Clay fish fauna at Herne Bay is fairly unremarkable in diversity and preservation, in comparison to the assemblages taken from the younger London Clay of Sheppey (q.v.) and the Hampshire Basin (see below).

Conclusion

The almost complete section through the Lower London Tertiaries and basal beds of the London Clay on the cliffs and foreshore at Herne Bay, has provided fish remains from almost all horizons. Those from the Thanet Formation are amongst the oldest British Tertiary fish remains, and the 'Beltinge Fish Bed' (Woolwich Bottom Bed) yields an exceptionally rich fossil fish fauna from which the site derives its conservation value.

UPNOR (TQ 757712)

Highlights

Upnor sand pit in Kent exhibits an unrivalled section through much of the Lower London Tertiaries and Thames Group, and vertebrate remains are found throughout the sequence. The quarry faces are clean, and individual fossiliferous beds can be sampled by bulk processing.

Introduction

The sand pit at Upnor, just north of Chatham, is one of few localities where a continuous section exists through the pre-London Clay 'Lower London Tertiaries' to the base of the London Clay (Figure 14.6A). Microvertebrate remains are recorded throughout the section and Upnor is the only inland site to have yielded fish from the Oldhaven Beds of the Blackheath and Oldhaven Formation. These beds are overlain by the 'Swanscombe Member' of the basal London Clay from which an undescribed fish fauna has been recovered in recent years (D. Ward, pers. comm., 1995).

The stratigraphical significance of the Upnor section was recognized early in the 19th century and has been described by many authors; more recently, parts of the sequence have been described by Dines *et al.* (1954), Stinton (1965a, 1965c), Hester (1965), Kennedy and Sellwood (1970) and Ellison (1983). The site is an SSSI for Tertiary stratigraphy, as it contains a complete sequence of the Woolwich Beds considered by Ellison (1983) to be the best extant exposure of these strata; see also Daley *in* Daley and Balson (1999). The fish fauna has been recorded by White (1931), Stinton (1965c), and Ward (1978a). Recent finds were communicated by S. Austen (pers. comm., 1995).

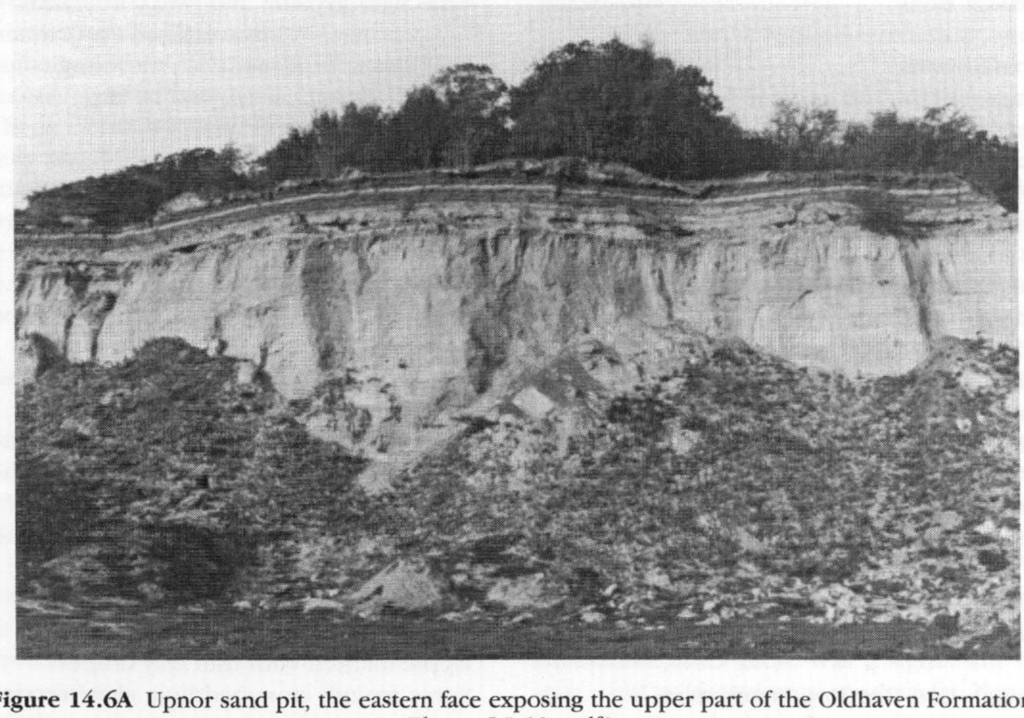


Figure 14.6A Upnor sand pit, the eastern face exposing the upper part of the Oldhaven Formation (Photo: S.J. Metcalf.).

Description

Altogether, the continuous sequence through the upper part of the Thanet Formation to the basal beds of the London Clay Formation exposed in Upnor sandpit is some 25–30 m thick (Daley *in* Daley and Balson, 1999). Published sections for the Upnor succession include those by Dines *et al.* (1954), Stinton (1965a) and Kennedy and Sellwood (1970). The following (in descending order) is a composite made from the latter two accounts:

Thickness (m)

London Clay Formation

23. Grey clay, unfossiliferous, compact and poorly bedded becoming sandy downwards — seen up to 2.0
22. Reddish-grey sandy clay, poorly bedded, with some glauconite; bioturbated? — 1.0
21. Sands and clays. Alternate layers of sand and clay with scattered, small (up to 2 cm) rounded black flint pebbles. Sands are ripple-drift bedded with clay-draped surfaces. Base of unit erosional with small (15 cm) scours and burrows (1.5 mm) — 1.1

Oldhaven and Blackheath Formation, Oldhaven Beds

20. Fine, buff, cross-bedded sands, unfossiliferous — 0.9
19. Impersistant line of cream-coloured septarian nodules — 0–0.6
18. Sands and clays. Lenticles of ripple-drift bedded sands and lignitic micaceous clays with *Glycymeris* — 1.0
17. Fine, buff, cross-bedded sands, ripple-drift bedded in top 10 cm. Small channels with coarser debris and small black flints at the base — 0.5
16. Shell Bed. Fine, buff sand packed with broken mollusc shells and flint pebbles. Erosion surface at base, probably a channel fill — 0.4
15. Shell Bed. Fine, yellow orcheous sand with numerous black pebbles and mollusc debris, including *Corbicula*, *Glycymeris* and *Nemocardium*. Lenses — 0.4–1.3

Woolwich and Reading Formation, Woolwich Beds

14. Low-angle cross-bedded yellow sands with lines of imbricated corbiculids, oysters etc. *Ophiomorpha* burrows occur in top 1.2 m; more shelly in basal 0.3 m, shark's teeth and teleost fragments occur. Erosional surface at base — 0.5–1.5
13. Grey sands and clays, with ripple-drift bedded and cross-bedded units. Burrowed by *Ophiomorpha*, profuse *Corbicula* and scattered fish remains occur — 1.0
12. Massive, mottled, grey-yellow sands, iron-stained, burrowed — 1.7
11. Sands with oysters and moulds of aragonitic bivalves. Poorly bedded, with wisps of clay — 1.1

Woolwich and Reading Formation, Woolwich Shell Beds

10. Low-angle cross-bedded, striped black, grey, green and pink sandy clays with abundant crushed and fragmentary *Corbicula*, a few fish remains and seams of lignite — 1.5

10a. Line of carbonaceous ironstone nodules — 0.1

9. Grey streaky sandy clay with sandy seams — 0.6
8. Laminated black and brown sandy clays with gypsum and rare corbiculids — 0.4
7. Carbonaceous iron-stained sandstone — 0.3
6. White to buff sands with low-angle cross-bedding. Burrowed by large *Ophiomorpha* — 0.6
5. Sandy ironstone — 0.2
4. Hard, massive, purple sandstones with scattered small flint pebbles. Burrowed, and passing down into purple and yellow, cross- and ripple drift- bedded sands. Erosion surface at base — 2.1

Woolwich and Reading Formation, Woolwich Bottom Bed

3. Grey and yellow, impersistently glauconitic sands with lenticles of gravel. Bed consists of low-angle cross-bedded units 0.3–0.6 m thick. Upper part of the unit ripple-drift bedded and burrowed, top surface ripple-marked with thin clay drapes. Some trough cross-bedding; clay breccias occur. *Ophiomorpha* occurs throughout — 8.0

2. Basal conglomerate of small black flint pebbles, with scattered fish teeth 0–0.3

Thanet Formation

1. Unfossiliferous whitish-grey and yellow sands, intensely burrowed seen to floor of pit 6.0

Although only the upper part of the Thanet Formation is exposed in Upnor sand pit, the locality is situated where this unit reaches its maximum thickness (Hester, 1965), and basal strata are exposed nearby (Weir and Catt, 1969). The Thanet Beds at Upnor have not yielded fish material. A complete sequence through the Woolwich Beds of the Woolwich and Reading Formation occurs in the pit, and three out of the six lithofacies described by Ellison (1983) are present there (Daley *in* Daley and Balson, 1999). Fish remains are found throughout the sequence, but are particularly common in the shelly units, such as Bed 14 in the above section (of Kennedy and Sellwood, 1970; roughly equivalent to bed 4 of Stinton (1965a)), although this might in part be due to collection bias in these beds. The overlying Oldhaven Formation is unconformable upon the Woolwich Formation, and a basal shell bed, packed full of *Corbicula*, *Glycymeris* and *Nemocardium*, occurs. The Oldhaven Formation has yielded abundant microvertebrate remains, but precise stratigraphical details have not been provided, although it is likely that much of the material was recovered by bulk sampling the channel-like shell beds (Beds 15 and 16 on the log, after Kennedy and Sellwood, 1970; equivalent to bed 2 of Stinton, 1965a). The Oldhaven Formation is relatively thin in this locality, and the basal beds of the London Clay are seen only a few metres above with a clearly erosive contact between the two units (Daley *in* Daley and Balson, 1999).

Fauna

The faunas described below from the Woolwich Formation and Oldhaven Beds, have been taken from White (1931), Stinton (1965b) and Ward (1978a, 1980).

Woolwich Formation

Osteichthyes: Actinopterygii: Neopterygii: Ginglymodi

Lepisosteus sp.

Osteichthyes: Actinopterygii: Teleostei: Euteleostei

indeterminate bones, teeth, scales, vertebrae and otoliths

Oldhaven Beds

Chondrichthyes: Elasmobranchii: Neoselachii: Squatinomorphii

Squatina prima (Winkler, 1874)

Chondrichthyes: Elasmobranchii: Neoselachii: Galeomorphii

Palaeohypotodus rutoti (Winkler, 1874)
Synodontaspis hopei Agassiz, 1843
S. teretidens White, 1931
S. macrota Agassiz, 1843
S. striata Winkler, 1874

Chondrichthyes: Elasmobranchii: Neoselachii: Batomorphii

Hypolophodus ('*Hypolophus*') *sylvestris* (White, 1931)

Chondrichthyes: Holocephali: Chimaeriformes

Amylodon (*Chimaera*) *eoceanica* (Woodward and White, 1930)

Osteichthyes: Actinopterygii: Neopterygii: Ginglymodi

Lepisosteus sp.

Osteichthyes: Actinopterygii: Teleostei: Euteleostei

Ardiodus marriotti White, 1931
Diophyodus sp.

Indeterminate bones, teeth, scales, vertebrae and otoliths

Interpretation

The Thanet Formation shallow-marine glauconitic sands give way at Upnor to the much more regressive facies of the Woolwich and Oldhaven Beds. The Woolwich Beds display marked facies changes across the extensive outcrop, and at Upnor the great development of sands is thought to represent a barrier sand complex (Ellison, 1985). These pass westwards into muds and sands of a back-barrier lagoon in the London region. The fauna of the Woolwich Beds at Upnor is of low diversity and suggests that salinities were less than fully marine. For example, the common trace fossil *Ophiomorpha*, cited as representing fully marine conditions by Kennedy and Sellwood (1970), is also found in brackish and freshwater environments (Stewart, 1978). In mid-Woolwich Formation times there was a significant regression, and a ferruginous sand facies developed upon the emergent barrier sands (Ellison, 1983).

At the top of the unit there is a significant unconformity, reflecting another period of emergence and erosion, following tectonic uplift in the eastern parts of the London Basin (Daley *in* Daley and Balson, 1999).

The overlying Oldhaven Beds are unusually fossiliferous at Upnor. This is because in most inland sections these beds have been decalcified (Ward, 1978a). The Oldhaven Formation was considered to have been deposited in a shallow marine environment by early authors (e.g. Monkton, 1904), but is now thought to be a nearshore facies of the initial London Clay transgression. The mixed fauna, including brackish-water molluscs, at Upnor hints at an inshore palaeoenvironment.

The list of Osteichthyes is relatively small, but includes the gar *Lepisosteus* and teleosts. Chondrichthyes are represented by both galeomorphs and batomorphs in appreciable numbers. This suggests that a wide variety of prey was available – small vertebrates and nektonic invertebrates – but as a large number of taxa are based on otoliths, further palaeobiological discussion is handicapped.

Comparison with other localities

A similar microshark fauna to that in the Woolwich Beds at Upnor has been found in the contemporaneous or slightly younger Suffolk Pebble Beds at Ferry Cliff, Suffolk (TM 278486), and Harwich Harbour, Essex (TM 2632; Hooker and Ward, 1980; D. Ward, pers. comm., 1995). The Suffolk Pebble Bed at Ferry Cliff has also yielded the only British Palaeocene amphibian material (Milner, 1986). Few indeterminate bones have been recovered, but they include an anterior caudal vertebra of the salamander *Koalliella* sp. This genus is recorded from the Upper Palaeocene of Germany (Herre, 1950) and France (Estes *et al.*, 1967).

As early as 1889, Whitaker alluded to the abundant yet low diversity of the Thanet Formation and overlying Woolwich Beds fauna at Upnor, compared with other localities in the London Basin such as Herne Bay (q.v.) and Pegwell Bay, Kent (q.v.), which subsequent authors (e.g. Monkton, 1904) suggested was related to differing depositional facies. However, the overlying Blackheath and Oldhaven Formation is richly fossiliferous at Upnor, yielding an abundant microvertebrate fauna. Elsewhere in Kent, the Oldhaven Beds have been decalcified, but components of the Upnor fish fauna are also found at Shelford quarry, Kent (TR 160600; Ward, 1972) and in the contemporary Blackheath Pebble Beds from western parts of the London Basin (see Abbey Wood report).

Conclusion

Upnor sand pit derives conservation value from the rich fossil fish assemblage within the Oldhaven Formation, including two type specimens of teleost fishes. The facies within the sand pit display an almost continuous sequence through the Lower London Tertiaries, and fish remains have been recovered from several horizons in the Woolwich Formation.

ABBEY WOOD (TQ 480786)

Highlights

Bulk sampling of an unconsolidated shell bed in the Oldhaven Formation at Abbey Wood in Greater London has yielded an unique microvertebrate assemblage, which includes many teleost otoliths, one type species of shark and one ray. The Lessness Shell Bed is particularly rich in fossil vertebrates, and continues to be worked by members of the Tertiary Research Group on a regular basis.

Introduction

The temporary 'fossil pit' situated in the grounds of the Lessness Abbey Wood Nature Reserve has yielded a rich vertebrate fauna, including land-derived mammals, birds and reptiles, in association with abundant fish remains. Excavations of the site for Tertiary vertebrate remains were made in the early part of the 20th century, yielding much material which was documented in the classic paper by White (1931). Since then excavation has been sporadic, until 1992, since when the Tertiary Research Group has undertaken a twice-yearly venture to recover as much information about the unique Lower Eocene assemblage as possible.

The fossiliferous horizon at Abbey Wood (Figure 14.6B), is the Lessness Shell Bed, an unconsolidated shelly horizon in the Blackheath and Oldhaven Formation, which can be bulk processed by wet sieving. Most of the fossil

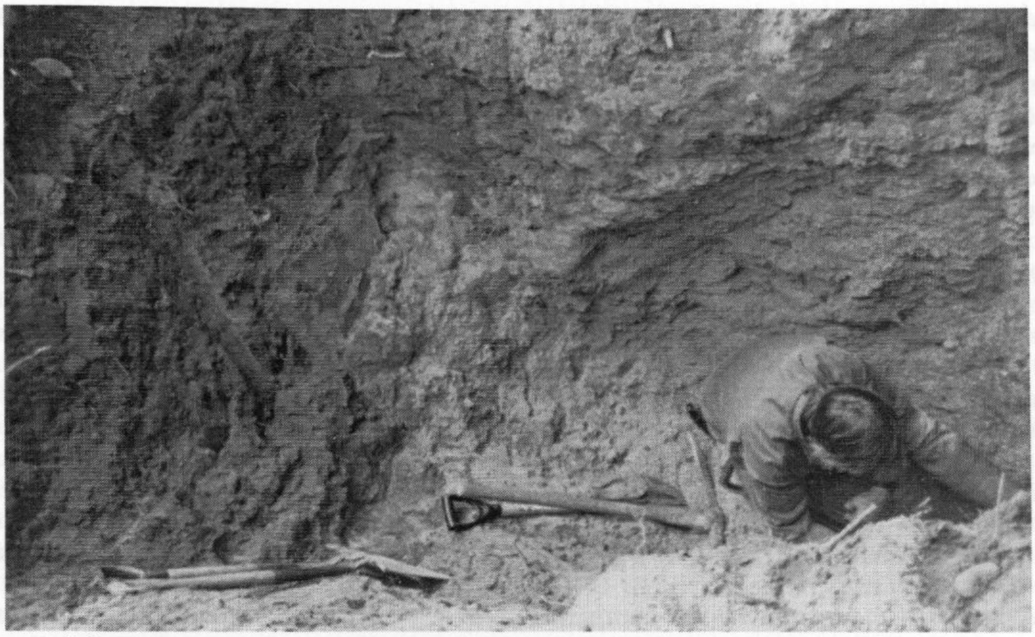


Figure 14.6B Exploratory trench in the Blackheath and Oldhaven Formation in Abbey Wood, Blackheath, (Photo: S.J. Metcalf, 1994).

recovery is done on site, and the yield of fossil vertebrate material is exceptionally high (S.M., pers. obs.). The fish assemblage is particularly rich in teleost otoliths and Abbey Wood is the type locality for several species of these microfossils. There is also an abundant fauna of shark teeth and some undescribed bony fish remains. The geology of the site has been described by Dewey *et al.* (1924), Rundle (1970), Cooper (1976b). Fish remains (otoliths) have been described by Frost (1931) and Stinton (1965c). The site is also important for the abundance of Eocene mammals recovered during bulk sampling (Collinson and Hooker, 1987; Hooker, 1979, 1991), and the site has been designated an SSSI for its fossil mammals. Fossil reptile remains have also been recorded from this site (Walker and Moody, 1974).

Description

The strata that crop out in the nature reserve range from the Chalk to the Blackheath Beds, although no complete or natural exposures through the section occur in the woods. There were previously many trial pits on Lessness Abbey Heath, but all were disused by the time the site was recorded the British Geological Survey in the early 20th century (Dewey *et al.*, 1924). The fossil pit occurs within the lower beds of the Blackheath and Oldhaven Formation, which in this area unconformably overlie the Woolwich Bottom Bed (Priest, 1919; Hooker, 1992). The Blackheath Beds are recorded as attaining a thickness of around 8 m in the Lessness area (Dewey *et al.*, 1924).

The Blackheath Beds of the Blackheath and Oldhaven Formation typically form cross-bedded, unconsolidated pebble units and cemented 'puddingstone' conglomerates, which occur in eastern Kent and the Greater London district and pass into the sands of the Oldhaven Beds in eastern Kent (Cooper, 1976b). At Lessness Abbey Wood the upper part of the Blackheath Beds consists of massive pebble beds, but the lower units are unusual in comprising sands with only scattered pebbles and a shell coquina known as the Lessness Shell Bed (Cooper, 1976b). This bed has yielded the vertebrate fauna. The coquina occurs as impersistent lenses lying upon the channelled surface of the underlying Woolwich Beds and is, in places, at least 1.6 m in thickness (J. Hooker, pers. comm., 1994).

The Lessness Shell Bed occurs as impersistent lenticles that can be rapidly exhausted by excavation, hence the Tertiary Research Group, in cooperation with the Bexley Ranger Service which maintains Lessness Abbey Wood Nature Reserve, monitor and supervise limited excavations in the woods on a twice-yearly basis. Fish teeth can be recovered from the fossil pit, by passing the matrix and overlying topsoil through a standard 500 mm sieve (D. Ward, pers. comm., 1994). The excavations are written up in a series of newsletter reports (Hooker, 1992, 1993a, 1994) and the position of the sampled shell-bed lenses mapped out for future reference. It is hoped that by attempting to stop uncontrolled excavations, restricted and carefully monitored sampling will preserve the fossil site for the future. As most of the finds made at the legal digs are deposited in the NHM and subsequently described by members of the Group (e.g. Hooker, 1993b, 1993c) new or important material will not be lost.

Fauna

The fossil fish assemblage includes 14 type specimens of teleost otoliths, one ray and one of the lamnid shark *Synodontaspis*, which were recovered during excavations in the 1930s (Frost, 1931). The fish fauna recovered from recent excavations at the trial pit includes bony fish remains, a chimaeroid and a rich neoselachian fauna (Ward, 1980; S. Austen, pers. comm., 1995).

Chondrichthyes: Elasmobranchii: Neoselachii: Squatinomorphii
Squatina prima (Winkler, 1874)
Chondrichthyes: Elasmobranchii: Neoselachii: Galeomorphii
Carcharias hopei (Agassiz, 1843)
Palaeohypotodus rutoti (Winkler, 1874)
Synodontaspis striatus (Winkler, 1874)
S. teretidens (White, 1931)
S. hopei (Agassiz, 1843)
Chondrichthyes: Elasmobranchii: Neoselachii: Batomorphii
Hypolophodon (*'Hypolophus'*) *sylvestris* (White, 1931)
Chondrichthyes: Holocephali: Chimaeriformes
Amylodon eocenica (Woodward and White, 1930)
Otoliths

Interpretation

The Lessness coquinas appear to have formed upon the deeply channelled underlying strata of the Woolwich and Reading Beds (Hooker, 1992). Fish remains and other vertebrate material were trapped within the channel infills, which are themselves composed of broken bioclastic material, whole mollusc shells and derived pebbles. The molluscan fauna is a mixture of brackish and marine types, with the former predominating. The shells often provide a cement, and elsewhere the coarser-grained facies are cemented into conglomerates by this carbonate. Terrestrial vertebrate material is well preserved in the coquina, suggesting that the shoreline was fairly close (Hooker, 1992).

The clasts within the Blackheath Pebble Beds are reworked Chalk flints and quartz derived from the underlying Woolwich and Reading Formation. They represent the coarse basal units of the transgressive London Clay sea, and contain a mixed fauna with derived, remanent and new faunal elements. Most of the invertebrates are estuarine species that are either derived from the underlying Woolwich Beds or are Woolwich taxa which have survived the advancing marine conditions. However, there is also a marine component, which includes new forms characteristic of London Clay assemblages, and some species make their first appearances in these beds.

The Blackheath Bed selachian fauna is rather restricted in diversity, and appears to be dominated by nearshore and benthic-generalist taxa, which are also common in the contemporary Oldhaven Beds and in the underlying Woolwich Beds. Several species of the sand shark *Synodontaspis* are common in the Lessness Shell Bed, including the type specimen of *S. teretidens* (White, 1931). The coastal assemblage also includes the type specimen of the small batoid *Hypolophodon* (*'Hypolophus'*) *sylvestris* (White, 1931) and the monkfish *Squatina prima* (Winkler, 1874). Otoliths are common: 14 new species have been described from this site (Stinton, 1965a, 1965b)

Comparison with other localities

Large shark teeth have been recovered from several localities in the Blackheath Beds of Greater London district, but most of these were found in long-disused pits and temporary road cuttings, such as that at Swanscombe (TQ 5973) which exposed an impersistant shell bed with fish material (Dewey *et al.*, 1924). Localities in the sandy facies Oldhaven Beds of eastern Kent have yielded abundant fossil fish teeth, in contrast to the Blackheath Beds, but this might be due to a sampling bias, as the former are exposed in large sand pits (Upnor (q.v.) and Shelford quarry: TR

160600) and along the northern Kent coast, e.g. at Herne Bay (q.v.). However, in terms of species richness, the fish assemblages, and in particular the teleosts, are much more representative in the Lessness Shell Bed than those of the other localities. This difference in faunal diversity may in part be on account of the focused sampling of the unit during excavations at Abbey Wood. The depositional environment of the shell coquina in the Blackheath Beds would also have concentrated vertebrate remains.

To the north-east, the Blackheath Beds grade into the marginal marine silts and sands of the Harefield Beds. Limited fish material has also been recovered from these units at Harefield Quarry, Middlesex (TQ 048911; Cooper, 1976b), and a road cutting at Bignell's Corner, Hertfordshire (TL 227007; Ward, 1976).

Conclusion

The conservation value of the temporary 'fossil pit' at Lessness Abbey Wood is derived from its exceptional Early Eocene fish fauna, which has been revealed by sporadic excavation over the past 60 years, and this includes 16 type specimens. Since 1992 regular supervised excavations of the fossiliferous horizon, the Lessness Shell Bed, has controlled the working of the deposit for research purposes. There is much potential for new and undescribed fish material to be recovered during the sampling.

LONDON CLAY FORMATION

The London Clay Formation (Thames Group; Early Eocene) is characterized by monotonous dark-grey to bluish marine mudstones, some of which are intensely bioturbated. London Clay facies are spread over the whole southern Britain basin, and represent deposition in a fairly deep sea (*c.* 180 m; Davis and Elliott, 1957; Curry, 1965). The London Clay is thickest in the London area (London Basin; over 160 m), although it reaches 90 m in the eastern parts of the Hampshire Basin, where the deposit is much more sandy and probably shallower in origin. The lowest few metres of the London Clay are known in the literature as the 'London Clay Basement Bed' and this unit is invariably a glauconitic and shelly sand (Curry, 1965), corresponding to deepening marine conditions following the initial transgressive pulse in Blackheath and Oldhaven Formation times. Towards the end of London Clay times the sea shallowed, and silty sandstones of the Claygate Beds and basal Bagshot Beds (Early–Late Eocene) were laid down in the London Basin (Curry, 1965). The Bagshot Beds are in part equivalent to the lower units of the Bracklesham Group of the Hampshire Basin (see below).

The London Clay Formation (London Clay and Claygate Beds) has been divided into five zones (termed A–E) on the basis of marine molluscs, and a correlation scheme, based on lithology, micro- and macrofaunas, has been developed by King (1970, 1981, 1984). Zones A and B of the London Clay are recorded only from borehole records in the London Basin, but are well known from condensed sequences at the basin edge in Essex and south Kent, and occur in the equivalent sections of the Hampshire Basin. Divisions C (12.3 m), D (16.2 m) and E (24.8 m) comprise silty clays with silt and sand partings at some levels, and beds of sandy silt.

The Claygate Beds consist of sparsely fossiliferous alternations of marine sands and clays, and are probably laterally equivalent to the highest London Clay sequences at Highgate and Sheppey (q.v.). The overlying Bagshot Beds are composed of decalcified, sparsely fossiliferous marine sands and continental clays of the London Clay Formation and Bracklesham Group.

The London Clay in the London and Hampshire Basins is the most uniform of the Palaeogene deposits. Its macrofossils are only locally common, but include about 350 species of molluscs and representatives of a wide range of other phyla, both animal and plant. Deposition occurred in the proximity of tropical rainforest land, where a mean annual temperature of about 25°C prevailed. Abundant fine sediment flowed in almost continuously, and there were probably seasonal floating mats of vegetation offshore. Despite this, there were well-oxygenated waters,which were highly productive organically and supported a range of animal bottom communities and nekton. This encouraged the development of broad trophic (feeding) pyramids upon which are sited, at several levels, the fish taxa listed. Bulk sampling methods provide a quantifiable means of assessing the ecological structure of the London Clay fauna.

The abundant London Clay fossils include diverse molluscs (bivalves, gastropods and nautiloids), crustaceans, fishes and tetrapods, and over 500 species of flowering plants (angiosperms) and gymnosperms, both groups being represented by pollen, logs, fruits and leaves (Reid and Chandler, 1933; Chandler, 1961). Many of the marine assemblages are facies controlled and faunal content varies widely over the whole outcrop. Fossil fish finds are relatively common within all divisions of the London Clay Formation, including the glauconitic sandy Basement Bed and the sands of the Claygate Beds (Hooker and Ward, 1980). Most finds are tiny fish teeth, scales and teleost otoliths, and are usually recovered by bulk sampling of the unconsolidated sediments. Hence, although some sampling was done in the early part of the 20th century (Sheppey (q.v.): Leriche, 1905, 1921; White, 1931; A.G. Davis, 1936), most of the literature has been written in the past 30 years, and includes important references by Venables (1963), Stinton (1965b, 1975–1980), Casier (1966), George and Vincent (1977), Cappetta (1976a), Cappetta and Ward (1977) and Ward (1979, 1988).

Collections of London Clay fossil fish are in the NHM.

FISH SITES

Sporadic fish material has been recovered from many localities throughout the outcrop of the London Clay Formation in the London and Hampshire Basins, and on the Isle of Wight. However, most of these sites have only yielded fragmentary remains of one or two fish species, and thus only the more significant ones are listed below by county from the south-west to north-east (taken mainly from Hooker and Ward, 1980):

ISLE OF WIGHT: Alum Bay, cliffs and foreshore exposures (London Clay Division A, 'Basement Bed'; SZ 305855; unusual shark fauna: D. Ward, pers. comm., 1995).

SUSSEX: Bognor Regis foreshore exposures (London Clay Division B, 'Aldwick Beds'; SZ 920979–SZ 924983; 76 species including otoliths, see report; Venables, 1963).

KENT: Herne Bay sea cliffs and foreshore exposures (London Clay, Division A, 'Basement Bed'–Division B, *Isselicrinus* horizon; TR 187683–TR 197684; over 22 species, see report; Cooper, 1978, Ward, 1979); Studd Hill, Herne Bay (London Clay Division B, *Isselicrinus* horizon; TR 152677; one species; Cooper, 1978); Sheppey (London Clay Divisions D–E; TQ 955738–TR 024717; over 50 species, see report; White, 1931, A.G. Davies, 1936); Swalecliff foreshore (London Clay Division B; TR 140685; phosphatic nodules containing partial and whole fish specimens, D. Ward, pers. comm., 1995).

ESSEX: Harwich Harbour foreshore (London Clay Division A2, Harwich Stone Band (volcanic tuff); TM 263317; five species; D. Ward pers. comm., 1995); Walton-on-the-Naze sea cliffs and foreshore exposures (London Clay Division A2 (volcanic ash and marine silty clays: beds 1–11 of George and Vincent, 1977); TM 267243; six species; George and Vincent, 1977); Grange Farm clay pit, South Ockendon (London Clay Division A (bed 1 of George and Vincent, 1977); TQ 611833–TQ 615833; six species; George and Vincent, 1977); Maylandsea foreshore and slipped river-cliff exposures (London Clay Division C; TL 908035; over 20 species, see report); Burnham-on-Crouch foreshore and river-cliff exposures (London Clay Division D; TQ 921967; 48 species, including 13 type specimens, see report; Cappetta and Ward, 1977).

Four sites are selected as GCR sites on the basis of their important Eocene fish faunas (the London Clay of Herne Bay, Kent, is described in the section as the pre-London Clay Tertiaries section). These are:

1. Bognor Regis, West Sussex (SZ 920979–SZ 924983). Early Eocene, London Clay Formation, Division B1 ('Aldwick Beds').
2. Maylandsea, Essex (TL 908035). Early Eocene, London Clay Formation, Division C.
3. Sheppey, Kent (TQ 955738–TR 024717). Early Eocene, London Clay Formation, Divisions D–E.
4. Burnham-on-Crouch, Essex (TQ 921967). Early Eocene, London Clay Formation, Division D.

BOGNOR REGIS (SZ 920979–SZ 924983)

Highlights

A rich fossil fish fauna has been derived from foreshore exposures of the Aldwick Beds

(London Clay, Division B) at Bognor Regis in West Sussex. The preservation is excellent and many type specimens of teleost otoliths have been described.

Introduction

The foreshore exposures of London Clay Formation at Bognor Regis have yielded a finely preserved vertebrate fauna, including land-derived mammals and reptiles, and shark and teleost debris, occurring mainly as teeth, scales, otoliths and bones, mostly from three horizons in the 'Aldwick Beds' (Division B of King, 1981). The vertebrate remains can be recovered from the outcrops on the foreshore, or frequently from pyritous debris pools on the shoreline that concentrate the scattered fossil material. Many species of elasmobranch and teleost fishes have been recovered by bulk processing the sediments and beach sands, although in more recent years coastal protection schemes have diminished the exposure.

Much of the early work on the London Clay at Bognor focused upon the palaeontology, and limited descriptions include those of Dixon (1850) and Reid (1897). Venables (1929, 1963) produced the most detailed account of the geology and the succession of beds exposed along the shoreline, and also produced descriptions of the insect fauna recovered from the 'Beetle Bed' (London Clay, Division B; Venables and Taylor, 1963). Subsequent work by King (1981) has focused on the stratigraphy and the site is also designated as an SSSI for Tertiary stratigraphy in the GCR volume by Daley and Balson (1999).

The fish fauna was listed by Venables (1963), and components of it have subsequently been described by Casier (1966); elasmobranchs) and Stinton (1965c, 1971; teleost otoliths).

Description

The London Clay Formation exposed along the coast from Bognor westwards to Aldwick and Pagham comprises intermittent foreshore outcrops of silty muds and sands, which dip at a low angle towards the south-west. The following composite section is taken from the description of the sequence by Venables (1963), with additional information on the formal stratigraphical nomenclature of beds from King (1981):

	Thickness (m)
London Clay Formation, Division C (of King, 1981)	
5. Upper Clay (of Venables, 1963)	
Undescribed deposits	6.1
Grey clay with plant remains	0.9
Undescribed deposits	3.5
Pagham Rock	0.6
Clay (partly described, sparsely fossiliferous)	18.6
Cainocrinus Bed	1.2
Pholadomya Bed	0.6
Clay, partly described, with basal glauconitic pebble bed	3.7
London Clay Formation, Division B (of King, 1981)	
4. Barn Rock Bed (of Venables, 1963)	2.4
3. Middle Clay (of Venables, 1963)	
Base of Barn Rock	1.2
Undescribed deposits	1.2
Craigwell Bed	1.5
Undescribed deposits	3.0
3.3. Upper Aldwick Beds (of Venables, 1963)	
Clay with pyritized plant remains	2.4
Two septarian bands	0.6
Clay with pyritized plant remains	1.2
Septarian band (with *Artica planata* in clay)	0.3
Upper Fish-Tooth Bed	1.5
3.2. Clay, unfossiliferous, with septarian band 1 m above base	3.7
3.1. Lower Aldwick Beds (of Venables, 1963)	
Beetle Bed. Clay with septarian band	1.2
Lower Fish-Tooth Bed. Earthy clay, with clay pellets and basal black flint pebble bed	0.6
London Clay Formation, Division A3, Bognor Member (of King, 1981)	
2. Bognor Rock Group (of Venables, 1963)	
Bognor Rock Bed. Interbedded unconsolidated grey sand and partially cemented, fine glauconitic sandstone	6.7
Sandy clay, and soft sandstone	3.0
London Clay Formation, Division A2, Walton Member (of King, 1981)	
1. Lower Clay (of Venables, 1963)	
Septarian band, with white clay,	

iron stained	0.6
'*Cyprina*' Bed	5.5
Starfish Bed	1.8
Clay	1.2
Astarte Bed	2.4
Friable clay	2.7
Clay with occasional pyritized plant remains	2.7
Sandy layer	0.3
Clay, partly described	4.6
Septarian band, with white clay, iron stained	0.3
Dark grey, silty clay	0.6
Deposits obscured by alluvium	3.0

Over 90 m of London Clay is exposed along the Bognor coastline (King, 1981). King (1981) recognized 3 m of the Oldhaven Formation (the London Clay Division A1 being apparently absent; Daley *in* Daley and Balson, 1999) beneath beach sand at the eastern end of the section. The junction between the London Clay and the overlying Bracklesham Group is unexposed (Daley *in* Daley and Balson 1999).

The fish assemblage occurs almost exclusively in the Aldwick Beds of the London Clay Division B, although Venables (1963, pp. 259–60) records the teleost *Cylindracanthus rectus* (Dixon) from the Starfish Bed of Division A3. Division B of King (1981) has a varied fauna and flora, much of which is preserved in pyrite. The invertebrate fauna of the fossiliferous horizons, a silty clay rich in molluscan shell debris, is somewhat different from that of the typical London Clay. Pyrite also occurs abundantly as small grains and nodules thoughout Division B. Amongst the pyritized fossils are insects and beetles (Britton, 1960; Venables and Taylor, 1963), that occur in association with a large assemblage of land-derived seeds and fruit, and fish remains, in the foreshore exposures of Divisions B1 and B2 (King, 1981, p. 73). Although fish remains can be recovered directly from the fossiliferous units, when these are exposed at low tide, some of the best material is found in the natural concentrates of pyritic debris or 'pyrite pools', and the beach sand can itself be sieved for tiny fish teeth and otoliths. Fish material from these accumulations is invariably disarticulated, but the preservation is very good (Figure 14.7). Scattered phosphatic nodules are also common in the Aldwick Beds, and these contain abundant semi-articulated fish remains, as well as crustaceans, nautiloids and reptile material (Daley *in* Daley and Balson, 1999).

Fauna

The fauna listed below is recorded from the classic work of Venables (1963) and lists in Casier (1966) and Ward (1980). Otoliths from this locality have been studied by Stinton (1957, 1965c, 1975–1980).

Chondrichthyes: Elasmobranchii: Neoselachii: Squalomorphii
Heterodontus sp.
Isistius trituratus (Winkler, 1874)
Notorhynchus serratissimus (Agassiz, 1844)
Squalus minor (Leriche, 1902)

Chondrichthyes: Elasmobranchii: Neoselachii: Squatinomorphii
Squatina prima (Winkler, 1874)

Chondrichthyes: Elasmobranchii: Neoselachii: Galeomorphii
Anomotodon sheppeyensis (Casier, 1966)
Carcharias hopei (Agassiz, 1843)
Carcharhinus (Hypoprion) sp.
Galeorhinus lefevrei (Daimeries, 1891)
G. formosus Arambourg, 1952
Heterodontus vincenti (Leriche, 1905)
H. wardenensis Casier 1966
Isurolamna affinis (Casier, 1946) (= *Lamna affinis*, *L. inflata*)
Isurus praecursor (Leriche, 1905)
Jaekelotodus trigonalis (Jaekel 1895)
'*Lamna*' *lerichei* (Casier, 1946) (= *L. vincenti*)
Odontaspis winkleri (Leriche, 1905)
Otodus obliquus Agassiz, 1836
Oxyrhina sp.
Physogaleus secundus (Winkler, 1874) (= *Physodon secundus*, *P. tertius*, *Galeorhinus minor*)
Scyliorhinus gilberti Casier, 1946
'*Scyliorhinus*' *minutissimus* (Winkler, 1873)
'*S.*. *biauriculatus* (Casier, 1950)
Synodontaspis macrotus (Agassiz, 1843)
S. robustus (Leriche, 1905)

Chondrichthyes: Elasmobranchii: Neoselachii: Batomorphii
Burnhamia (Rhinoptera) daviesi (Woodward, 1889)
Dasyatis duponti (Winkler, 1874)
D. tricuspidata Casier, 1946
Myliobatis dixoni Agassiz, 1843
M. toliapicus Agassiz, 1843
Myliobatis sp.

Raja sp.
Chondrichthyes: Holocephali: Chimaeriformes
Elasmodus hunteri Egerton, 1843
Chimaera sp.
Osteichthyes: Actinopterygii: Teleostei: Elopomorpha
Albula oweni Leriche, 1905
Osteichthyes: Actinopterygii: Neopterygii: Euteleostei
Cylindracanthus rectus (Dixon, 1850)
Egertonia isodonta Cocchi, 1866
Eutrichiurides winkleri Casier, 1946
Palaeogadus (Trichiurides) sagittidens (Winkler, 1874)
Sciaenurus bowerbanki Agassiz, 1845
Scomberomorus sp.
Sphyraena sp.
Undifferentiated 'teleosts'
Siluroid spine, cf. *Arius* sp.
Pseudosphaerodon sp.
Platylaemus sp.
Glyptorhynchus sp.

Interpretation

The fish-bearing horizons within the Aldwick Beds of the London Clay at Bognor Regis represent deposition within a nearshore marine environment at the eastern edge of the Hampshire Basin. Depths of less than 70 m have been postulated by Hewitt (1988a, 1988b) based upon his studies of nautilid fossils. A nearshore environment is also suggested by the abundance of well-preserved insect and beetle material (Jarzembowski, 1991) and drifted plant matter (Chandler, 1964). The Bognor assemblages suggest that the palaeoclimate was similar to the humid, subtropical conditions of the Mediterranean (Collinson, 1983).

The list of fossil fishes is impressive, with 34 species of elasmobranchs, two holocephalians and 21 species of actinopterygians (and 26 species of otoliths) at least. In an inshore environment, as is suggested here, the possibility of occasional catastrophic mixing of vertebrate

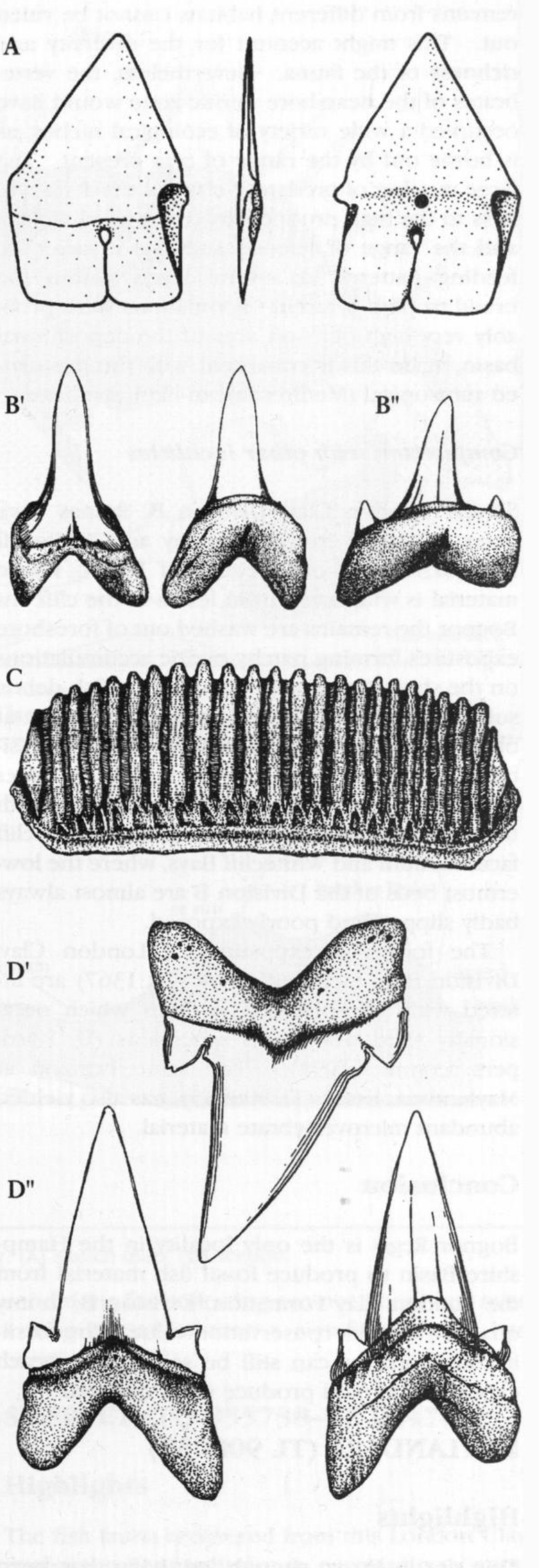


Figure 14.7 Fossil fishes from the London Clay at Bognor Regis. (A) labial, mesial and lingual views of *Isistius triangularis* (Probst), lower lateral tooth (after Capetta, 1987), × 9; (B) *Isurolamna affinis* (Casier): (B') anterior tooth, labial and lingual views × 2; (B") antero-lateral tooth, labial view × 2; (C) *Myliobatis dixoni* Agassiz median tooth, basal view, × 2; (D) *Otodus obliquus* Agassiz: (D') upper lateral tooth labial view × 1; (D") lower anterior tooth, lingual and labial views, × 1. (B)–(D) from Kemp *et al*., 1990).

remains from different habitats cannot be ruled out. This might account for the diversity and richness of the fauna. Nevertheless, the vertebrates of the nearshore neritic zone would have occupied a wide variety of ecological niches, as is borne out by the range of taxa present. The large number of predatory elasmobranchs is witness to the high productivity of the local waters, and the range of teleosts suggests a variety of feeding patterns at several levels within the broad trophic pyramid. Populations were probably very high per unit area of the depositional basin, again this is consistent with the postulated subtropical (Mediterranean-like) conditions.

Comparison with other localities

Similar London Clay, Division B, faunas have been recovered from Alum Bay and Whitecliff Bay (SZ305855) on the Isle of Wight, where material is winnowed from levels in the cliff. At Bognor the remains are washed out of foreshore exposures forming patchy pyritic accumulations on the shoreline. Consequen-tly, the fish debris suffers less abrasion and weathering than at other sites. Fossils are also much more accessible at Bognor as the shallow dip produces wider outcrops along the foreshore, contrasting with the narrow exposures of the near-vertical cliff faces at Alum and Whitecliff Bays, where the lowermost beds of the Division B are almost always badly slipped and poorly exposed.

The foreshore exposures of London Clay, Division B, at Swalecliff, Kent (TR 1367) are littered with phosphatized nodules which occasionally yield whole fish specimens (D. Ward, pers. comm., 1994). The same horizon at Maylandsea, Essex (TL 908035), has also yielded abundant microvertebrate material.

Conclusion

Bognor Regis is the only locality in the Hampshire Basin to produce fossil fish material from the London Clay Formation, Division B, in any quantity, thus its conservation value. The fossiliferous horizons can still be sampled at beach exposures, should produce more material.

MAYLANDSEA (TL 908035)

Highlights

This site in Essex, though low lying, has been remarkably productive. Amongst the 20 or more taxa present are some unique to Maylandsea and may include open-water or deep-water species.

Introduction

The site is situated on Lawling Creek in the Blackwater Estuary; lying in the intertidal zone and the low banks, it forms part of the Blackwater Estuary SSSI. Access is easy, but the intertidal area is given over to thick mud banks. The London Clay Member in this area has been subdivided into lithological units on borehole evidence (Bristow, 1985). These are, however, not distinguishable at the surface. Vertebrate fossils are commonly limited to teeth or other rare hard parts washed free from matrix.

Description

The (Ypresian) London Clay Member outcrops on the banks of the creek, but exposures are small and tend to become masked rapidly with vegetation, soil and other debris. The London Clay here is of Division C fine grained and relatively sand free.

Fauna

Twenty-one taxa have been described from here, mainly based on teeth or otoliths (Stinton, 1966, 1971–1980), but also including a skull and 'gaping jaws' of *Rhinocephalus planiceps*.

Chondrichthyes: Elasmobranchii: Neoselachii: Squalomorphii

Squalus minor (Leriche, 1902)

Chondrichthyes: Elasmobranchi: Neoselachi: Galeomorphi

Scyliorhinus gilberti Casier, 1946

Galeorhinus minor (Agassiz, 1843)

Osteichthyes: Euteleostii: Gadiformes: Gadoidei

Rhinocephalus planiceps Casier, 1946

Interpretation

The London Clay facies at Maylandsea is said to represent the time of maximum transgression of the sea and to include the deposits of the deepest water. The faunal assemblage may well reflect this, with (deeper-water) species that are not seen at Sheppey (q.v.) or any of the other sites.

In common with many of the other

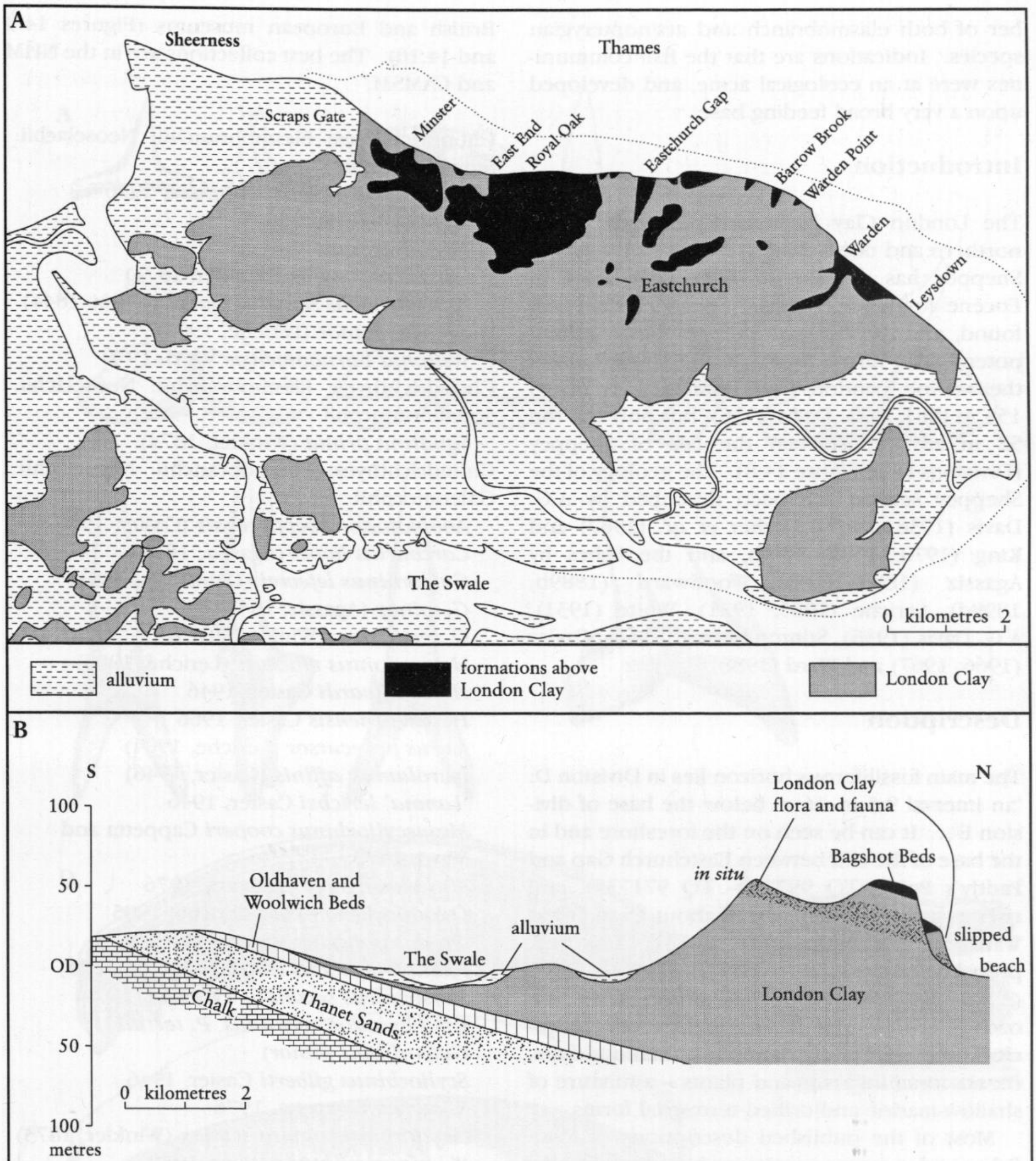


Figure 14.8 The Isle of Sheppey: (A) sketch map, (B) section.

Palaeogene sites described in this volume, this one yields a fauna similar to those known in the Paris Basin, north Belgium–south Holland and north Germany.

Conclusion

This locality provides a small continuing flow of teeth, otoliths and other hard remains of fish, including species not common elsewhere. Local conditions for collecting are not good, but over a long period of time a significant fauna has been recorded.

SHEPPEY (TQ 955738–TR 024717)

Highlights

The fish fauna recovered from this London Clay outcrop in Kent includes an extraordinary number of both elasmobranch and actinopterygian species. Indications are that the fish communities were at an ecological acme, and developed upon a very broad feeding base.

Introduction

The London Clay Formation exposed on the northern and north-eastern shores of the Isle of Sheppey has yielded an important fauna of Eocene fossil vertebrates. Specimens are still found, and the coast of Sheppey has excellent potential for future finds. In the London Basin the marine London Clay Formation is up to 153 m thick (A.G. Davis 1936), but only the top 52 m are exposed on the Isle of Sheppey (Divisions D–E; Figure 14.8). The geology of the Sheppey section has been described by A.G. Davis (1936, 1937), Pitcher *et al*. (1967) and King (1970, 1981, 1984), and the fishes by Agassiz (1833–1845), Woodward (1889b, 1899d), Leriche (1905, 1921), White (1931), A.G. Davis (1936), Stinton (1965c, 1966), Casier (1966, 1967) and Ward (1988).

Description

The main fossiliferous horizon lies in Division D: 'an interval 9.5 m–16 m below the base of division E ... It can be seen on the foreshore and in the base of the cliff between Eastchurch Gap and Paddy's Point (TQ 997730– TQ 971735), and rises eastwards to a height of about 15 m OD at Warden Point' (King, 1981, p. 53). This bed, probably equivalent to bed C of A.G. Davis (1936, 1937), yields molluscs, brachiopods, bryozoans, crustaceans (including decapods, barnacles and ostracods), annelids, echinoderms, corals, foraminiferans and plants – a mixture of shallow-marine and drifted terrestrial forms.

Most of the published descriptions of fossil fishes and museum specimens have little locality information except 'London Clay, Sheppey'. Hooker and Ward (1980, p. 5) noted that fossil vertebrates occur at various points in the section from TQ 955738 to TR 024717. Particular fossil localities include Minster (TQ 955736), Royal Oak (TQ 967757), Bugsby's Hole (TQ 974725), East Church Gap (TQ 997730), Barrow Brook (TR 013718) and Warden Point (TR 021725).

Fauna

Fossil fish from Sheppey are to be found in many British and European museums (Figures 14.9 and 14.10). The best collections are in the NHM and CAMSM.

Chondrichthyes: Elasmobranchii: Neoselachii: Squalomorphii

Hexanchus agassizi Cappetta, 1976
H. hookeri Ward, 1979
H. collinsonae Ward, 1979
Isistius trituratus (Winkler, 1874)
Notorhynchus serratissimus (Agassiz, 1844)
Squalus minor (Leriche, 1902)
Weltonia burnhamensis Ward, 1979

Chondrichthyes: Elasmobranchii: Neoselachii: Squatinomorphii

Squatina prima (Winkler, 1874)

Chondrichthyes: Elasmobranchii: Neoselachii: Galeomorphii

Anomotodon sheppeyensis (Casier, 1966)
Carcharias hopei (Agassiz, 1843)
Galeorhinus lefevrei (Daimeries, 1891)
G. minor (Agassiz, 1843)
G. recticonus (Winkler, 1873)
Heterodontus vincenti (Leriche, 1905)
H. woodwardi Casier, 1946
H. wardenensis Casier, 1966
Isurus praecursor (Leriche, 1904)
Isurolamna affinis (Casier, 1946)
'Lamna' lerichei Casier, 1946
Megascyliorhinus cooperi Cappetta and Ward, 1977
Mustelus whitei Cappetta, 1976
Odontaspis winkleri Leriche, 1905
Otodus obliquus Agassiz, 1843
Palaeohypotodus rutoti (Winkler, 1874)
Physogaleus secundus (Winkler, 1874) (= *Physodon secundus*, *P. tertius*, *Galeorhinus minor*)
Scyliorhinus gilberti Casier, 1946
S. casieri Cappetta, 1976
'Scyliorhinus' minutissimus (Winkler, 1873)
'S.' biauriculatus (Casier, 1950)
Synodontaspis macrotus (Agassiz, 1843)
S. striatus (Winkler, 1874)
Triakis wardi Cappetta, 1976
Xiphodolamia eocaena (Woodward, 1889)

Chondrichthyes: Elasmobranchii: Neoselachii: Batomorphii

Aetobatus irregularis (Agassiz, 1843)
Burnhamia daviesi (Woodward, 1889)
Dasyatis daviesi Casier, 1966
Myliobatis raouxi Arambourg, 1952
M. dixoni Agassiz, 1843
M. latidens Woodward, 1888

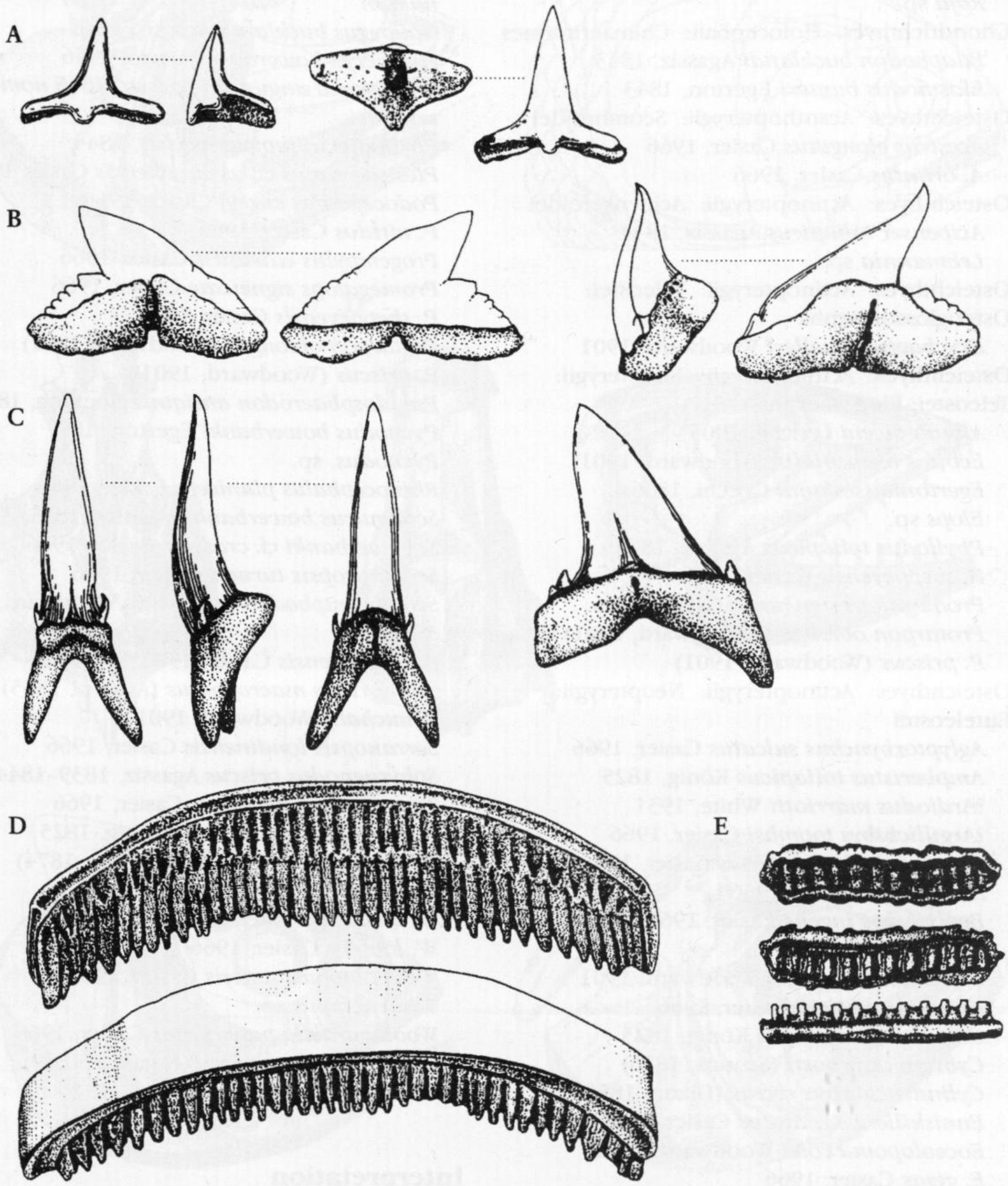


Figure 14.9 Common elasmobranch fossils from the London Clay, as at the Isle of Sheppey (after Kemp *et al.*, 1990). (A) *Squatina prima* (Winkler), lateral tooth (left) and anterior tooth (right), × 2.5. (B) *Physogaleus secundus* (Winkler) female antero-lateral tooth, × 2, lingual and labial views (left) and male antero-lateral tooth, lingual and labial views (right). (C) *Carcharias hopei* (Agassiz), lower anterior tooth, × 1.23, labial lateral and lingual views (left) and upper lateral tooth, lingual view (right). (D) *Aetobatus irregularis* (Agassiz), single tooth from lower dentition, × 1.2, basal and occlusal views. (E) *Burnhamia daviesi* (Woodward), tooth, × 1.25, occlusal, basal and lateral views.

M. toliapicus Agassiz, 1843
Myliobatus sp.
Raja sp.
Chondrichthyes: Holocephali: Chimaeriformes
Edaphodon bucklandi Agassiz, 1843
Elasmodus hunteri Egerton, 1843
Osteichthyes: Acanthopterygii: Scombroidei
Acestrus elongatus Casier, 1966
A. ornatus Casier, 1966
Osteichthyes: Actinopterygii: Acipenseroidei
Acipenser toliapicus Agassiz, 1844
Lehmannia sp.
Osteichthyes: Actinopterygii: Teleostei: Osteoglossomorpha
Brychaetus muelleri Woodward, 1901
Osteichthyes: Actinopterygii: Neopterygii: Teleostei: Elopomorpha
Albula oweni Leriche, 1905
Echilus branchialis (Woodward, 1901)
Egertonia isodonta Cocchi, 1866
Elops sp.
Phyllodus toliapicus Agassiz, 1844
P. sheppeyensis Casier, 1966
Promegalops signeuxae Casier, 1966
Protarpon oblongus (Woodward, 1901)
P. priscus (Woodward, 1901)
Osteichthyes: Actinopterygii: Neopterygii: Euteleostei
Aglyptorhynchus sulcatus Casier, 1966
Ampheristus toliapicus König, 1825
?*Ardiodus marriotti* White, 1931
?*Argillichthys toombsi* Casier, 1966
Aulopopsis depressifrons Casier, 1966
A. egertoni Casier, 1966
Beerichthys ingens Casier, 1966
Beerichthys? sp.
Brychaetus muelleri Woodward, 1901
Bramoides brieni Casier, 1966
Bucklandium diluvii König, 1825
Cybium cf. *proosti* (Storms, 1876)
Cylindracanthus rectus (Dixon, 1850)
Enniskillenus radiatus Casier, 1966
Eoceolopoma colei Woodward, 1901
E. gigas Casier, 1966
E. hopwoodi Casier, 1966
Eothynnus salmoneus (Agassiz, 1844)
Esocelops cavifrons (Agassiz, 1845)
Eutrichiurides winkleri Casier, 1944
Goniocranion arambourgi Casier, 1966
Halecopsis insignis (Delvaux and Ortlieb, 1887)
Hemirhabdorhynchus elliotti Casier, 1966
Labrophagus esocinus Agassiz, 1844
Laparon alticeps Casier, 1966
Lehmanamia sheppeyensis Casier, 1966
'*Myripristis toliapicus*' Agassiz, 1845 *nomen nudum*
Naupygus bucklandi Agassiz, 1844
Paraberyx bowerbanki David, 1946
Percostoma angustum Agassiz, 1845 *nomen nudum*
Phyllodus toliapicus Agassiz, 1844
Plesioserranus cf. *wemmeliensis* Casier 1966
Podocephalus curryi Casier, 1966
P. nitidus Casier, 1966
Progempylus edwardsi Casier, 1966
Promegalops signeuxae Casier, 1966
P. sheppeyensis Casier, 1966
Protarpon oblongus (Woodward, 1901)
P. priscus (Woodward, 1901)
Pseudosphaerodon antiquus Noetling, 1885
Pycnodus bowerbanki Egerton, 1877
Pycnodus. sp.
Rhinocephalus planiceps Casier, 1966
Sciaenurus bowerbanki ?Agassiz, 1845
S. bowerbanki cf. *crassior* Casier, 1966
Sciaenuropsis turneri Casier, 1966
Scombramphodon crassidens Woodward, 1901
S. sheppeyensis Casier, 1966
Scombrinus macropomus (Agassiz, 1835)
S. nuchalis Woodward, 1901
Serranopsis londinensis Casier, 1966
Sphyraenodus priscus Agassiz, 1839–1844
Tamesichthys decipiens Casier, 1966
Teratichthys antiquitatis König, 1825
Trichiurides sagittidens (Winkler, 1874)
Wetherellus brevior Casier, 1966
W. cristatus Casier, 1966
W. longior Casier, 1966
Whitephippus tamesis Casier, 1966
Whitephippus sp.
Woodwardella patellifrons Casier, 1966
Xiphiorhynchus priscus (Agassiz, 1839)
X. parvus Casier, 1966

Interpretation

The London Clay Formation on Sheppey is interpreted by King (1984, p. 121) as a marine deposit laid down in a 'well-oxygenated low-energy shelf environment, varying in depth from *c.* 20 to *c.* 100 metres. Alternation of fine and coarser layers is ascribed to minor sea-level fluctuations. The upper part of the London Clay Formation was deposited in a progressively shallowing environment.'

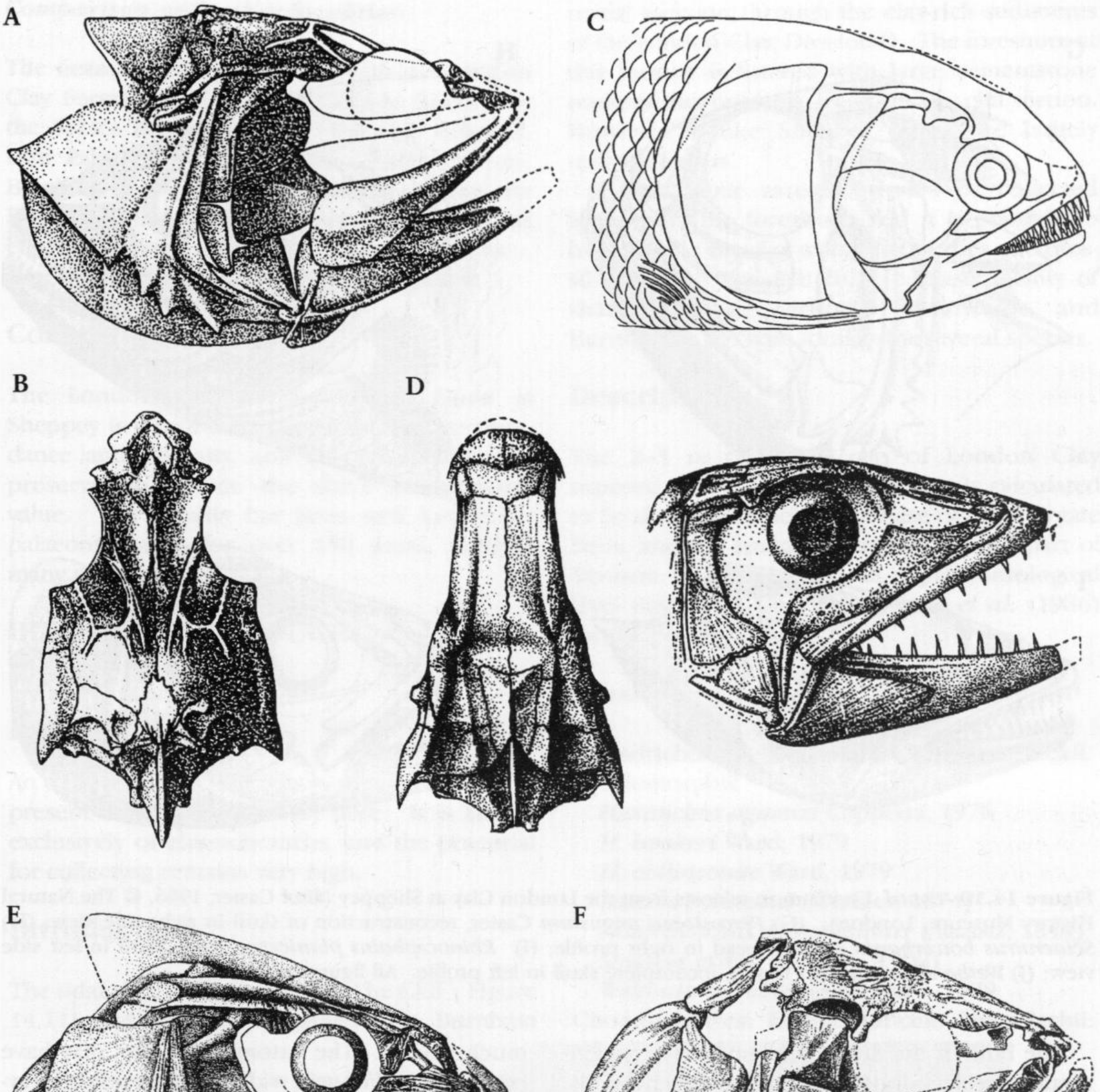


Figure 14.10 Uncommon teleosts from the London Clay at Sheppey (after Casier, 1966, © The Natural History Museum, London). (A), (B) *Ampheristus toliapicus* Konig, reconstruction of the skull, right side and dorsal views; (C) *Brychaetus muelleri* Woodward, right side of head; (D) *Eocoelopoma hopwoodi* Casier, reconstruction of skull in dorsal and right side views; (E) *Eothynnus salmonens* Woodward, reconstruction of head in right side view; (F) *Promegalops signeuxae* Casier, right lateral view of skull. All figures *c.* × 0.5. (Continued on page 514.)

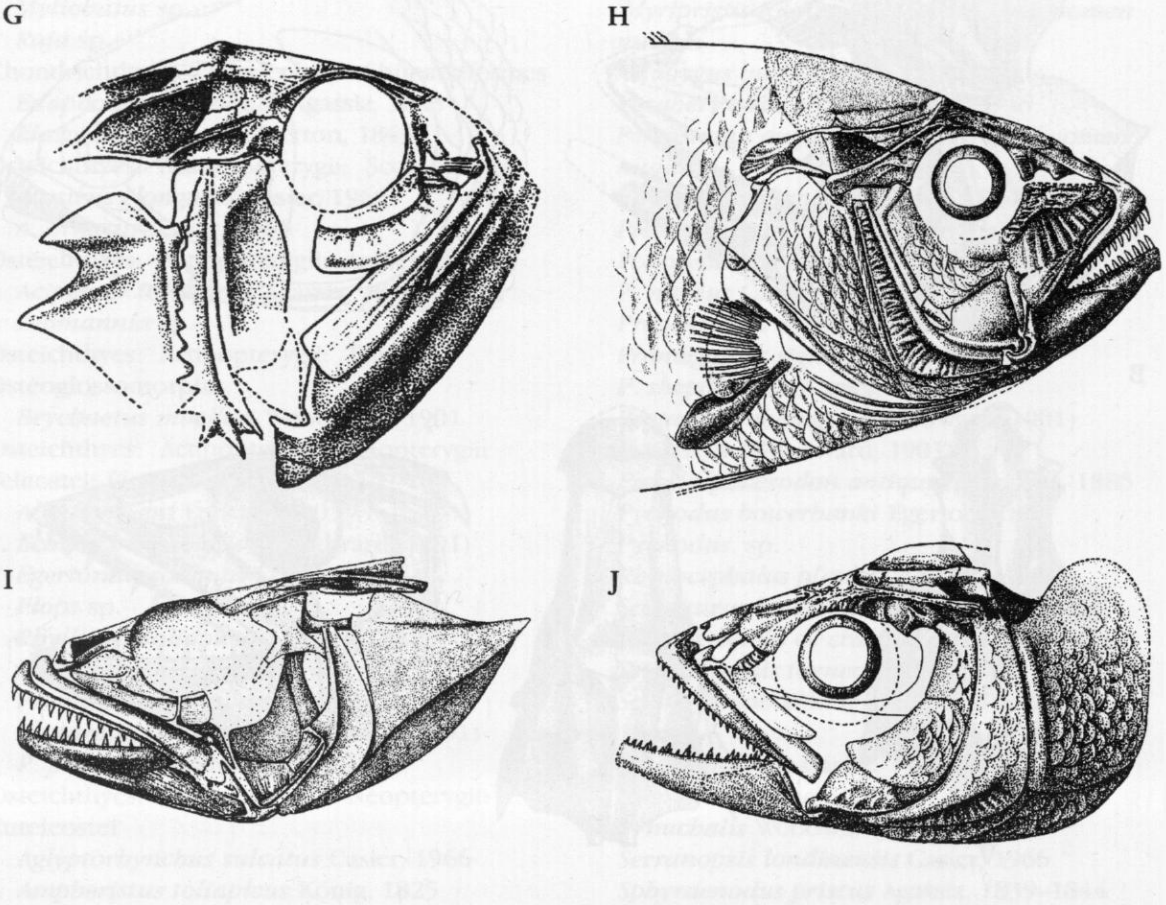


Figure 14.10 *–contd.* Uncommon teleosts from the London Clay at Sheppey (after Casier, 1966, © The Natural History Museum, London). (G) *Percostoma angustum* Casier, reconstruction of skull in right side view; (H) *Sciaenurus bowerbanki* Agassiz, head in right profile; (I) *Rhinocephalus planiceps* Casier, skull in left side view; (J) *Wetherellus cristatus* Casier, incomplete skull in left profile. All figures *c.* × 0.5.

The bulk of the fauna – foraminifera, coelenterates, scolecodonts, serpulids, brachiopods, bryozoans, benthic molluscs, pteropods, ostracods, crustaceans and echinoderms were predominantly epifaunal or infaunal in habit. The fishes and turtles were indigenous marine forms, but the remainder (as with wood, leaves, pollen and spores and insects) may have been washed in.

The abundance of elasmobranch fishes indicates a great range of predatory forms attracted to the wealth of small animals present, especially the benthos. The primitive squalomorphs were probably bottom-dwelling forms, like the extant dogfishes. *Squatina prima* is present, as in almost all the sites described and is the single squatinomorph, but the galeomorph sharks were in great variety as active fusiform-bodied predators. Their prey presumably included much nekton. The batomorphs, too, may have been, like *Myliobatis*, widespread benthonic ray-like animals. Teleosts, though by no means rare, are by contrast poorly represented, perhaps for overall reasons of taphonomy.

Allison (1988) has studied the taphonomy of the prolific and diverse London Clay biota at Sheppey. He found that apatite was the first preservational mineral to form, followed by calcite and pyrite. Only those organisms with an original phosphate content (such as the vertebrates) have become phosphatized. Organisms preserved during the earliest phase of mineralization retain the most detail. Soft-part preservation is very rare while the hard parts are almost always preserved in three dimensions within the pyrite and calcium phosphate concretions (Casier, 1966; Ward, 1979).

Comparison with other localities

The nearest comparable units with the London Clay Formation of Sheppey outside Britain are the Sables de Erquelinnes (Hainaut, Belgium; Late Palaeocene), the Argile d'Ypres (France, Belgium; Early Eocene), and the Sables de Bruxelles (Belgium; Mid-Eocene), as well as equivalent-age units in France, Morocco, Nigeria, Mali and the eastern United States.

Conclusion

The London Clay Formation fish fauna at Sheppey is important for both its relative abundance and diversity, and the good quality of preservation, hence the site's conservation value. The locality has been well known by palaeontologists for over 150 years, yielding many type specimens.

BURNHAM-ON-CROUCH (TQ 921967)

Highlights

An extraordinarily rich assemblage of fish taxa is present in the London Clay here. It is almost exclusively of elasmobranchs, and the potential for collecting remains very high.

Introduction

The tidal river cliffs (known as 'The Cliff'; Figure 14.11) and foreshore exposures at Burnham reveal asection through the clay-rich sediments of the London Clay, Division D. The foreshore at this locality is littered with large cementstone nodules that originate from the low cliff section. However, unlike Sheppey, these are largely unfossiliferous.

A rich biotic assemblage can be collected loose from the foreshore, and it is possible to bulk sample the clay matrix for further microfossil remains. The fish fauna consists mainly of sharks, and in particular hexanchids, and Burnham is the type locality for several species.

Description

The 2–3 m thick outcrop of London Clay exposed in 'The Cliff' at Burnham is calculated to be about 26 m below the base of the Claygate Beds, and the strata falls within the top part of Division D (King, 1981), at a palaeontological level defined as Unit P13 by Lake *et al*. (1986) for the Southend area.

Fauna

Chondrichthyes: Elasmobranchii: Neoselachii: Squalomorphii

Hexanchus agassizi Cappetta, 1976
H. hookeri Ward, 1979
H. collinsonae Ward, 1979
Isistius trituratus (Winkler, 1874)
Notorhynchus serratissimus (Agassiz, 1844)
Squalus minor (Leriche, 1902)
Weltonia burnhamensis Ward, 1979

Chondrichthyes: Elasmobranchii: Neoselachii:

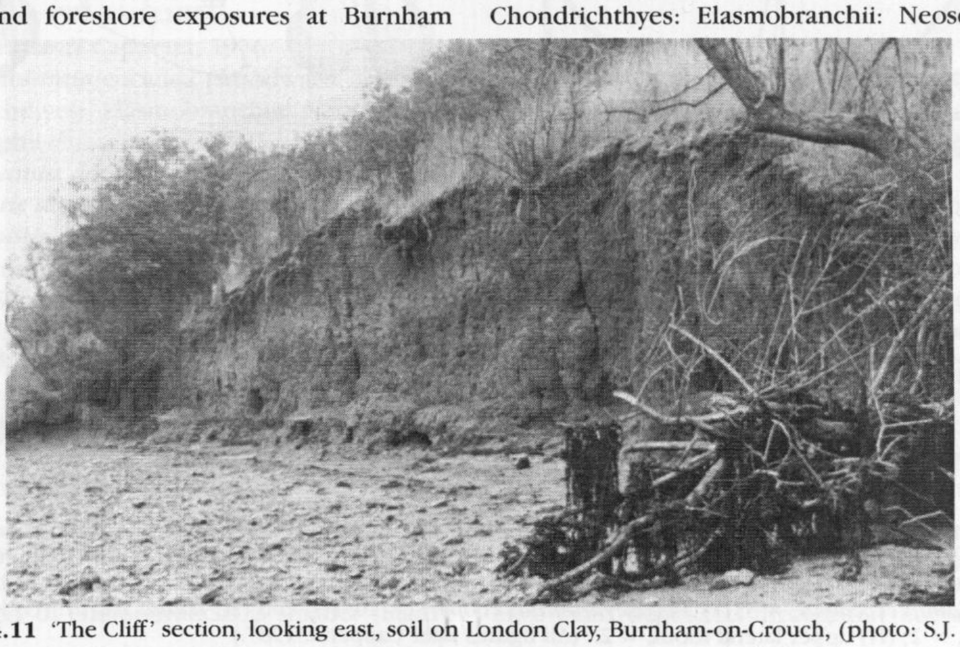


Figure 14.11 'The Cliff' section, looking east, soil on London Clay, Burnham-on-Crouch, (photo: S.J. Metcalf).

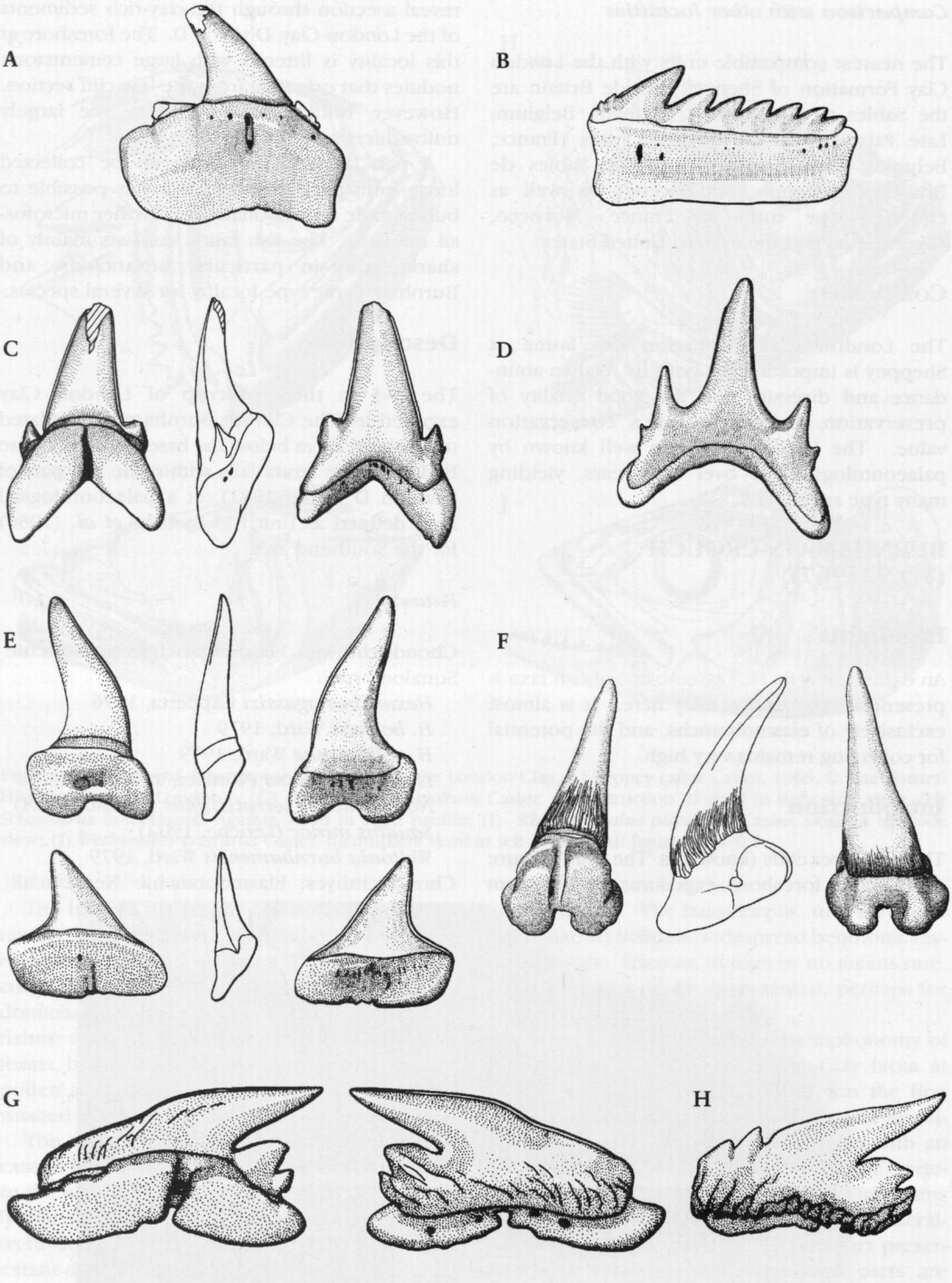


Figure 14.12 Chondrichthyes from Sheppey and Burnham-on-Crouch. Sheppey: (A) *Notorhynchus serratissimus* upper anterolateral tooth, × 5. Burnham-on-Crouch: (B) *Hexanchus agassizi*, lower lateral tooth, × 5; (C) *Hypotodus verticalis*, lower anterior tooth, × 4; (D) *Odontaspis winkleri*, lower lateral tooth, × 4; (E) *Xiphodlamia ecocaena*, × 3; (F) *Megascyliorhinus cooperi*, × 10; (G) and (H) *Triakis wardi*: (G) lower lateral tooth, × 2; (H) upper lateral tooth, × 2. (All figures after Cappetta, 1987.)

Squatinomorphii
Squatina prima (Winkler, 1874)
Chondrichthyes: Elasmobranchii: Neoselachii: Galeomorphii
Alopias crochardi Ward, 1978
Anomotodon sheppeyensis (Casier, 1966)
Carcharias hopei (Agassiz, 1843)
Galeorhinus lefevrei (Daimeries, 1891)
G. minor (Agassiz, 1843)
G. recticonus (Winkler, 1873)
Heterodontus vincenti (Leriche, 1905)
H. woodwardi Casier, 1946
Isurus praecursor (Leriche, 1904)
Isurolamna affinis (Casier, 1946)
Jaekelotodus trigonalis (Jaekel, 1895)
'*Lamna*' *lerichei* Casier, 1946
Megascyliorhinus cooperi Cappetta and Ward, 1977
Mustelus whitei Cappetta, 1976
Odontaspis winkleri (Leriche, 1905)
Otodus obliquus Agassiz, 1836
Palaeohypotodus rutoti (Winkler, 1874)
Palaeorhincodon wardi (Herman, 1975)
Pararhincodon ypresiensis Cappetta, 1976
Physogaleus secundus (Winkler, 1874)
P. tertius (Winkler, 1874)
Scyliorhinus gilberti Casier, 1946
S. burnhamensis Cappetta, 1976
S. casieri Cappetta, 1976
S. pattersoni Cappetta, 1976
S. woodwardi Cappetta, 1976
'*Scyliorhinus*' *minutissimus* (Winkler, 1873)
'*S.*' *biauriculatus* (Casier, 1950)
Synodontaspis macrotus (Agassiz, 1843)
S. striatus (Winkler, 1874)
Triakis wardi Cappetta, 1976
Xiphodolamia eocaena (Woodward, 1889)
Chondrichthyes: Elasmobranchii: Neoselachii: Batomorphii
Burnhamia daviesi (Woodward, 1889)
Dasyatis davisi Casier, 1966
Myliobatis raouxi Arambourg, 1952
M. dixoni Agassiz, 1843
M. latidens Woodward, 1888
M. toliapicus Agassiz, 1843
Myliobatus sp.
Raja harrisae Ward, 1984
Raja sp.

Interpretation

Much that has been said for the Sheppey site can be repeated here, although the overall number and variety of elasmobranchs is smaller (Figure 14.12). Active galaeomorphs were the most abundant, but squalomorphs and batomorphs were common in the middle and lower (bottom) waters respectively. *Squatina prima* again is present.

Comparison with other localities

Burnham-on-Crouch yields a similar fauna, in terms of composition and age, to that from the London Clay series (Division D) of Sheppey (q.v.). However, at Burnham the fish fossils occur free within the clay matrix and can be extracted by bulk sampling methods. Therefore, although whole fossil fishes are not found in nodules, the scattered bones and teeth are recovered in a much better state than similar remains recovered from Sheppey exposures.

Conclusion

Although the London Clay at this site is no more than 3 m thick, the conservation value of the site is derived from its very large fauna of macrofossils, both vertebrate and invertebrate. The vertebrate material corresponds to that of the London Clay, division D, at Sheppey. The fact that many taxa are poorly known, despite being first recorded many years ago, should stimulate collecting from a site which is relatively accessible and easy to work.

LATE PALAEOGENE OF THE HAMPSHIRE BASIN

Deposition of the Tertiary sediments of the Hampshire Basin (including the Isle of Wight) began slightly later than in the London Basin, with the Late Palaeocene Reading Formation, the Early Eocene London Clay Formation, and the Early to Late Eocene Bracklesham Group (Insole and Daley, 1985; Edwards and Freshney, 1987). These deposits represent a major Late Palaeocene–Early Eocene marine transgression from the North Sea over East Anglia and south-eastern England as far west as Dorset. The sequence in the Hampshire Basin spans from the latest Palaeocene to the Mid-Oligocene, and it consists of lateral equivalents of the Belgian and Paris basins including sands, clays and thick deposits of lignite.

The Bracklesham Group is comprised of marine and continental facies that appear to have been deposited throughout Eocene time.

The marine units of the Group are restricted to the east, while in the Isle of Wight it is in part continental, and the commonest fossils are leaves and palynomorphs. The succeeding 'Barton Sands' and lower part of the Headon Hill Formation (Totland Bay Member; Late Eocene) are marine in the lower section and broadly continental toward the top. The upper parts of the Headon Hill Formation (Colwell Bay Member to Seagrove Bay Member; latest Eocene), and the Bembridge Limestone and Bouldnor formations (Early to Mid-Oligocene), which is confined to the north of the Isle of Wight, consist of mainly continental facies, with rare marine-influenced units in the Cranmore Member of the Bouldnor Formation (Insole and Daley, 1985). This whole sequence, barring the 'Barton Sands' at the base, is placed in the Solent Group (Insole and Daley, 1985).

Fossil fishes are relatively common within all divisions of the Bracklesham Group, the Barton Clay and Headon Hill Formation (Hooker and Ward, 1980). Rare amphibian remains have also been found in Barton Clay of Barton Cliff (q.v.; Milner, 1986) and Headon Hill Formation at Hordle Cliff (q.v.) and Headon Hill (q.v.; Rage and Ford, 1980; Meszoely *et al.*, 1984; Milner *et al.*, 1982). Fish material is rarer in the overlying Osborne Beds, Bembridge Marls and Hampstead Beds of the Isle of Wight. Most finds are tiny fish teeth, scales and teleost otoliths, and are usually recovered by bulk sampling of the unconsolidated sediments. Amphibians and small reptile remains have been recorded from the Osborne Beds in the Fishborne area of the Isle of Wight (SZ 537941–SZ 556934) (Rage and Ford, 1980) and a Lower Oligocene amphibian assemblage is preserved in foreshore exposures of the Lower Hamstead Beds at Cranmore Ledge, Bouldnor Cliff, Isle of Wight (SZ 370900–SZ 405920; Milner, 1986).

Collections of Late Palaeogene fossil fish are in the NHM. A brief *Illustrated Guide to the British Middle Eocene Vertebrates* (Kemp *et al.*, 1990) and a guide to the fossils of the Bracklesham Beds (Bone, 1985) have been published privately.

FISH SITES

Sporadic fish material has been recovered from many localities spread throughout the entire Hampshire Basin Late Palaeogene outcrop, and in exposures on the Isle of Wight. However, most of these sites have only yielded fragmentary remains of one or two fish species and thus, only the more significant ones are listed below (taken mainly from Hooker and Ward, 1980).

HAMPSHIRE: Yateley (Bracklesham Group, Earnley Formation; SU 826611; 29 species; James, Ward and Cooper, 1976); Lee-on-Solent (Bracklesham Group, Marsh Farm and Huntingbridge Division; SU 552014–SU 563002; over 50 species; see report); Highcliffe, Christchurch (Barton Clay, Beds A1–3; SZ 199928–SZ 224930; 33 species and one frog vertebra referable to 'discoglossid 1' of Milner *et al.*, 1982; Burton, 1929; Ward, 1980; Milner, 1986); Barton Cliff, Christchurch (Barton Clay, Beds B–H; SZ 218930–252925; 24 species; see report); Taddiford–Long Mead End, Milford (Barton Beds, Barton Sand I–K; SZ 251925–SZ 263923; 11 species; Burton, 1929, 1933); Hordle Cliff (Headon Hill Formation; Lower–Middle Headon Beds; SZ 263923–SZ 273918; nine species of fish, four species of amphibian; see report); Park Hill, Lyndhurst (Headon Hill Formation, Middle Headon Beds, *Venus* Bed; SU 302058; ten species; Ward, 1980).

ISLE OF WIGHT: Whitecliff Bay (London Clay–Osborne Beds; SZ 638898; 19 species; Fisher, 1862; White, 1921); Headon Hill (Headon Hill Formation, Lower-Upper Headon Beds and Osborne Beds; SZ 315858–SZ 318862; three species of fish, four species of amphibian; see report); Colwell Bay (Headon Hill Formation, Middle Headon Beds, *Venus* and Oyster Bed; SZ 327878–SZ 328881; ten species; White, 1921); Wotton Creek, Fishbourne (Osborne Beds; SZ 5592; one species of discoglossid frog; Rage and Ford, 1980); Kingsquay (Osborne Beds; SZ 538941–SZ 556934; two species; see report); Bouldnor Cliff, Hamstead (Hamstead Beds; SZ 370900–SZ 405920; two species of fish, five species of amphibian; Milner, 1986).

SUSSEX: Bracklesham Bay (Bracklesham Group, Wittering–Selsey Divisions; SZ 823951–SZ 825947; over 160 species; see report); Selsey (Bracklesham Group, Selsey Division; SZ 825947–SZ 843932; 18 species; Curry *et al.*, 1978).

Six sites are selected as GCR sites on the basis of their important Late Eocene fish faunas:

1. Bracklesham Bay, West Sussex (SZ 823951–SZ 825947). Early–Middle Eocene, Bracklesham Group (Wittering, Earnley, Marsh Farm and Selsey Divisions).
2. Lee-On-Solent, Hampshire (SU 552014–SU 563002). Middle Eocene, Bracklesham Group (Marsh Farm and Huntingbridge Division).
3. Barton Cliff, Hampshire (SZ 218930–SZ 252925). Late Eocene, Barton Clay, Beds B–H.
4. Hordle Cliff, Hampshire (SZ 263923–SZ 273918). Late Eocene, Headon Hill Formation, Lower and Middle Headon Beds.
5. Headon Hill, Isle of Wight (SZ 315858–SZ 318862). Late Eocene–Early Oligocene, Headon Hill Formation (Lower, Middle and Upper Headon Beds) and Osborne Beds. This site is reported in Chapter 15 where it is treated as one for amphibians.
6. Kings Quay, Isle of Wight (SZ 538941–SZ 556934). Late Eocene–Early Oligocene, Osborne Beds.

BRACKLESHAM BAY (SZ 823951–SZ 825947)

Highlights

This locality in the mid-Eocene Bracklesham Group of the Hampshire Basin in West Sussex has yielded over 160 described species of fossil fish. It continues as a productive site, even after intense collecting for over 100 years. The number of chondrichthyans is unsurpassed for beds of this age in Britain.

Introduction

Historically, Bracklesham Bay has been an important Tertiary fossil fish site since the mid-19th century. The numerous fish species have been listed from the Bracklesham Group exposed along the foreshore, and Bracklesham Bay is the type location for a great many of these. Fish material is still actively collected from the foreshore exposures and there is still some potential for future finds to be made.

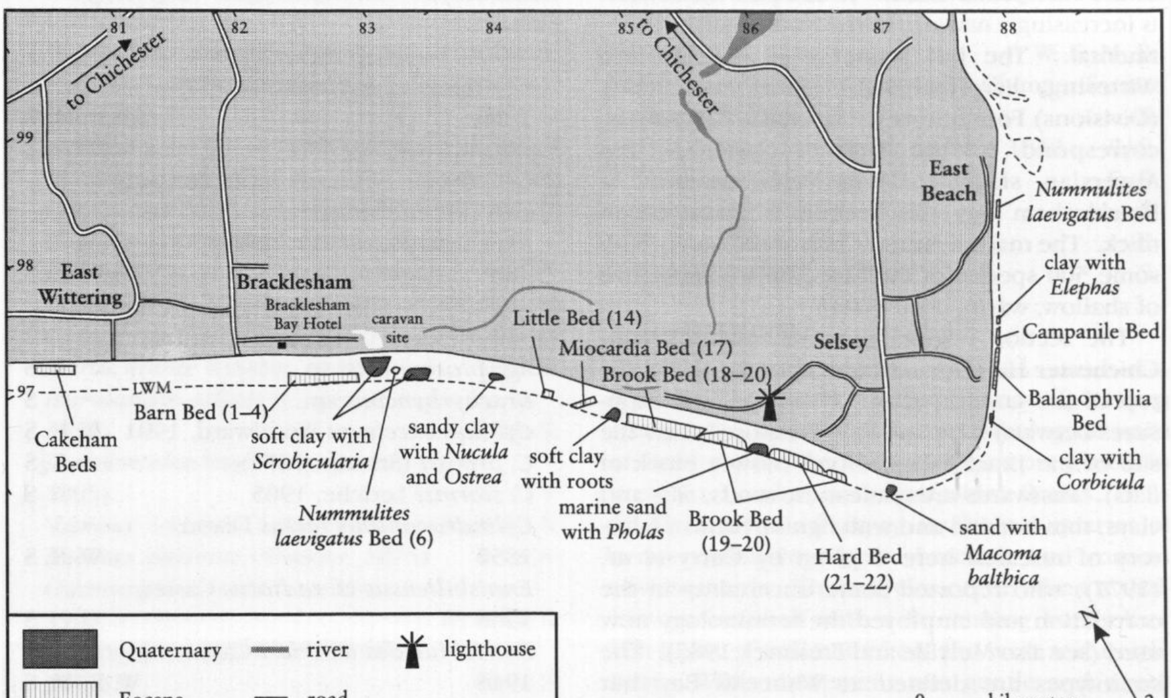


Figure 14.13 Sketch map of the foreshore at Bracklesham Bay, West Sussex (after Curry *et al.*, 1977).

In recent years, the introduction of coastal defence measures has greatly reduced the exposure of the fossiliferous beds above high tide levels on the beach. However, scattered vertebrate debris can still be collected from combing the strandline and exceptionally low tides expose the fish beds.

Description

As recorded by Curry (*in* Curry and Wisden, 1958) and Curry *et al*. (1977), the Bracklesham Beds occur along the sea coast of the Selsey Peninsula from Chichester Harbour to Pagham Harbour, though they are locally much obscured by recent beach deposits. Exposure of the solid geology depends on the state of the tide and the shifting beach sands and shingle. The map (Figure 14.13) provided by Curry (*in* Curry and Wisden, 1958. and updated Curry *et al*., 1977) remains a useful guide to the locality where a total section of about 105 m is revealed. The current stratigraphical practice is to recognize both marine and continental beds within the Bracklesham Group throughout the central part of the Hampshire Basin. To the east the section is increasingly marine; to the west it is more continental. The full sequence is divided into Wittering, Earnley, Marsh Farm and Selsey (Divisions) Formations (Cooper, 1976b), said to correspond to the Cuisian, Lutetian and Auversian stages of the Paris Basin. At Bracklesham Bay this section is about 90 m thick. The marine fauna is rich and diverse, with some 500 species of molluscs, mostly indicative of shallow, warm, clear water.

The section begins some way south-east of Chichester Harbour entrance, not far above the top of the London Clay. There are few exposures between here and the foreshore below the site of the Bracklesham Hotel (now a block of flats). Eastwards are glauconitic sands, silts and clays, thin-bedded and with lignitic bands. A history of research here is given by Curry *et al*. (1977), who reported some uncertainty in the correlation and employed the terminology now used (see also Melville and Freshney, 1982). The stratotypes are defined at Whitecliff Bay, but Curry *et al*. (1977) have presented a log of the Bracklesham Bay succession based on detailed mapping of the foreshore of the Bay and on East Beach, Selsey. Vertebrate fossils are present at many levels, commonly in coarse sands. Although reptiles and mammals are represented by a variety of bones and teeth, the fish remains are preponderantly isolated teeth.

Fauna

Fauna in the Bracklesham Group at Bracklesham Bay:

W = Wittering Formation; E = Earnley Sand Formation; M = Marsh Farm Formation; S = Selsey Sand Formation.

Osteicthyes: Actinopterygii: Chondrostei: Acipenseroidei

Acipenser toliapicus Agassiz, 1844	E; S

Osteichthyes: Actinopterygii: Neuropterygii: Ginglymodi

Lepisosteus suessionensis Gervais, 1888	W; E; M; S

Osteichthyes: Actinopterygii: Neopterygii: Amiiformes

Amia sp.	E; M; S

Osteichthyes: Actinopterygii: Neopterygii: Siluriformes

Arius egertoni (Dixon, 1850)	W; E; S

Osteichthyes: Actinopterygii: Neopterygii: Elopomorpha

Albula oweni Leriche, 1905	W; E; S
Egertonia cf. *isodonta* Cocchi, 1866	W; E; M; S
Phyllodus sp.	W; E; S

Osteichthyes: Actinopterygii: Neopterygii: Pyncnodontiformes

Pycnodus toliapicus Agassiz, 1833	W; E; M; S

Osteichthyes: Acanthopterygii: Percomorpha: Scombroidei

Aglyptorhynchus sp.	E; S
Brachyrhynchus sp.	S
Cybium excelsum Woodward, 1901	W; E; S
C. proosti (Storms, 1876)	E; S
C. stormsi Leriche, 1905	S
Cylindracanthus rectus Dixon, 1850	W; E; S
Enniskillensus cf. *radiatus* Casier, 1966	S
Eutrichiurides winkleri Casier, 1946	W; E; M; S
E. sp.	W; E
Sphyraenodus lerichei ?Agassiz, 1844	E; S
Palaeogodus (Trichiurides) sagittidens (Winkler, 1874)	W; E; M; S
Trichiurus gulincki Casier, 1967	W; E; S
Xiphiorhynchus sp.	E; S

Osteichthyes: Acanthopterygii: Perciformes: Labroidei
Labrus eocaenus ?Casier, 1966 S
Platylaemus colei Dixon, 1850 W; E; M; S
Pseudosphaerodon antiquus Casier, 1966 E; S

Osteichthyes: Acanthopterygii: Perciformes: Percoidei
Prolates sp. E; S
Sparus sp. W; E; M; S

Osteichthyes: Acanthopterygii: Perciformes: Sphyraenidei
Sphyraena striata ?Agassiz, 1843 E; S

Osteichthyes: Acanthopterygii: Tetradontiformes: Tetradontoidei
Eotrigodon serratus (Gervais, 1852) W; E; S
E. sp. S
Ostracion cf. *meretrix* Daimeries, 1888 E; S
Triodon antiquus ?Agassiz, 1844 W; E; S

Chondrichthyes: Elasmobranchii: Neoselachii: Squalomorphii
Heterodontus vincenti (Leriche, 1905) E
Isistius trituratus (Winkler, 1874) E; S
Squalus minor (Leriche, 1902) W; E; S

Chondrichthyes: Elasmobranchii: Neoselachii: Squatinomorphii
Squatina prima (Winkler, 1874) W; E; S

Chondrichthyes: Elasmobranchi: Neoselachii: Galeomorphii
Carcharocles (Procarcharodon) auriculatus (de Blainville, 1818) E; S
Carcharias hopei (Agassiz, 1843) W; E; M; S
Galeocerdo latidans Agassiz, 1843 W; E; S
Galeorhinus minor (Agassiz, 1843) W
G. recticonus (Winkler, 1873) W
G. formosus Arambourg, 1952 W
Isurus novus Winkler, 1874 W; E; M
Isurolamna affinis (Casier, 1946) W; E; M; S
Jaekelotodus trigonalis (Jaekel, 1895) W; E; S
'*Lamna*' *lerichei* Casier, 1946 W; E; M; S
Nebrius thielensi (Winkler, 1873) W; E; S
Odontaspis winkleri Leriche, 1905 W; E; M; S
Physogaleus secundus (Winkler, 1874) W; E; S
P. tertius (Winkler, 1874) W
'*Scyliorhinus*' *minutissimus* (Winkler, 1873) W
'*S.*' *biauriculatus* (Casier, 1950) W
Synodontaspis macrotus (Agassiz, 1843) W
S. striatus (Winkler, 1874) W

Chondrichthyes: Elasmobranchii: Neoselachii: Batomorphii
Aetobatus irregularis Agassiz, 1843 W; E; M; S
Archeomanta melenhorsti Herman, 1979 W; E; M; S
Burnhamia daviesi (Woodward, 1889) W; E; M; S
Dasyatis duponti (Winkler, 1874) W; E
D. jaekeli (Leriche, 1905) W; E
D. tricuspidatus Casier, 1946 W; E; M; S
D. spp. W
Gymnura sp. M
aff. *Gymnura* sp. M
Heterotorpedo fowleri Ward, 1983 M
Myliobatis dixoni Agassiz, 1843 W; E; S
M. latidens Woodward, 1888 E; S
M. nzadinensis (Darteville and Casier, 1943) W
M. striatus Buckland, 1837 W; E; S
M. toliapicus Agassiz, 1843 W; E; M; S
M. sp. W; M
Pristis lathami Galeotti, 1837 W
P. sp. W
Rhinobatos bruxelliensis Jaekel, 1894 W
Rhinoptera sherborni White, 1926 W; S
Rhynchobatus vincenti (Jaekel, 1894) W; E; M; S

Chondrichthyes: Holocephalii: Chimaeriformes
Amylodon sp. S
Edaphodon bucklandi Agassiz, 1843 E; S
E. leptognathus Agassiz, 1843 E; S
E. minor S
E. munsteri E
E. kempi Ward, 1976 S

Interpretation

The Bracklesham (= Bournemouth) Group comprises a number of distinct lithological units of Early to Middle Eocene age, represented in both the London and Hampshire Basins. It is locally a series of clayey sands in a quartet of cycles containing fresh, brackish and marine environments. These cycles occurred on a shallow-marine shelf with a fluctuating but unbroken input of sediment from the west and north-west. Water movement was gentle and depth was generally less than 100 m, with widespread seaweed thickets and lawns, and areas of local calcalgal and foraminiferal production. The sea was relatively clear and warm (about 18°C) and of slightly reduced salinity. Water movement was gentle. The molluscan fauna was locally very prolific and indicative of a high organic productivity. This provided a substantial food base for both chondrichthyan and osteichthyan fishes, with abundant opportunity to occupy all manner of shallow-water environments and feeding niches, whether bottom or midwater sited.

The sheer variety and number of chondrichthyan taxa and individuals suggest that populations were high, feeding easy and climatic conditions stable. The preserved fish fauna was at its most diverse and abundant during Wittering Division time and diminished to a minimum by that of the Selsey Division. Changing environment affecting modes of life and fossil preservation may have been responsible. The batomorphs and galeomorphs predominate, but there is a good representation of chimaeroids throughout. There are fewer osteichthyans but the numerous teeth suggest both predators (*Albula*, *Egertonia*, etc.) and shell-crushing feeders (*Eutrichiurides*, *Sphyraenodus*, etc.) abounded.

Comparison with other localities

This locality is unique in its productivity of fossils and is the same age as others nearly as fossiliferous in the Paris Basin and in Belgium. In localities to the west, as at Alum Bay, Isle of Wight, and in Dorset, the beds are sandier and less fossiliferous; plants are, however, common there. In the London Basin, the Bagshot Formation is far less fossiliferous.

Conclusion

The conservation value of this highly fossiliferous site is derived from its unique record of chondrichthyan species of this Early–Mid-Eocene age. It remains worthy of further collecting and attention to its palaeoecology.

LEE-ON-SOLENT (SU 552014–SU 563002)

Highlights

This site offers a range of chondrichthyan taxa comparable to that described immediately above. It has a very good range of teleost otoliths, in addition to the abundant selachian teeth and other remains.

Introduction

A diverse vertebrate fauna has been recovered from several levels within the uppermost beds of the Bracklesham Group on the lower foreshore at Lee-on-Solent. The fauna is particularly rich in shark teeth and the site has yielded over 30 species of selachians. Chimaeroids, which are poorly known elsewhere in the Middle Eocene, are represented at Lee by five species, including the type of *Elasmodus kempi* Ward, 1976. Teleost otoliths are extremely well represented in the fossiliferous beds.

Description

The vertebrate-bearing beds occur within the uppermost part of the Bracklesham Group, the Selsey and Huntingbridge Divisions of Fisher (1862). The vertebrate fauna is composed of mammals, reptiles, birds and fishes, in association with a diverse invertebrate fauna in which crustacea and molluscs predominate.

Fauna

Marsh Farm Formation

Chondrichthyes: Elasmobranchii: Neoselachii: Squalomorphii

Heterodontus vincenti (Leriche, 1905)
H. woodwardi Casier, 1946
Isistius trituratus (Winkler, 1874)
Notorhynchus kempi Ward, 1979
Squalus minor (Leriche, 1902)

Chondrichthyes: Elasmobranchii: Neoselachii: Squatinomorphii

Squatina prima (Winkler, 1873)

Chondrichthyes: Elasmobranchii: Neoselachii: Galeomorphii

Alopias leeensis Ward, 1978
Carcharias hopei (Agassiz, 1843)
Carcharinus sp.
Carcharocles auriculatus (de Blainville, 1818)
Eostegostoma angusta (Nolf and Taverne *in* Herman, 1977)
Galeocerdo latidens Agassiz, 1843
Galeorhinus minor (Agassiz, 1835)
G. recticonus (Winkler, 1874)
G. cf. *ypresiensis* (Casier, 1946)
Hemiscyllium bruxelliensis (Herman, 1977)
Isurus praecursor (Leriche, 1904)
Isurolamna affinis (Casier, 1946)
Jaeckelotodus trigonalis (Jaekel, 1895)

'Lamna' lerichei Casier, 1946
Nebrius thielensi (Winkler, 1873)
Odontaspis winkleri (Leriche, 1905)
Physogaleus secundus (Winkler, 1874)
P. tertius (Winkler, 1874)
Scyliorhinus gilberti Casier, 1946
S. pattersoni Cappetta, 1977
Scyliorhinus spp.
'Scyliorhinus' minutissimus (Winkler, 1873)
'S.' biauriculatus Casier, 1950
'Scyliorhinus' sp.
Synodontaspis macrotus (Agassiz, 1843)
S. acutissima (Agassiz, 1843)
S. striatus (Winkler, 1874)

Chondrichthyes: Elasmobranchii: Neoselachii: Batomorphii
Aetobatus irregularis Agassiz, 1843
Aetobatus sp.
Burnhamia davesi (Woodward, 1889)
Dasyatis duponti (Winkler, 1847)
D. jaekeli (Leriche, 1905)
Dasyatis sp.
Myliobatis dixoni Agassiz, 1843
M. latidens Woodward, 1888
M. nzadinensis (Dartevelle and Casier, 1943)
M. striatus Buckland, 1837
M. toliapicus Agassiz, 1843
Myliobatis sp.
Pristis lathami (Galeotti, 1837)
Pristis sp.
Propristis schweinfurthi Dames, 1883
Rhinobatos bruxelliensis (Jaekel, 1894)
Rhinoptera sherbourni White, 1926
Rhynchobatus vincenti (Jaekel, 1894)

Chondrichthyes: Holocephali: Chimaeriformes
Amylodon venablesae (Casier, 1966)
Callorhinchus newtoni Ward, 1973
Edaphodon bucklandi (Agassiz, 1843)
E. leptognathus Agassiz, 1843
Elasmodus kempi Ward, 1976

Huntingbridge Division

Chondrichthyes: Elasmobranchii: Neoselachii: Squalomorphii
Heterodontus vincenti (Leriche, 1905)
H. woodwardi Casier, 1946
Notorhynchus kempi Ward, 1979
Squalus minor (Leriche, 1902)
Isistius trituratus (Winkler, 1874)

Chondrichthyes: Elasmobranchii: Neoselachii: Squatinomorphii
Squatina prima (Winkler, 1873)

Chondrichthyes: Elasmobranchii: Neoselachii: Galeomorphii
Carcharias hopei (Agassiz, 1843)
Galeocerdo latidens Agassiz, 1843
Galeorhinus minor (Agassiz, 1835)
G. recticonus (Winkler, 1874)
G. cf. *ypresiensis* (Casier, 1946)
Hemiscyllium bruxelliensis (Herman, 1977)
Isurus praecursor (Leriche, 1904)
Isurolamna affinis (Casier, 1946)
Jaeckelotodus trigonalis (Jaekel, 1895)
'Lamna' lerichei Casier, 1946
Odontaspis winkleri (Leriche, 1905)
Physogaleus secundus (Winkler, 1874)
P. tertius (Winkler, 1874)
Scyliorhinus gilberti Casier, 1946
S. pattersoni Cappetta, 1977
Scyliorhinus spp.
'Scyliorhinus' minutissimus (Winkler, 1873)
'S.' biauriculatus Casier, 1950
'Scyliorhinus' sp.
Synodontaspis macrotus (Agassiz, 1843)
S. acutissima (Agassiz, 1843)
S. striatus (Winkler, 1874)

Chondrichthyes: Elasmobranchii: Neoselachii: Batomorphii
Archaeomanta melenhorsti Herman, 1979
Aetobatus sp.
Burnhamia davesi (Woodward, 1889)
Dasyatis duponti (Winkler, 1847)
D. jaekeli (Leriche, 1905)
D. tricuspidata Casier, 1946
D. wochadunensis Ward, 1979
Myliobatis dixoni Agassiz, 1843
M. latidens Woodward, 1888
M. cf. *toliapicus* Agassiz, 1843
Myliobatis sp.
?Myripristis sp.
Pristis lathami (Galeotti, 1837)
Pristis sp.
Rhinobatos bruxelliensis (Jaekel, 1894)
Rhynchobatus vincenti (Jaekel, 1894)

Chondrichthyes: Holocephali: Chimaeriformes
Edaphodon bucklandi (Agassiz, 1843)
E. leptognathus Agassiz, 1843

Bracklesham Group, undifferentiated

Indeterminate selachian dermal denticles, vertebrae, tail spines and coprolites

Osteichthyes: Actinopterygii: Acipenseroidei
Acipenser sp.

Osteichthyes: Neopterygii: Amiiformes
Amia sp.

Osteichthyes: Teleostei: Osteoglossiformes
Brychaetes sp.

Osteichthyes: Neopterygii: Pycnodontiformes

Pycnodus sp.
Osteichthyes: Acanthopterygii: Scombroidei
Cybium proosti (Storms, 1876)
Cylindracanthus rectus (Dixon, 1850)
Sphyraenodus cf. *antiquus* Casier, 1966
Trichuroides sagittidens (Winkler, 1874)
T. winkeri Casier, 1944
T. gulincki Casier, 1967
Xiphiorhynchus sp.
Osteichthyes: Acanthopterygii: Perciformes
Platylaemus colei Dixon, 1850
Platylaemus sp.
Sparcus sp.
?*Lutianus concavus* (Priem, 1912)
Osteichthyes: Elopomorpha: Anguilliformes
Conger sp.
Osteichthyes: Euteleostei: Tetradontiformes
Eotrigodon serratus (Gervais, 1852)

Interpretation

The uppermost Bracklesham Beds at Lee-on-Solent were deposited under conditions very similar to those that prevailed at Bracklesham Bay (q.v.), and the faunal list is correspondingly similar. Its richness in neoselachians and chimaeriforms is especially conspicuous and in part suggests a rich supply of food at upper and mid-water levels i.e. nekton and larger plankton.

The number of chondrichthyan species is large, with batomorphs and galeomorphs predominating, as elsewhere. Nevertheless there is an appreciable teleost element present, plus *Acipenser* and *Amia*. The scombroid teleosts and perciforms represent a fauna of active, small- to middle-sized fishes. Some genera such as *Conger*, *Acipenser* and *Amia* (which reach larger sizes) may have been somewhat migratory in habit, but it is difficult to impute such behaviour to these fossil forms.

Since most of the taxa are based on teeth, it is unlikely that taphonomic data will ever be significant. Selective sedimentation of hard parts cannot be ruled out, so that concentration of fossils may have occurred. On the other hand, there is no reliable evidence of mass mortality, nor of periodic influx of dead fish from other environments. The simplest interpretation of the fossils is that they accrued from large and flourishing fish populations.

Comparison with other localities

Comparison with the fossil yield at Bracklesham Bay (q.v.) is obvious, and similar depositional conditions and habitats are indicated. No other localities are as productive of fossil fishes at this level.

Conclusion

The conservation value of this site lies in its exceptionally rich fauna of fossil shark remains. The population of such predatory fishes would have depended upon a large mass of prey. The latter may have included other fishes as well as pelagic invertebrates and bottom-dwelling molluscs. However, the disarticulated remains and lack of taphonomic information precludes speculation about the rates and causes of mortality.

BARTON CLIFF (SZ 218930–SZ 252925)

Highlights

From the Barton Group at Barton Cliff in Hampshire, a large number of vertebrates, including sharks and teleosts, come from several horizons. At least 30 chondrichthyan taxa are present and one anuran is also recorded.

Introduction

The stretch of sea cliffs in Christchurch Bay between Chewton Bunny (on the Hampshire –Dorset border) eastwards to Becton Bunny, known as Barton Cliff (Figure 14.14A,B), has produced an excellent vertebrate fauna of Mid–Late Eocene age. Fossils from the Barton Beds have been collected for more than two centuries and the site has excellent potential for further finds.

The stratigraphy of the marine Barton Beds at Barton Cliff has been discussed in detail by Gardiner *et al.* (1888), Burton (1929, 1933), Hooker (1986) and Edwards and Freshney (1987). The succession was divided by Gardiner *et al.* (1888) into the Lower, Middle and Upper Barton Beds on the basis of faunal changes through the sequence. Burton (1929) gave faunal lists and lettered the Barton Beds A1–AL based on different lithologies and faunal content. Hooker (1986) formally designated the Barton Clay Formation and erected the new unit, the Becton Sand Formation, for the Barton Sand of earlier stratigraphical schemes. The site has been described by Benton and Spencer

Figure 14.14A Exposure of the Barton Clay, looking east from below Highcliffe, in the vicinity of Barton-on-Sea, Hampshire (photo: S.J. Metcalf).

(1995) as one providing a notable reptile fauna; much of the following is based on their account.

Description

The Barton Clay Formation (*sensu* Hooker, 1986, pp. 203–5) is exposed in the cliff section between Friar's Cliff, Mudeford in the west to just east of Barton-on-Sea in the east (SZ 194927–SZ 242927). The beds (*c*. 40–60 m thick) consist of grey to brown silty, usually shelly, sandy clay. There are several layers of calcareous phosphatic and sideritic nodules. The faunal list is large and diverse, including malacostracan crustaceans, ostracods, foraminiferans, brachiopods, molluscs (bivalves and gas-

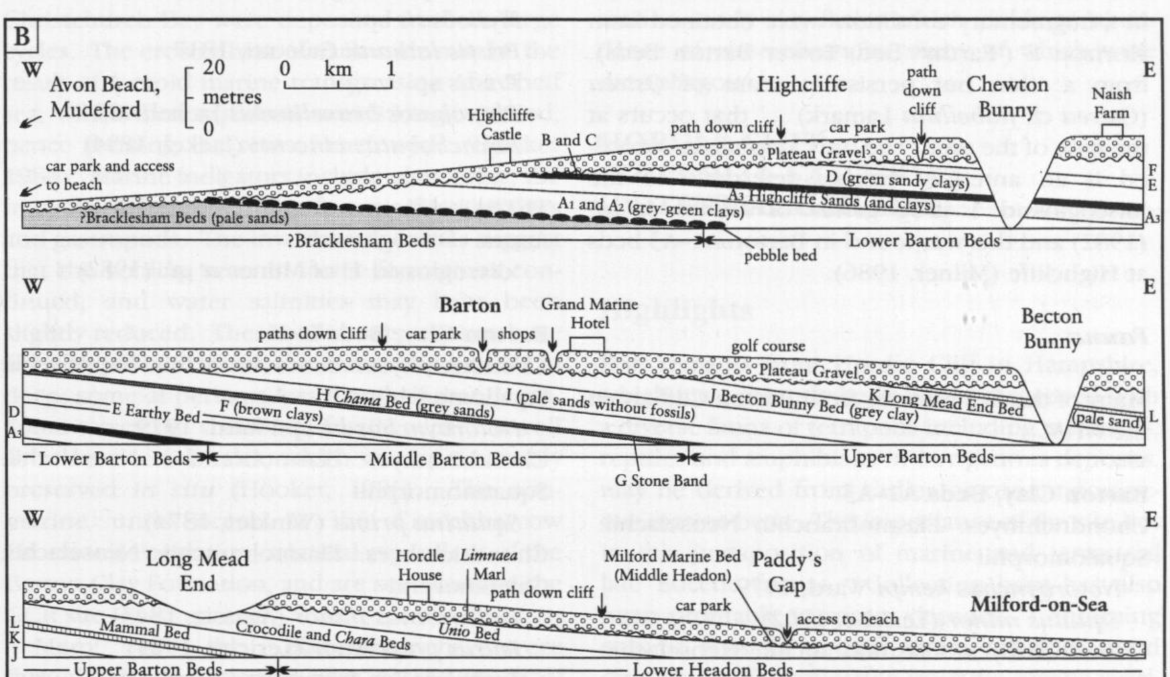


Figure 14.14B Section from Mudeford to Milford-on-Sea.

tropods), asteroids and ophiuroids, sharks, teleosts, marine mammals and turtles, and land-derived mammals, birds, and reptiles (Burton, 1929; Hooker, 1986). An associated flora of fruits, seeds, cones and wood indicates the close proximity of land, and the marine aspect of the fossils and the sediments suggests a predominantly low-energy nearshore environment for the formation.

The Becton Sand Formation (*c.* 25 m; Hooker, 1986, p. 205) occurs in the cliff section to the west of Sea Road Gap, and may be traced eastwards to Long Mead End (Taddiford Gap) at the eastern end of Beacon Cliff (SZ 229931–SZ 262922). The lithology is fine sand, which is clayey and silty at the base of the formation. The biota is sparse, but essentially the same as that of the Barton Clay below. Terrestrial fossil material is similarly reduced and no mammals have been found. Towards the top of the sequence, the molluscs indicate shallowing waters with a change to brackish conditions, leading to the non-marine Lower Headon Beds of Hordle (Hordwell) Cliff that succeed conformably to the east.

The fishes come from a number of levels, but have most commonly been obtained from horizons in the Lower and Middle Barton Beds, where they are commonly associated with shell-rich clays and silts. Burton (1929, p. 229) noted that 'Vertebrae of fishes and remains of Chelonia in a fragmentary condition' were obtained from Horizon E ('Earthy' Bed, Lower Barton Beds), from a 'thin but persistent seam of *Ostrea* (*Ostrea* cf. *flabellula* Lamark) ...' that occurs at the base of the unit. The only amphibian recorded is an anterior vertebra referrable to the 'discoglossid 1' frog genus of Milner *et al.* (1982) and this was found in Barton A1–A3 beds at Highcliffe (Milner, 1986).

Fauna

Many of the fish remains from Barton Cliff are in the NHM.

Barton Clay, Beds A1–A3

Chondrichthyes: Elasmobranchii: Neoselachii: Squalomorphii
- *Notorhynchus kempi* Ward, 1979
- *Squalus minor* (Leriche, 1902)

Chondrichthyes: Elasmobranchii: Neoselachii: Squatinomorphii
- *Squatina prima* (Winkler, 1874)

Chondrichthyes: Elasmobranchii: Neoselachii: Galeomorphii
- *Carcharias hopei* (Agassiz, 1843)
- *Carcharocles* (*Procarcharodon*) *auriculatus* (de Blainville, 1818)
- *Eostegostoma angusta* (Nolf and Taverne) in Herman, 1977
- *Galeocerdo latidens* Agassiz, 1843
- *Galeorhinus minor* (Agassiz, 1843)
- *G. recticonus* (Winkler, 1873)
- *Isurus praecursor* (Leriche, 1904)
- *Jaekelotodus trigonalis* (Jaekel, 1895)
- '*Lamna*' *lerichei* Casier, 1946
- *Odontaspis winkleri* Leriche, 1905
- *Physogaleus secundus* (Winkler, 1874)
- *P. tertius* (Winkler, 1874)
- *Scyliorhinus woodwardi* Cappetta, 1976
- *S. pattersoni* Cappetta, 1977
- '*Scyliorhinus*' *minutissimus* (Winkler, 1873)
- '*S.*' *biauriculatus* Casier, 1950
- '*Scyliorhinus*' sp.
- *Synodontaspis macrotus* (Agassiz, 1843)
- *S. striatus* (Winkler, 1874)
- *S. acutissima* (Agassiz, 1843)

Chondrichthyes: Elasmobranchii: Neoselachii: Batomorphii
- *Dasyatis jaekeli* (Leriche, 1905)
- *Dasyatis*. sp.
- *Gymnura* sp.
- *Myliobatis striatus* Buckland, 1837
- *M. toliapicus* Agassiz, 1843
- *Myliobatis* sp.
- *Pristis lathami* Galeotti, 1837
- *Pristis* sp.
- *Rhinobatos bruxelliensis* Jaekel, 1894
- *Rhynchobatus vincenti* (Jaekel, 1894)

TETRAPODA

Anura: Discoglossidae
- 'discoglossid 1' of Milner *et al.* (1982)

Barton Clay, Beds B–H

Chondrichthyes: Elasmobranchii: Neoselachii: Squalomorphii
- *Notorhynchus kempi* Ward, 1979

Chondrichthyes: Elasmobranchii: Neoselachii: Squatinomorphii
- *Squatina prima* (Winkler, 1874)

Chondrichthyes: Elasmobranchii: Neoselachii: Galeomorphii
- *Galeorhinus minor* (Agassiz, 1843)
- *Isurus praecursor* (Leriche, 1904)
- *Jaekelotodus trigonalis* (Jaekel, 1895)
- '*Lamna*' *lerichei* Casier, 1946

Odontaspis winkleri Leriche, 1905
Physogaleus secundus (Winkler, 1874)
P. tertius (Winkler, 1874)
Scyliorhinus sp.
'*Scyliorhinus*' *minutissimus* (Winkler, 1873)
'*S.*' *biauriculatus* Casier, 1950
'*Scyliorhinus*' sp.
Synodontaspis macrotus (Agassiz, 1843)
S. striatus (Winkler, 1874)
S. acutissima (Agassiz, 1843)
Chondrichthyes: Elasmobranchii: Neoselachii: Batomorphii
Aetobatus irregularis Agassiz, 1843
Burnhamia sp.
Dasyatis jaekeli (Leriche, 1905)
Gymnura sp.
Myliobatis toliapicus Agassiz, 1843
Pristis sp.
Rhinobatos bruxelliensis (Jaekel, 1894)
Chondrichthyes: Holocephali: Chimaeriformes
Amylodon sp.
Edaphodon leptognathus Agassiz, 1843
Otoliths

Interpretation

The depositional environments of the Bartonian of the Hampshire Basin are divided into marine and non-marine provinces by Hooker (1986). The Barton Clay and Becton Sands formations in Christchurch Bay were deposited in three large cycles. The erosive base of each cycle may be the result of a rapid marine transgression of a shelf sea, which then withdrew over a longer period, hence forming the rest of each cycle (Hooker 1986). Marine indicators include glauconite, the trace fossil *Ophiomorpha*, foraminifera, bivalves and gastropods. The invertebrate faunas suggest that the cooling seen in lower formations continued, and water salinities may have been slightly reduced. These sediments seem to have been deposited in marine waters up to 100 m deep, some at perhaps less than half that depth. Some terrestrial vertebrate fossils occur, as well as archaeocete whales, which were presumably preserved *in situ* (Hooker, 1986). The non-marine units occur in the Creechbarrow Limestone Formation, a lateral equivalent of the Barton Clay Formation, and are seen outside the GCR site.

Many of the elasmobranchs were durophagous and would have passed much of their time in the vicinity of shell banks. Other invertebrates, especially arthropods, may have formed the food base for elasmobranchs and osteichthyans alike. About 20 species of teleosts are known from the Elmore Member of the Barton Clay (Kemp *et al.*, 1990), and they are sturdy, active, largely predatory forms.

Comparison with other localities

On the basis of the perissodactyl mammal *Plagiolophus cartailhaci* from the Middle Barton Beds, the Barton succession, at least in part, is tentatively considered to be coeval with the Castrais fauna of the Aquitaine Basin of southern France (Hooker, 1972, p. 182). The mammal fauna of the Totland Bay Member of the Headon Hill Formation, which succeeds the Barton Beds, correlates with the upper part of the Calcaire de Fons at Fons; thus the Becton Sand Formation ('Upper Barton Beds') may correlate with the Robiac unit below. The Lower Barton Beds may be Marinesian, perhaps partly equivalent to the Calcaire de St Ouen, since these lie above the Bracklesham Group that are well correlated with the Auversian Stage.

Conclusion

The Barton Cliff sites are situated within marine and non-marine facies distributed within three cycles. Their conservation value lies in the marine sandy clay facies which yields an abundance of elasmobranchs, many of which were durophagous.

HORDLE CLIFF (SZ 263923–SZ 273918) (POTENTIAL GCR SITE)

Highlights

Fish remains from Hordle Cliff in Hampshire, which have recently been found associated with a diverse fauna of tetrapods including mammals, reptiles and amphibians in terrigenous deposits, may be derived from earlier or contemporaneous marine beds. The importance of the site lies in this juxtaposition of marine and terrestrial late Eocene faunas. Collecting here has also been profitable in recent decades. Continuing natural erosion of soft strata provides good opportunity for collecting from the several yielding horizons.

Introduction

The Late Eocene (Priabonian) Totland Bay Member of the Headon Hill Formation (formerly the Lower Headon Beds or Headon Member) is exposed at Hordle Cliff, in a series of low cliffs between Becton Bunny and Milford-on-Sea that have produced an important assemblage of vertebrates including fishes, reptiles and mammals. A recent discovery of abundant amphibian remains in the Mammal Bed (Milner *et al.*, 1982) has greatly enlarged the faunal list. The section is usually masked by a thin talus, and some parts are heavily slipped, but the relevant horizons remain accessible and may easily be cleared. The geology of Hordle Cliff has been described by Hastings (1848, 1852, 1853), Gardiner *et al.* (1888), Curry (1958), Cray (1973), Milner *et al.* (1982) and Benton and Spencer (1995).

The first vertebrate remains reported from the sections of Hordle (or Hordwell) Cliff were described from the extensive collections of Searles Wood and Barbara, Marchioness of Hastings, which were assembled during the late 1840s. These remains, including numerous specimens of fishes, reptiles and mammals, were initially reported by Wood (1844) and Charlesworth (1845). Wood (1846) listed and figured further material from Hordle Cliff, and Hastings (1852, 1853) reported the results of six years' further collecting, listing important finds of mammals, fishes, reptiles and birds. Subsequently, in 1855, the Hastings collection was acquired by the Natural History Museum. The site has been selected as an SSSI on the basis of its reptile fauna (Benton and Spencer, 1995). A collection of small tetrapods, including numerous well-preserved amphibian remains, made from Hordle Cliff between 1976 and 1981, containing numerous new specimens, has greatly expanded the faunal list. The specimens were obtained by Mr Roy Gardiner of Fareham from the Mammal Bed, from the same locality which had produced some of the Hastings material. Milner *et al.* (1982) reported the new finds and identified the occurrence of seven taxa of salamanders and frogs, some of which were previously unknown from the British Eocene.

Description

As Benton and Spencer (1995) report, the stratigraphy of Early Palaeogene rocks at Hordle Cliff was described by Gardiner *et al.* (1888) and Cray (1973). The following section is abridged from Cray (1973, p. 11). The beds dip gently south-east at about 2.5° (Figure 14.15).

	Thickness (m)
Totland Bay Member ('Lower Headon Beds')	
Marl	seen 0.5
Rodent Bed: *Limnaea* Marl with overlying dark clay (= Rodent Bed Marl)	0.25
Unio Beds: grey clays with sandy layers	3.5
Green clays	2.5
Chara Bed: dark clays	1.4
Blue and green clays	2.7
Limnaea Limestone	0.4
Ironstone Bed	1.2
Crocodile Bed: sands	2.0
Rolled-Bone Bed: sand with abraded bones	0.3
Clay and sands	1.4
Leaf Bed: carbonaceous clay	1.0
Mammal Bed: clays, sands and sandy clays	3.5
Ironstone bed	0.4
Clays	1.1 m
Lignites	seen 1.4 m

The Totland Bay Member (Late Eocene) is included in the zone of the dinoflagellate *Wetzeliella perforata*. At Hordle Cliff the sediments form a series of low cliffs and slipped undercliffs between east of Barton-on-Sea (just west of Becton Bunny) and Milford-on-Sea. The Mammal Bed, at the base, occurs beneath Plateau Gravel to the west of Becton Bunny, from where it may be traced as a distinct scar obliquely down the cliffs to reach sea level just east of Long Mead End. Just east of Hordle House, the highest unit in the Totland Bay Member, the *Limnaea* Marl and associated horizons, crops out. The basal Colwell Bay Member ('Middle Headon Beds' (pars)) is represented at Paddy's Gap by the occurrence of the Milford Marine Bed.

It has been established (e.g. Cray, 1973; Milner *et al.*, 1982) that the Hordle amphibians were all found in the Totland Bay Member. The provenance of the early collections, however, is difficult to assess, the locality information provided by Hastings being merely 'Upper Eocene, Hordwell', or in Lydekker's catalogue (1888a, 1888b) 'from the Headon Beds of Hordwell'. The sparse matrix on a number of specimens

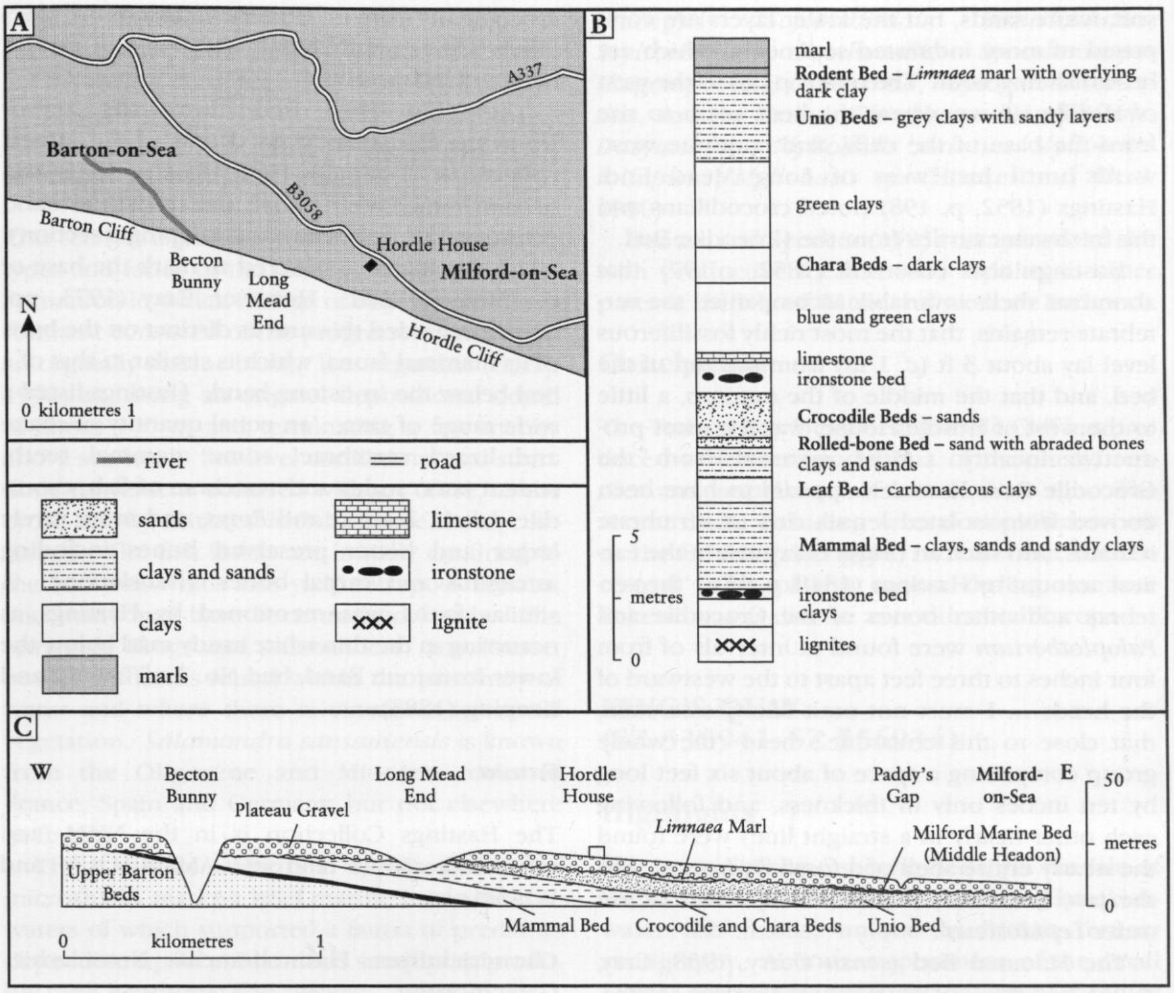


Figure 14.15 Headon Beds at Hordle Cliff, Hampshire (after Cray, 1973).

cannot be used to demonstrate provenance with accuracy. Some of the specimens with adhering greenish blue sandy clay may have come from the Mammal Bed, but other lithologies are undiagnostic. It may, however, be assumed from the accounts of Hastings (1848, 1852, 1853) that most of the material came mainly from the Mammal Bed and the Rodent Bed, and also from fossiliferous pockets within the Crocodile Bed.

The Rodent Bed (Hastings' Bed 1), predominantly grey clays and marls, is limited in lateral extent, cropping out just to the east of Hordle House, and extending eastwards for some 275 m before wedging out. To the west, the beds have been removed by recent erosion. The highest horizon of the Rodent Bed consists of clays, tinted pink and overlying a thin, dark, clayey sand, which in turn rests on a comminuted shell bed, the *Limnaea* Marl.

Hastings (1852, p. 194) recorded an extensive vertebrate fauna from the Rodent Bed. The finds may be bracketed with the dark clayey marl on the basis of Hastings' detailed description of the host sediment and mention of the underlying *Limnaea* Marl.

Cray (1973, pp. 10–12) described the occurrence and preservation of the vertebrates: 'occasional rodent teeth and turtle fragments were recovered from the upper levels of the *Limnaea* marl, and the overlying dark sandy clay has yielded a moderate quantity of small-sized vertebrate debris ... This material is always of very small size and evidently represents a current-sorted accumulation; all the large Headon Beds species are absent. All the specimens are fragmentary and ... some of the material is water worn'. Fish were not included.

The upper part of the Crocodile Bed is of fine, soft, white sands, but the lower layers are composed of more indurated sediments, which are brownish in colour. The outcrop lies to the west of Hordle House, where the beds seem to rise from the base of the cliffs, and continue westwards until just west of Long Mead End. Hastings (1852, p. 198) noted crocodilians and the freshwater turtles from the Crocodile Bed.

Hastings also observed (1852, p.197) that abundant shells invariably accompanied the vertebrate remains, that the most richly fossiliferous level lay about 3 ft (*c.* 1 m) from the top of the bed, and that the middle of the outcrop, a little to the west of Hordle House, was the most productive locality. Most material from the Crocodile Bed, however, appears to have been derived from isolated lenses rich in vertebrate remains, and such an origin is explicit in the earliest account by Hastings (1848, p. 63): 'the vertebrae and other bones of the Crocodile and *Paloplotherium* were found at intervals of from four inches to three feet apart to the westward of the heads … I must not omit likewise to state, that close to this crocodile's head (the whole group comprising a space of about six feet long by ten inches only in thickness, and following each other nearly in a straight line) were found the nearly entire shell of a fossil *Trionyx* … and the jaw, vertebrae, and scales of a fish of the order *Lepidosteus*'.

The Mammal Bed (*sensu* Curry, 1958; Cray, 1973), bed no. 9 of Tawney and Keeping (1883), and the upper part of bed 15 of Hastings, outcrops from beach level just west of Hordle House, westwards to Becton Bunny. Reptile material, although rare, was reported (Hastings, 1852) as coming from layers of white sand containing abundant remains of shells but no fish were mentioned.

The specimens collected recently by Mr Gardner also derive from the Mammal Bed, from the stretch of Hordle Cliff sometimes referred to as Beacon Cliff, between Becton Bunny in the west and Long Mead End in the east (upper part of bed 15 of Hastings, 1852; bed 9 of Tawney and Keeping, 1883). The material, consisting of many thousands of small bones, was found in numerous bone-bearing shelly pockets composed of pale greenish, grey sand differing in some respects from the same level as described by Hastings (1852, p. 200).

Other horizons that have yielded vertebrate remains include the Rolled-Bone Bed. In 1852 (p. 199) Hastings reported finds of turtles and crocodilians from it. However, most of the specimens are generally highly abraded and cannot be identified precisely.

The Thin Shell Bed above the Lower Ironstone Band has yielded one of the largest collections of reptiles from Hordle. This bed occurs immediately above the ironstone band (numbered 8 in Tawney and Keeping's section), which is usually considered to mark the base of the Mammal Bed. However, Cray (1973, pp. 17–18) regarded this unit as distinct on the basis of its mammal fauna, which is similar to that of a bed below the ironstone band. Hastings listed a wide range of taxa: 'an equal quantity of snake and lizard vertebrae, some mammal teeth, rodent jaws, scales and vertebrae of fish, crocodile debris, *Trionyx* and *Emys*, and more rarely larger and better preserved bones including astragalus and carpal bones' [translation]. A similar fauna was mentioned by Hastings as occurring in the thin white sandy marl below the lower Ironstone Band, bed No. 7 of Tawney and Keeping (1883).

Fauna

The Hastings Collection is in the NHM, and other material is held in CAMSM, OUM and YORMS.

Chondrichthyes: Elasmobranchii: Neoselachii: Galeomorphii
- *Physogaleus secundus* (Winkler, 1874)
- *Syliorhinus woodwardi* Cappetta, 1976
- '*Scyliorhinus*' *biauriculatus* (Casier, 1950)
- *Synodontaspis acutissima* (Agassiz, 1843)

Chondrichthyes: Elasmobranchii: Neoselachii: Batomorphii
- *Dasyatis* spp.
- *Myliobatis striatus* Buckland, 1837
- *M. toliapicus* Agassiz, 1843
- *Myliobatis* sp.
- *Rhinobatos bruxelliensis* (Jaekel, 1894)

Otoliths

TETRAPODA

Lissamphibia: Anura: Discoglossidae
- 'discoglossid 1' of Milner *et al.* (1982)
- 'discoglossid 2' of Milner *et al.* (1982)

Anura: Pelobatidae
- *Eopelobates* cf. *E. hinschei* Estes, 1970

Anura: Palaeobatrachidae
- *Albionbatrachus wightensis* Meszoely *et al.*, 1984

Caudata: Salamandridae
Salamandra sansaniensis Lartet, 1851
Chelotriton cf. C. *paradoxus* Pomel, 1853
Triturus sp.

Interpretation

This section exposes a wide variety of sediment types and facies of the late Eocene Headon Hill Formation in which change of depositional environment consisted of the progressive infilling of an orginally marine basin. It is regarded (Curry, 1992) as having an original depositional depth of about 100 m and terminating a few metres above sea level. Sea-level oscillations and strandline movement occurred without cease, as the cyclic activity, initiated in Palaeocene times, continued. The fish fossils are initially confined to the horizons which also yield tetrapod remains, and many may have been derived fossils. The tetrapods (frogs and salamanders) are diverse, but all are forms found within the proximity of water and where there is extensive terrestrial vegetation. *Salamondra sansaniensis* is known from the Oligocene and Miocene rocks in France, Spain and Germany, but not elsewhere in Britain.

The Milford Marine Band fauna of microsharks marks a brief marine incursion, the waters of which supported a fauna of predators dependent upon unidentified small prey, probably both benthonic and pelagic.

Comparison with other localities

The Totland Bay Member at Hordle Cliff is directly correlated with the top of the same unit (Insole and Daley, 1985) at Headon Hill, Isle of Wight, on the basis of their Late Eocene (Priabonian) mammal faunas and occurrence of calcareous nannoplankton zones NP17 and NP20 (Curry *et al.*, 1978). The Hordle fauna includes a range of amphibians and fishes comparable to the Headon Hill finds (see Headon Hill report). However, there are differences between the two localities in the range and abundance of taxa, with the Hordle fauna being at least quantitively different from that at Headon Hill. This may be a local ecological or taphonomic effect (Milner *et al.*, 1982).

The Milford Marine Bed within the overlying Middle Headon Beds (Colwell Bay Member) at Paddy's Gap, Hordle (SZ 278917), has yielded a diverse microshark fauna that includes the galeomorphs *'Scyliorhinus' biauriculatus*, *Scyliorhinus woodwardi*, *Synodontaspis (Eugomphodus) acutissima*, *Physogaleus secundus*, and the batiods *Rhinobatos bruxelliensis*, *Dasyatis* sp., *Myliobatis striatus*, *Myliobatis toliapicus*, *Myliobatis* sp. (Hooker and Ward, 1980).

Benton and Spencer (1995) compared the site with productive localities for reptiles in other parts of the Isle of Wight and western Europe.

Conclusion

The Totland Bay Member at Hordle Cliff has produced a rich tetrapod fauna of mammals, reptiles and amphibians of Late Eocene age. The recent finds, including several amphibians new to the British Palaeogene, indicate that the terrestrial fauna of this region during the Late Eocene was as diverse as continental Europe.

KING'S QUAY (SZ 538941–SZ 556934)

Highlights

The latest Eocene Osborne Beds, on the Isle of Wight in Hampshire, contain fresh- and brackish-water fish fossils, unique in British Tertiary stratigraphy. Abundant specimens of the small teleost *Vectichthys vectensis* (Newton), both as complete fishes and crushed partial bodies, occur in a discrete bed, perhaps recording sudden mortality by asphyxiation.

Introduction

King's Quay in the Fishbourne area of the north-eastern Isle of Wight is famous for the lenticular bone-bed horizons that crop out on the foreshore, and occur within the Osborne Beds at the top of the Upper Eocene. The bone beds are within a series of blue and grey, hard, laminated clays (Osborne facies) and yield exceptionally preserved, three-dimensional fossil fishes. The fish fauna is unusual in the context of the British Eocene, as it developed within a freshwater or brackish palaeoenvironment, with limited access to the open ocean.

Excavations at several points along this coastline yielded three fish species to Gaudant and Quayle (1988), including a new genus.

Description

Well-preserved small fishes here attracted local collectors in the late 19th century, one of the more active being G.W. Colenutt, who found these fossils 'near Ryde House and in the cliff section east of King's Quay' (Colenutt, 1888, p. 358; 1903, p. 99). The section given below and drawn up by Clement Reid and G.W. Colenutt was recorded by H.J. Osborne White (1921). Colenutt (1903) had traced the productive bed from the vicinity of Ryde House westwards to King's Quay and east to Sea View.

	Thickness (m)
Section east of King's Quay	
Bembridge Limestone	
Red and mottled clay (only seen in landslips)	12.0
Green clay, with scattered fish bones Scales and vertebrae of *Lepidosteus* abundant, *Alligator*, *Emys* [*Ocadia?*], *Trionyx*, and *Chelone*, *Theridomys* and snake vertebra	1.2
[Fish Bed] Hard grey shaley clay, full of fish bones, and whole fish (*Vectichthys* (*Clupea*) *vectensis*)	0.6
Similar clay with grass-like leaves and lenticular masses of cement stones	0.9
Blue clay, with abundance of mollusca *Paludina lenta* (*Viviparus*), *Melanopsis carinata* etc.	1.8
Unfossiliferous green clay, to low water	16.5

White reported (1921) that the best exposures were on the shore to the west of the mouth of Wootton Creek, where the fish bed (Chapelcorner Fish Bed) crops out just below high water mark as a rib projecting through the beach. Fish preserved in the strata above are incomplete (White, 1921), as are the tetrapod remains.

Insole and Daley (1985) have proposed a lithostratigraphical nomenclature for this part of the Hampshire Basin succession. The fish bed occurs in the Fishbourne Member of the Headon Hill Formation, Solent Group.

Fauna

Osteichthyes: Actinopterygii: Neopterygii: Teleostei

Amia (?) sp.

Potamoschistus (?) cf. *bleicheri* (Sauvage, 1883)

Vectichthys vectensis (Newton, 1889)

Osteichthyes: Actinopterygii: Ginglymodi

Lepisosteus sp.

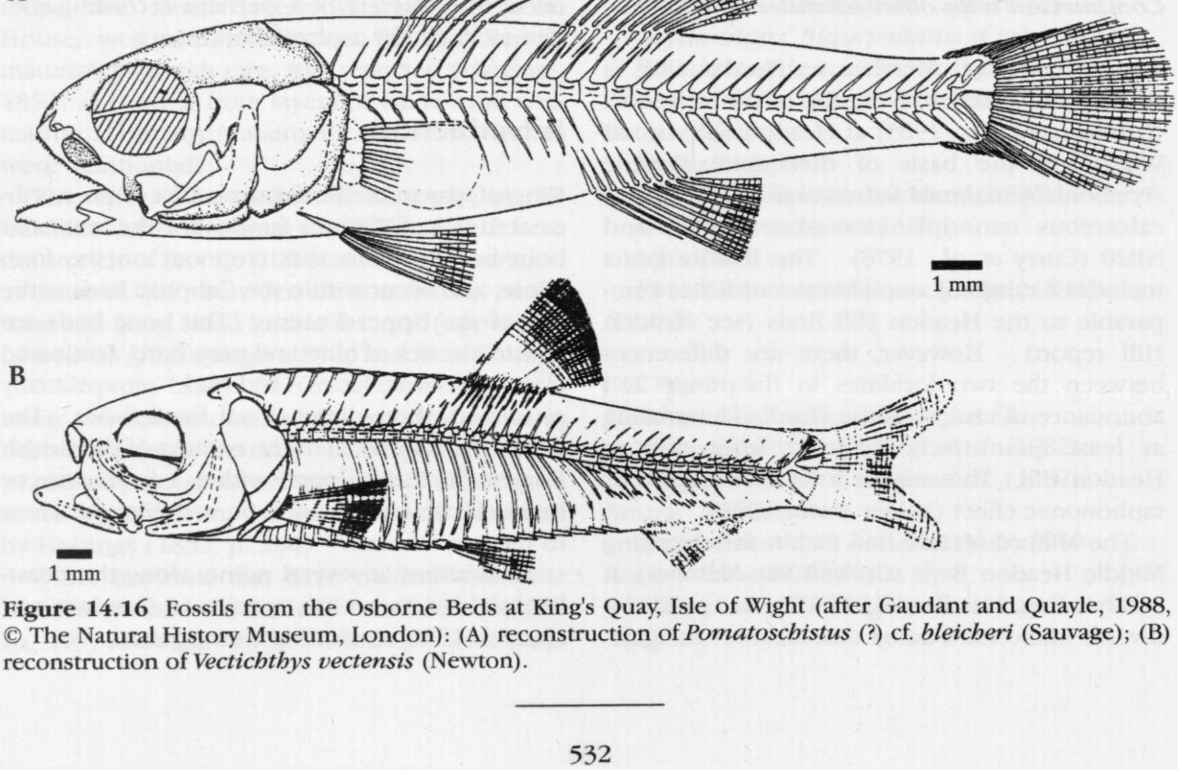


Figure 14.16 Fossils from the Osborne Beds at King's Quay, Isle of Wight (after Gaudant and Quayle, 1988, © The Natural History Museum, London): (A) reconstruction of *Pomatoschistus* (?) cf. *bleicheri* (Sauvage); (B) reconstruction of *Vectichthys vectensis* (Newton).

Interpretation

The Headon Beds, Osborne Beds and Hamstead Beds all contain fresh- and brackish-water fossil assemblages (Figure 14.16) where these facies are interspersed with deltaic clastics. Lacustrine deposits tend to occur as fine, laminated, clay-grade clastics, containing well-preserved fossil fishes. The Osborne Beds are about 50 m of clays and marls with hard bands of limestone. Freshwater molluscs (*Limnaea*, *Viviparus*, etc.) are common.

The succession seems to record a phase of shallow sedimentation under quiet brackish or freshwater conditions, which culminated in the formation of the Bembridge Limestone. The presence of plant remains and tetrapod bones indicates the proximity of a vegetated land surface. The environment about the water mass was low, contributing only clay-grade sediment, probably via sluggish small streams and under subtropical conditions (see Gaudant and Quayle, 1988). A truly freshwater regime was established before the appearance of the fishes, *vide* the mollusca *Paludina* and *Melanopsis*. Whether or not the fishes normally inhabited these waters or were introduced as floating corpses from elsewhere is not certain. The completeness of many of the bodies and the gaping mouths suggest sudden asphyxiation and burial without much transport. The death of the fishes was not violent, and may have been induced by sudden oxygen depletion of the waters where they swam or by their entry into a lower stagnant water level. The green clay with scattered tetrapod bones and *Lepisosteus* may represent an episode of influx of terrestrial organic debris. No fishes are recorded from the Bembridge Limestone, which may have thus originated in an aquatic environment without fishes.

Comparison with other localities

The preservational style and faunal composition of the King's Quay fish bed is similar to that of some parts of the Early to Middle Eocene Green River Formation shales of Wyoming, USA. No other comparable localities have been found in Britain. In the Paris Basin the Montmartre gypsum beds are thought to be equivalent to the Bembridge Limestone, but no direct connection existed.

Conclusion

The succession near King's Quay has yielded abundant remains of the small teleost *Vectichthys* from a series of pale clays, hard marls and concretions of brackish-water-freshwater origin. The conservation value of the site is derived from its fish fauna and unique stratigraphical position within British Tertiary stratigraphy.