

GEOLOGY OF THE SOLENT ESTUARINE SYSTEM

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Introduction

The estuaries of the Solent, Southampton Water and of Portsmouth, Langstone and Chichester Harbours lie at the centre of the Hampshire Basin. They are the latest of a series of shallow-water bodies that have existed here since the relatively deep Chalk sea-floor was uplifted about 65 million years ago. In the Palaeogene Period, (Eocene and Oligocene) a wide variety of sediments accumulated in shallow seas, estuaries, lakes and lagoons and these frequently contain abundant plant and animal remains. These deposits now exist beneath and around the modern estuaries. After their deposition there was a long phase of folding, uplift and erosion during the Neogene (Miocene and Pliocene). Relatively recently, during glacial phases of the Pleistocene, the valleys of the local rivers were excavated to well below the present sea-level before being finally flooded during the Flandrian Transgression which thus created the modern estuaries. It is the Eocene, Oligocene, Pleistocene and Holocene (Flandrian) sediments of the region that are discussed in this account.

The geology of this estuarine area has been described in numerous publications and the more important ones are mentioned below. A useful general introduction is "The Hampshire Basin and Adjoining Areas" booklet (Chatwin, 1960), since revised by Melville, (in press). More detailed background information on the ancient sediments exposed at the margins of the estuaries can be found in various Memoirs of the Geological Survey (now the NERC Institute of Geological Sciences), notably those by Bristow (1862), Bristow *et al.* (1889), Reid and Whitaker (1902), Whitaker (1910), White (1915, 1921), Edmunds (1928) and Buchan *et al.* (1942). The early publications on the Solent region have been listed by Whitaker (1873) and more recent literature, mainly concerning Southampton, has been reviewed by Hodson and Shelford (1964). Reference to previous papers on the Palaeogene strata will be found in Curry *et al.* (1968, 1977), Edwards (1971), Keen (1977), Murray and Wright (1974) and Stinton (1975). It is not possible in this short account to refer to many of the numerous palaeontological publications relating to this area but key papers above provide references to a substantial number.

The Quaternary deposits of the Solent region have been discussed recently by Brown *et al.* (1975), Dyer (1971, 1972, 1975, Section 4) and Hodson and West (1972). In addition to the wealth of published data, Civil Engineering investigations can contribute much to our knowledge of the region (Barton, 1978). Records of more than 1,400 shallow boreholes in and around Southampton Water are catalogued at the Department of Geology, Southampton University. The NERC Institute of Geological Sciences has extensive records for borehole activities around the estuaries and Portsmouth Polytechnic holds similar records for the Portsmouth area. The geology of the adjacent regions of the English Channel has been comprehensively reviewed by Dingwall (1971) and in the symposium arranged by Dunham and Smith (1975) and bibliographies have been provided by Smith *et al.* (1972) and Hamilton *et al.* (1975). The "Wight" 1:250,000 solid geology map of the NERC Institute of Geological Sciences shows the outcrops on the seafloor around this area. A Bouguer gravity anomaly

map and an aeromagnetic map of the "Wight" area have also been published. Geological maps of the land area around the estuaries are sheets number 315, 316, 317, 330 and 331 (map 315, Southampton, is currently being revised). Additional information, mostly confidential and predominantly concerning the strata at depth, is in the possession of oil and gas companies.

Structure

Although not always above sea-level, the outcrop of the Chalk forms a border to the Hampshire Basin except in the southeast (Fig. 1; Dingwall, 1971). Within the major monocline which trends east-west through the Isle of Wight, it dips very steeply to the north, while around the northern margins of the basin the southerly dips are quite gentle. The axial part of the basin lies under the West Solent, where the upper surface of the Chalk descends to a depth of about 518m (Dyer *et al.*, 1969) with Southampton Water, the East Solent and Spithead to the north of the axis and approximately parallel to the regional strike. Portsmouth, Langstone and Chichester Harbours are close to the northeastern margin of the Basin (Fig. 1) and partly overlie the Portsdown Anticline, the axis of which is almost parallel to this margin. Other, smaller folds of generally northwest-southeast trend are the Bouldnor and Thorness Bay Synclines and the Porchfield Anticline beneath the West Solent (White, 1921), a minor anticline under the East Solent between Osborne and St Helens (White, 1921) and small undulations at Portsmouth (James, 1847) and near Fawley. Obvious faults under the estuaries are relatively few, although small faults exist at Colwell Bay and Horestone Point (White, 1921). The valleys of the western Yar and the Medina may, however, lie on unexposed faults (Bristow, 1862), which extend northward beneath the Solent. Concealed faults in Jurassic strata may give rise to oil traps. Occasional earthquakes (Cook, 1749-50 referred to by Bristow *et al.*, 1889; Fisher, 1862; Tillotson, 1974) suggest that some minor movement still occurs in the region.

Pre-pleistocene strata

(a) Introduction

The Palaeogene sequence beneath the estuarine system consists only of strata belonging to the Palaeocene, Eocene and Oligocene Series. These are shown in Table 1, together with approximate thicknesses, which vary to some extent over the area, often increasing in a southeasterly direction. Surface examination of these strata is possible in the famous cliff exposures on the Isle of Wight (Curry, *et al.*, 1972). The Bembridge and Hamstead Beds are exposed for example at Bouldnor Cliff near Yarmouth. Alum Bay provides a section from the Chalk to the Headon Beds but the Bracklesham Group is of unusual facies there and can best be seen at Whitecliff Bay.

Before considering the details of the Palaeogene strata attention must be drawn to some recent proposals for new lithostratigraphical nomenclature for the Eocene by Stinton (1975), Cooper (1976), Curry *et al.* (1977) and Curry *et al.* (1978). Unfortunately, in spite of a defence (Stinton and Curry, 1979) much of the new scheme seems not to conform to current British or International codes of stratigraphical nomenclature

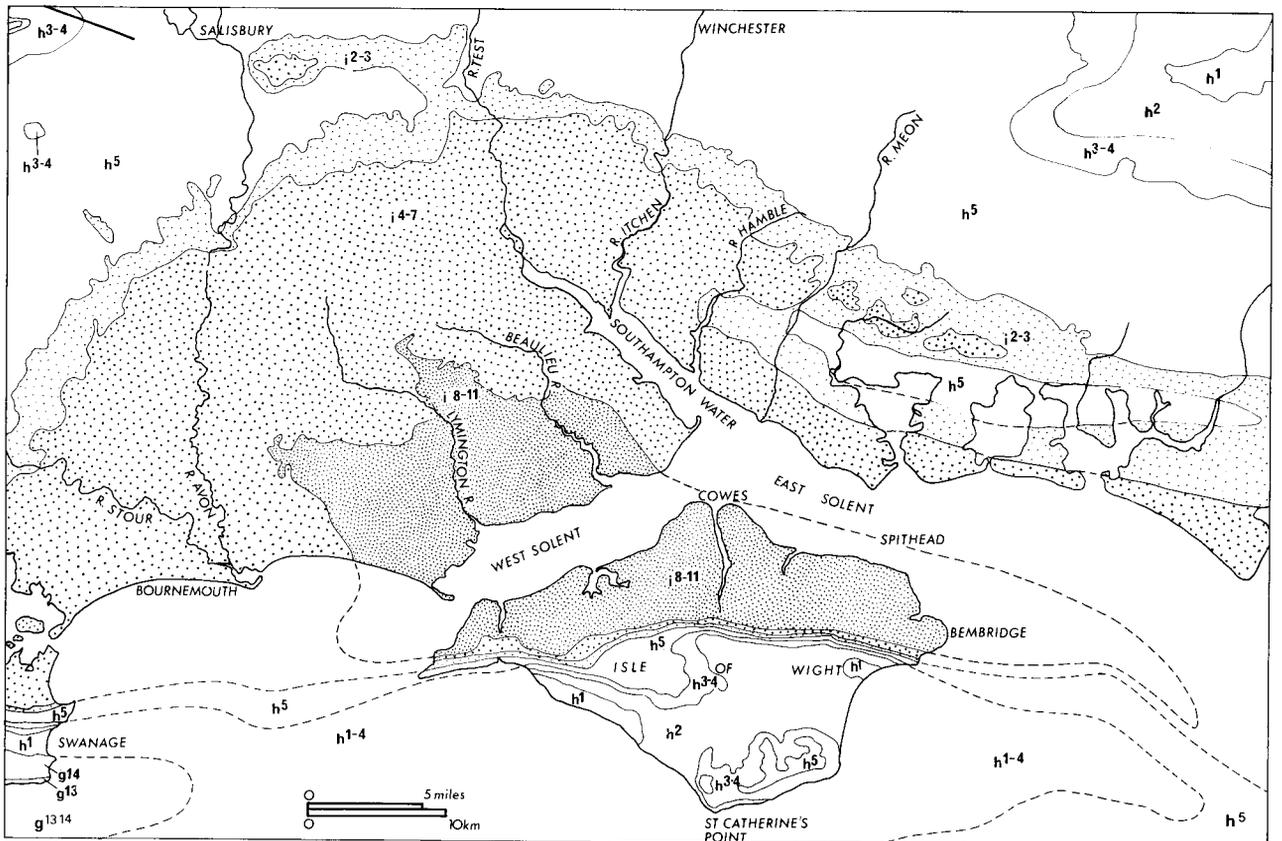


Fig. 1 Simplified "solid" geological map of the region around the Solent estuarine system, based on Geological Survey maps, the B.R.G.M. English Channel map and Dingwall (1971). Symbols: *g*¹³⁻¹⁴ Portland and Purbeck Groups, *h*¹ Wealden, *h*² Lower Greensand, *h*³⁻⁴ Gault and Upper Greensand, *h*⁵ Chalk, *i*²⁻³ Reading Beds and London Clay, *i*⁴⁻⁷ Bagshot, Bracklesham and Barton Beds. The positions of the offshore geological boundaries are approximate.

(Daley *et al.*, 1979) and could lead to some confusion. Very useful, however, is the splitting of the thick Bracklesham Beds into lithological units (see King and King, 1977) and these subdivisions, regarded here as members, are used in the account which follows (Table 1). Because of the controversy and the likelihood that the lithostratigraphy will be resolved in the near future (Daley *et al.*, 1979), apart from these Bracklesham members the traditional names are generally used here; the term "Beds" being replaced, however, by "Formation" (Table 1). In any case these names are more widely understood at present. The scheme shown is similar to that which is under consideration by the NERC Institute of Geological Sciences for the new Southampton map, except that the Huntingbridge Member might be included within the Barton Clay Formation (pers. comm. E. Freshney, 1979).

A further problem to be noted is that the position of the Eocene-Oligocene boundary is difficult to determine

FORMATION	THICKNESS	LITHOLOGY	NANNOPLANKTON	STRATIGRAPHIC POSITION
Hamstead	38m	Clays with brackish and marine molluscs. Black clay band with roots at base.		23
Benbridge Marls	21-37m	Clays with brackish and freshwater molluscs. Oyster bed at base.		21
Benbridge Lst.	5-8.5m	Freshwater limestone		
Osborne	24-33m	Clays with brackish molluscs		20
Headon	43-65m	Clays, often shelly, with some soft limestones and sands. Fresh to brackish with marine beds in the middle		19
Barton Sands	35-67m	Sands with <i>Chama</i> Bed or oyster bed at base		18
Barton Clay	45-68m	Blue-green clays - marine molluscs		17
Huntingbridge Member	35m	Unfossiliferous blue-green clays		16
Selsey Member	39m	Green sand with molluscs. <i>Nummulites variolarius</i> (- <i>Auversian</i>)		15
Marsh Farm Member	14m	Laminated lignitic clay (estuarine)		14
Earnley Member	23m	Green shelly sand with marine molluscs (- <i>Lucetian</i>)		13
Wittering Member - Upper	23m	Laminated lignitic clay (estuarine) with coal seam		13
Wittering Member - Lower	5m	Sands and silts with some marine molluscs		13
Bracklesham				
Bagshot	23-42m	Sands with pipe-clay and pebble beds		12
London Clay	98-123m	Brown clay with marine molluscs and some carbonate nodules		11
Reading	25-47m	Mottled clays		9
Upper Chalk	311-406m	Coccolith limestone with flint nodules		5

Right, - Table 1: Succession of Palaeogene strata beneath the Solent Estuarine System. Traditional terminology is used except that "Beds" (i.e. Headon Beds) are given "Formation" status and that the Bracklesham Formation is divided into the divisions described by Stinton (1975), Cooper (1976), Curry *et al.* (1977), King and King (1977) but which are given the status of "Members". N.P. - occurrence of *Nummulites prestwichianus*; N.V. *Nummulites variolarius* bed; N.L. - occurrence of *Nummulites laevigatus*; C.B. - *Campanile* bed; L.C. - *Lentipeecten corneum* occurrence.

in this area because so many of the strata are non-marine. Although various positions above the Barton Beds have been suggested (Curry, 1966; Murray and Wright, 1974; Costa and Downie, 1976; Odin *et al.*, 1978) evidence from nannoplankton shows that it lies somewhere between the Middle Haddon and the Upper Hamstead marine strata (Curry *et al.*, 1978) and the transgression at the base of the Bembridge Marls is provisionally taken as the boundary.

(b) *Succession*

The Upper Chalk is the oldest unit that outcrops under the estuaries. In addition to the southern side of Alum Bay it underlies an extensive area of Portsmouth, Langstone and Chichester Harbours (Brydone, 1912; White, 1915; Martin, 1938). Lying on an eroded surface of the Chalk is the Reading Formation usually regarded as Palaeocene (e.g. Curry *et al.*, 1978), but classified as basal Eocene by Odin *et al.* (1978). It consists predominantly of red-mottled plastic clays, often with a flint pebble bed at the base and is exposed at Alum Bay. It also occurs under Portsmouth and other eastern harbours where the clays have been used locally for brick-making (Prestwich, 1854).

Used on a larger scale in the past for the manufacture of bricks is the London Clay Formation. This marine sediment formed about 50 million years ago (Odin *et al.*, 1978) and consists of brown clays, mainly of montmorillonite and illite (Gilkes, 1968a) with calcareous nodules and pebble beds at certain horizons.

The best exposure is at Alum Bay, although there it is unusually sandy, particularly in the upper part of the sequence (Burnett and Fookes, 1974). Shark teeth have been found and the remains of marine molluscs are common (Curry *et al.*, 1972). Much useful stratigraphical information and rich faunal remains were obtained during excavation of the London Clay in Portsmouth dockyard (Meyer, 1871; Evans, 1873; White, 1915). The clay also underlies much of both Langstone and Chichester harbours (King in Bone and James, 1975).

Sand and pebble beds above the London Clay, which in the Isle of Wight vary from 23 to 42m in thickness, have traditionally been termed the "Bagshot Beds", referred to here as the Bagshot Formation. Microplankton show that this corresponds in age to part of the London Clay of the London Basin (Curry *et al.*, 1978). These permeable strata have yielded water supplied in the Fawley and Gosport regions and elsewhere (Whitaker, 1910).

The Bracklesham Formation underlies extensive areas of Southampton Water, the Solent and the Spithead (Fig. 2) and the lithological subdivisions together with faunal contents have been listed by Fisher (1862) and Curry, *et al.* (1977). Microplankton zones have been described by Eaton (1971, 1976). These beds consist of clayey sands and sandy clays with much vertical variation in character. They contain such interesting features as seams of brown coal occasionally with amber,

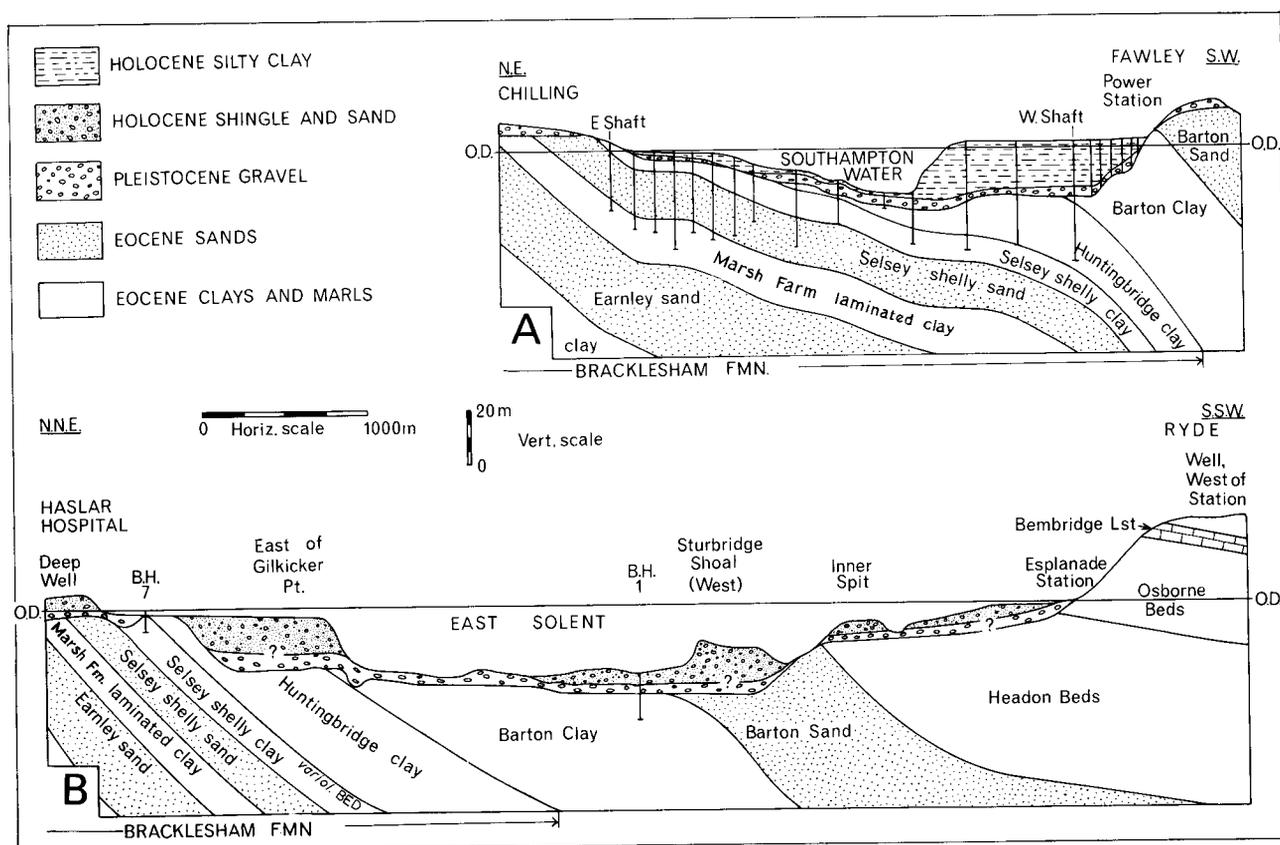


Fig. 2 A. Vertically exaggerated, transverse section of strata beneath the southern end of Southampton Water from near Fawley (SU 468018) to Chilling (SU 505045), based on sections of Curry, *et al.* (1968) and Hodson and West (1972).

B. Vertically exaggerated, transverse section through the East Solent or Spithead from Haslar Hospital (SZ 616987), near Gosport, to Ryde, Isle of Wight (SZ 592919). Minor changes of direction occur at borehole 1, (50° 45.38'N, 01° 09.0' W) and at borehole 7 (50° 46.72'N, 01° 07.51'W). This interpretation is based on unpublished borehole and geophysical data, Geological Survey maps and information in Fisher (1862), Whitaker (1910) and Dyer (1972).

and sometimes associations of the zeolite clinoptilolite and the clay mineral montmorillonite perhaps resulting from a fall of volcanic ash (Gilkes, 1968a). Boreholes, tunnels, geophysical data and information from wells under the Spithead forts (Fisher, 1862; Whitaker, 1910) have enabled the Bracklesham succession and structure under much of the estuarine system to be determined with reasonable accuracy (Fig. 2b).

A common Bracklesham facies is that of glauconitic sands of marine origin containing molluscan remains and calcareous nodules. Since these sands are pyritic, they can rapidly produce acidic groundwaters on artificial oxidation. Plant-debris rich, laminated, sandy clays and clayey sands, sometimes with ripple and flaser-bedding either of intertidal or fluvial-marsh origin (Murray and Wright, 1974; King and King, 1977), form another common facies. These two facies alternate.

The basal part of the Bracklesham Group, the Withering Member, is of Cuisian age. It consists mainly of sands and sandy clays and estuarine deposits with local oyster reefs. The overlying Lutetian beds, or Earnley Member, characterised by the large foraminifer *Nummulites laevigatus*, were exposed during excavations for both the Eastern and Western Docks of Southampton (Shore and Elwes, 1889; Anderson, 1933). Large spherical carbonate concretions were found at the Western Docks (Fig. 3) and examples are displayed on Southampton Royal Pier. Molluscan remains have been listed by Wrigley (1934) and a fine collection made by St. J Burton is housed at the Geology Department, Southampton University. Plant-debris rich, laminated beds which follow belong to the Marsh Farm Member, that has been recently exposed in the New Forest area at Copythorne (King and King, 1977).

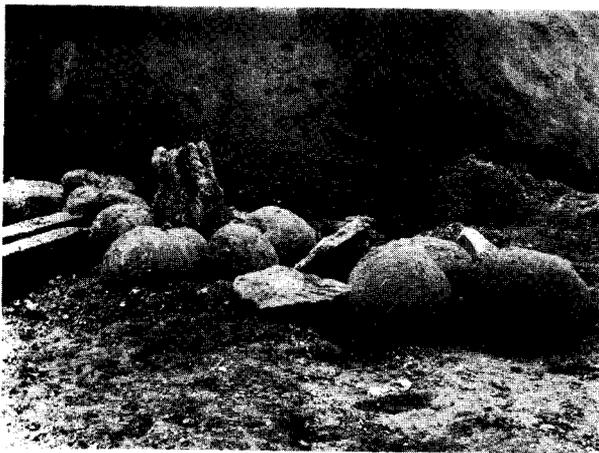


Fig. 3 Fossiliferous spherical concretions from the Earnley Member of the Bracklesham Formation excavated from the Western Docks, Southampton in 1932. I.G.S. photo A5828.

Above the Lutetian strata are the Auversian beds, or Selsey Member; mainly shelly clayey sands, containing *Nummulites variolarius* which have been dredged in the northwestern parts of Southampton Water and have been seen in shore exposures at Lee-on-Solent (Fisher, 1862; Evans, 1873; Kemp, 1976). The construction of a tunnel under the estuary from Fawley to Chilling provided a section (Fig. 2a) through these strata (Curry *et al.*, 1968; Gilkes, 1968b; Barker, 1974), although water under artesian pressure and the presence of large calcareous nodules caused some engineering problems. A rich fauna including coccoliths of calcareous nannoplankton zone NP15 was present in the glauconitic

clayey sands and sandy clays of these sediments (Hodson and West, 1970). Completing the Bracklesham Formation is the Huntingbridge Member (Auversian in part) which consists of relatively unfossiliferous greenish clays (Curry *et al.*, 1968) probably of marsh origin (Murray and Wright, 1974).

Above is the Barton Clay Formation (Highcliffe and Naish Members of Stinton) which is a blue-grey illite and montmorillonite clay (Gilkes, 1968a) with remains of marine molluscs. It varies in thickness from 30 to 50m and occurs beneath the central part of the East Solent and the southern part of Southampton Water (Fig. 2). It was temporarily exposed at Fawley Power Station under Pleistocene gravel where it was found to have been much fissured by periglacial processes (Marsland and Butler, 1967). The Barton Sand Formation (or Becton Member) is next in succession, being about 32m in thickness at Barton but attaining 63m at Whitecliff Bay (White, 1921). It occurs under the Spithead, the East Solent and the eastern part of the West Solent and is exposed in a low cliff between Calshot Spit and Stone Point.

The overlying strata are largely marls, quite different in character from the underlying clays and sands. Although some marine beds exist, they mostly contain abundant fresh and brackish-water molluscan faunas (White, 1921). They are well-developed on the northern coasts of the Isle of Wight, and occur beneath part of the West Solent where the lower beds extend to the mainland shores, (Fig. 1). The lowest of these strata are the Headon Formation.

These marls, soft limestones and sands vary in total thickness from 45 to 65m and contain interesting vertebrate remains (of snakes, rodents, crocodiles, turtles, large herbivores, etc) and abundant charophytes and pondsnails. Ostracods have shown that the conditions were lagoonal and that salinities fluctuated in the range between freshwater and normal marine. Similar to the Headon Formation in many respects although with less evidence of marine influence, are the marls of the Osborne Formation (24 to 43m), named after Queen Victoria's residence near Cowes where they were formerly well-exposed. Mammal, reptile and fish remains have also been found in these beds in addition, of course, to fresh and brackish-water mollusc shells. Capping these easily eroded formations is the freshwater Bembridge Limestone Formation which although only 5 to 8.5m in thickness is sufficiently resistant to form ledges and reefs on the north coast of the Isle of Wight (White, 1921). It was much quarried in the past as Binstead Stone and has been extensively used in old walls and buildings of Southampton.

The Bembridge Marls Formation (21 to 37m) commences with an oyster bed at the base testifying to an influx of seawater into the former freshwater lake (Daley, 1972; Gilkes, 1978). Above this the molluscs point to brackish conditions. Although the Hamstead Formation (78m thick) which overlies, contains brackish water molluscs through most of the sequence, these are not very useful for correlation. Marine beds at the top, however, possess coccoliths making possible a link with Oligocene strata (Lattorfian, nannoplankton zone NP.22) of the European mainland (Curry *et al.*, 1978). These Hamstead strata are the youngest Palaeogene beds of the Hampshire Basin.

(c) Pre-pleistocene history of the estuarine system

As the end of the Cretaceous Period approached, the Solent region was beneath part of an extensive sea in

which the slow accumulation of vast quantities of calcareous plates of planktonic algae formed the Chalk. In due course the sea-floor was gently but unevenly uplifted and erosion took place, particularly north of this region. After a long interval, gentle downwarping produced a smaller, shallower sea over southeast England and the eastern English Channel and one characterised by clastic sedimentation.

The Palaeogene climate was in general warmer than at present as indeed the remains of palm trees, alligators and pond-turtles at various horizons testify. In this sea, away from the shores, dark pyritic clays with marine mollusc shells, such as the London and Barton Clays were deposited. In near shore shoal waters, shelly glauconitic sands were laid down while unfossiliferous sands with plant debris, such as parts of the Bracklesham Formation, were products of small deltas which extended from the northwest into the shallow marine embayment that occupied this area (Murray and Wright, 1974). Sometimes the influx of river water was of sufficient quantity to reduce the salinity of the whole embayment and convert it into an estuary.

By the late Eocene and early Oligocene Periods (during deposition of the Lower Headon to Hamstead Formations) the basin was almost filled with sediment and early folding further reduced its size until it became a shallow lagoon or lake with margins that resembled the modern Florida cypress swamps. There was now little influx of coarse clastic detritus, low energy conditions prevailed and salinities were very variable (Keen, 1977). Sluggish rivers which cut channels like that at Hordle Cliff, supplied fresh water and at certain times the sea had access and the lagoon then acquired estuarine characteristics. Comparison has been made to brackish coastal lagoons of the Gulf of Mexico (Keen, 1977) although instead of a barrier beach restricting access of seawater it is more likely that a barrier of tectonic origin was periodically transgressed as sea-level oscillated.

The quieter sedimentation of this part of the Palaeogene is probably in part the consequence of a climatic change. A decrease in rainfall would accord with the major evaporite deposition taking place at this time in Northern France (Curry, *et al.*, 1978).

After the last Oligocene sedimentation a long period of uplift and low relative sea level commenced. Folding on the Isle of Wight anticlines, a process probably initiated during the Eocene, now intensified and erosion planed off the folded strata. There was a very long interval, many millions of years, for which there is no good record in this area, before the Pleistocene deposits were laid down as thin sheets of unconsolidated sediment lying unconformably on the Palaeogene formations.

Pleistocene deposits

(a) *Subangular flint gravels*

The most conspicuous and widespread of the Pleistocene deposits are the Plateau and Valley Gravels, consisting of subangular flint pebbles in matrices of brown, limonite-stained, coarse sands. They rarely exceed about 5 or 6m in thickness and are undisturbed by faulting or folding. Although elephant remains and palaeolithic implements are occasionally found (Shore, 1905; White, 1915), molluscan fossils are absent. The gravels have been exposed in low cliffs by wave action and are also seen in broad shallow commercial excavations around the margins of the estuarine system (Advisory Committee on

Sand and Gravel, 1950). These deposits lie on a series of terraces around the estuaries and descend from levels of about 128m in the northern part of the Hampshire Basin, with their lower members at about 5, 11, 21, 30, 46, 50 and 56m (Everard, 1954a; Swanson, 1970). Since the estuaries are drowned river valleys, similar gravels occur on submerged terraces and old valley floors (Everard, 1954b). The form of the buried channel under the southern end of Southampton Water has been revealed by boreholes to consist of submerged terraces with gravel bases at depths of -5, -11, -13 and -20m and with the valley floor at a depth of -24.4m (Curry *et al.*, 1968). Similarly, gravels lie at appreciable depths under Portsmouth, Langstone and Chichester Harbours.

The shape of the river valley under the East Solent has been determined by Dyer (1975) using seismic profiling. The old river channel of Southampton Water is known from borehole data to pass beneath Calshot Spit (Fig. 4), continuing in a southeasterly direction under the Bramble Bank before joining the main channel which descends eastwards through the Solent. Near Ryde Middle Bank this Solent channel branches into three parts, merging again to form a broad channel which deepens southeastwards through the East Solent and Spithead before eventually descending to below -46m beyond the area of the estuarine system (Dyer, 1972, 1975).

(b) *Interglacial mud and beach deposits*

Shingle deposits about 30m high to the north of Chichester and Portsmouth Harbours (Prestwich, 1872; Palmer and Cooke, 1923) belong to the Goodwood-Slindon-Wallington raised beach. Although a greater age has been suggested by Mitchell *et al.* (1973), evidence of palaeolithic handaxes (ApSimon *et al.*, 1977) firmly supports the conventional theory, based mainly on its height, that the beach is of Hoxnian age.

Forming the lower ground around the estuaries in the Portsmouth and Chichester areas are more extensive raised beach deposits, probably of Ipswichian age and therefore broadly equivalent to Eemian deposits of the continent. These are beds of pebbles and sands which lie on a wave-cut platform at heights between 1.8 and 5.6 O.D. (Hodgson, 1964) and grade northeastwards into subangular river gravels. This raised beach is also present in the Bembridge area of the Isle of Wight where it forms a coastal terrace (White, 1921).

Mud deposits of limited distribution are to be found in channels beneath the Ipswichian raised beach or equivalent low-level gravels and are also attributed to an Ipswichian (Eemian) age. The complexity of these interglacial deposits may be explained by the fact that there seem to have been three separate Eemian Interglacials (Bowen, 1979). Muds with estuarine faunas and floras and vertebrate remains have been found in such channels at West Wittering and Selsey (Reid, 1892; Johnson, 1901) while at Stone Point, in the West Solent, there are deposits of clay and peat within a channel containing remains not only of *Hydrobia* and other molluscs, but also of coccoliths and elephants (West and Sparks, 1960; Brown *et al.*, 1975). At Newtown Estuary, on the Isle of Wight, remains of a Pleistocene vertebrate fauna (Lucas, 1972) probably indicate a similar deposit. The age of a clay-filled channel under gravel at Southampton Western Docks (Wrigley, 1934) has not been established but it could be interglacial. There are erratics in the low-level raised beach and in the

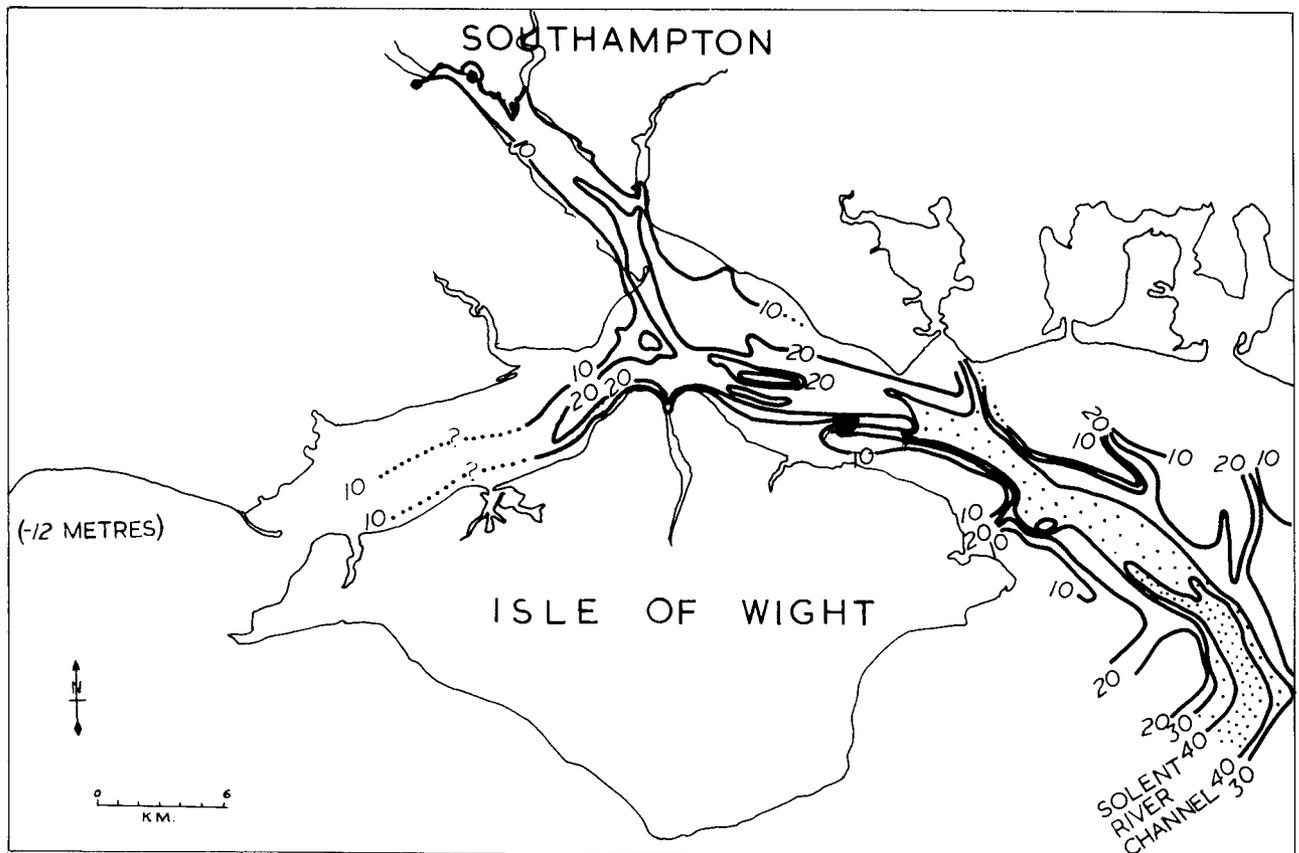


Fig. 4 Map of the buried channel of the Solent River showing the sub-Pleistocene surface in metres below Ordnance datum. Based on seismic profiling of the Solent by Dyer (1975) and on extensive unpublished borehole data on Southampton Water compiled by Hodson and West. The valley was cut to about -12m in Christchurch Bay and to a depth southeast of the Isle of Wight of about -46m. Note the discrepancy between the ancient valley and the modern channel at Calshot Spit.

channel deposits (West and Sparks, 1960) particularly around Portsmouth, Langstone and Chichester Harbours where igneous and metamorphic rocks are included (Prestwich, 1892; White, 1915).

(c) *Coombe rock and brickearth*

Overlying certain parts of the Ipswichian raised beach and therefore presumably Devensian in age, is some coombe rock. Such chalk debris, the result of solifluction in former periglacial conditions, occurs mainly in the region of the Chalk outcrops of the Portsdown Anticline and has been exposed around Chichester, Langstone and Portsmouth Harbours (White, 1915; Palmer and Cooke, 1923). The coombe rock grades southwards in these areas into the structureless brown silt known as brickearth, a type of deposit which near Southampton frequently overlies Pleistocene river gravels. Although brickearths in other regions have been regarded as loess, much of the Hampshire brickearth occurring as thin regular sheets on fluvial terraces, seems to have been deposited by water rather than by wind (Swanson, 1970; Fisher, 1973).

(d) *Pleistocene history of the estuarine system*

The distribution of the Pleistocene deposits is closely related to the positions of the modern rivers and estuaries of the Hampshire Basin. Study of them reveals the history of the rivers and periodical flooding of river valleys to form the estuaries.

By Pleistocene times the local rivers had already been established in approximately their present positions on a

coastal plain (Wooldridge and Linton, 1955) which probably had a slight curvature related to that of the Hampshire Basin (Bury, 1927). During periods of glacial advance, sea-level was very low and at times the English Channel was dry. Then a major river, the "Solent River" (Fig. 5), with a drainage area near that of the present Thames, flowed eastwards on the site of the Solent and Spithead (Fox, 1862; Codrington, 1870; Dyer, 1975) and deposited the sheets of Plateau and Valley Gravels (Everard, 1954b; Tremlett, 1965). During the interglacial ages the sea-level rose, normally to above the present level, and flooded the lower parts of the river system to form broad estuaries in the Solent area.

A detailed description of these events is difficult partly because the early Pleistocene history of this area is poorly known and partly because there are indications that the development and destruction of the "Solent River" was much more complex than is usually suggested. The earliest known Pleistocene evidence directly relating to the Solent estuarine system are the Slindon raised beach deposits formed at the eastern mouth of an interglacial precursor of the Solent estuary. It should be noted, however, that Kellaway (1971) and Kellaway *et al.* (1975) have challenged conventional theories by suggesting that during the Anglian and Wolstonian glacial age a major ice sheet existed in the English Channel and that the Goodwood-Slindon deposits are of fluvio-glacial origin. They considered the erratics of the Selsey and Portsmouth areas to be the remains of a moraine. The usual and apparently satisfactory explanation of these erratics is that they have simply been rafted to their

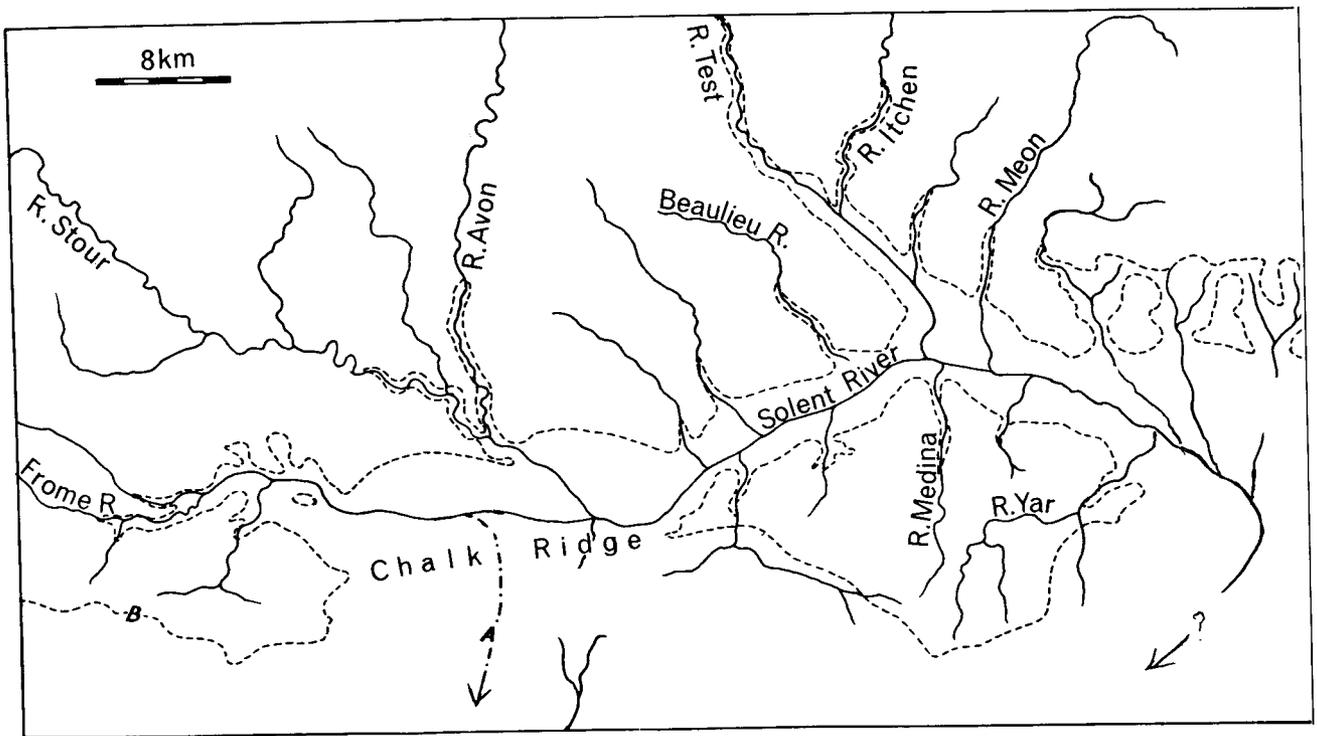


Fig.5 Reconstruction of the Solent River and its tributaries, modified from Everard (1954a) and Small (1964). Line A shows the approximate position of the stream which breached the Chalk ridge. Line B shows the area finally inundated during the Flandrian Transgression.

present sites by drifting masses of floating sea ice at a time of relatively high sea-level (e.g. Hodgson, 1964), thus explaining their restriction to the low coastal plain. A further suggestion of Kellaway *et al.* (1975) is that the hypothetical English Channel glacier dammed the "Solent River" and produced a glacial "Lake Solent" in which the submerged gravel terraces of Southampton Water were formed. Such an origin is difficult to reconcile with the uniformity in thickness of these gravels, their close similarity to the Pleistocene river gravels (Plateau and Valley Gravels) of this area and their downstream slope. Kidson and Bowen (1976) were quick to point out that the evidence from erratics is very weak and that there is a complete absence of stratigraphical evidence for the hypothetical English Channel glacier.

After the Hoxnian Interglacial sea-level fell, the estuary disappeared and some of the gravels below 30m originated on river floodplains. It was later during the Ipswichian Interglacial that a broad estuary was again developed as sea-level attained at least 7.6m above the present level (West and Sparks, 1960). Extensive marine erosion caused the formation of raised beaches in the eastern seaward part of the estuary, while terraces of subangular flint gravel, apparently horizontal, were formed in the western part (Everard, 1954a). It is unlikely that the West Solent was at this time connected westwards to the sea because of the lack either of erratics or of beach-rounder pebbles, both of which are present in equivalent deposits at Selsey (Brown *et al.*, 1975). During the existence of this Ipswichian estuary climate conditions were broadly similar to those at present. This explains why the invertebrate faunas of the estuaries resembled the modern ones, but it should be noted that in contrast the vertebrate fauna of the surrounding area included elephant, rhinoceros and hippopotamus.

The next major change was a return to cold conditions during the Devensian when the sea retreated and left the English Channel dry once more. Now the eastern

part of the "Solent River" again extended through the area (Everard, 1954a) and excavated a channel to a greater depth than previously. It swung round the eastern part of the Isle of Wight and connected with a westward-flowing extension of the River Seine (Dingwall, 1975). The gravel on the central valley floors of the estuaries (Fig. 2b) was deposited during this final phase of the Pleistocene.

The history of the upper part of the "Solent River" between the area of the present West Solent and the mouth of the Frome is poorly understood. There is a buried channel under Poole Harbour at -11m O.D. (Godwin *et al.*, 1958; Devoy, 1972) at too great a depth to fit Dyer's (1975) longitudinal profile of the "Solent River". The implication on this rather limited evidence, is that the Chalk ridge between the Isle of Wight and Purbeck was already breached by a major valley during this last glaciation, the Devensian, when sea-level was low, so that the extension of the Frome flowed southwards through a gap, somewhere south of Bournemouth.

Holocene deposits

(a) Marine shingle and sand

The Solent and Spithead region is the site of extensive Holocene (Flandrian) deposits of shingle and sand containing marine molluscs. An almost continuous belt runs along the northern coast of the Spithead and East Solent (White, 1915) and is particularly thick at the site of spits such as outside Portsmouth Harbour, where it reaches 21m (Whitaker, 1910) and at Calshot (Hodson and West, 1972). Calshot Spit is a barrier beach of the static type discussed by Evans (1979) which has remained on the same site as sedimentation has kept pace with rising sea level.

Most of the marine shingle lies below sea-level at the borders of the deep channel, 27m being found beneath No Mans Land Fort and 21m under Horse Sand Fort in the Spithead (Whitaker, 1910). Shingle at Browdown



Fig. 6 The peat sequence exposed during the excavation in 1932 of the King George V Graving Dock, Southampton. It is overlain by estuarine alluvium (with bivalves?). Compare with section 2 of Fig. 8. I.G.S. photo A5829.

Point and Stone Point, however, occurs above the high water mark (Godwin-Austen, 1857; Evans, 1873) but these are thin deposits, probably the result of recent storm-wave activity and do not indicate recent uplift.

(b) *Estuarine and freshwater clays, peat and tufa*

Within the more sheltered parts of the estuarine system, fine-grained, organic-rich sediments of Flandrian age are extensively developed. While some of these originated in river valleys prior to submergence by a rising sea-level and included fluviatile silty clays, peat and calcareous tufa, others, particularly the uppermost deposits, originated within or adjacent to estuarine waters. The very organic-rich, estuarine silty clays, are occasionally interrupted by beds of peat and often contain remains of salt marsh vegetation or *Scrobicularia* and other tidal-flat molluscs.

At the Western and Eastern Southampton Docks, beds of peat (Figs. 6, 7) with calcareous tufa of freshwater algal origin, mammalian bones and implements overlie the Pleistocene gravels (Shore and Elwes, 1889; Kemp, 1890; Hooley, 1905). The lower part dates from very early Flandrian (Mesolithic) while the upper layer is Sub-boreal (Neolithic) in age (Godwin and Godwin, 1940) and is surmounted by thin estuarine deposits, at least partly of Romano-British age (Fig. 8). Southward in Southampton Water, the boundary between Flandrian fluviatile and estuarine deposits occurs at progressively older horizons (Fig. 8). At Fawley, estuarine clays containing coccoliths (Fig. 9), diatoms (Fig. 10) foraminifera, ostracods and sponge spicules (Hodson and West, 1972; Goss, 1972; Barker, 1972) are present, but very early Flandrian deposits have not been found here. Carbon-dating (Churchill, 1965; Churchill *in* Godwin and Switzer, 1966), however, shows that sediments at -7.5m O.D. were formed when this was sea-level at a date of about 6300 B.P. A conspicuous bed of peat at about -3m O.D. both overlain and underlain by estuarine deposits originated at about 3500 B.P. and is thus of Sub-boreal age.

A peat bed of similar age according to pollen analysis fills a 15m deep buried channel of the River Yar at Yarmouth, Isle of Wight (Devoy, 1972) and a further Holocene succession comparable to that at Fawley

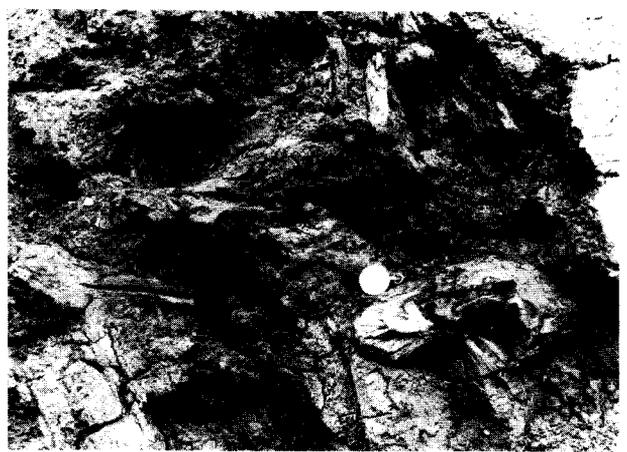


Fig. 7 Fallen tree trunks in the bed of peat at the King George V Graving Dock, Southampton, I.G.S. photo A5830.

occurs at Portsmouth Dockyard (James, 1847; Meyer, 1871). Within the latter a bed of tree roots and stumps between -6m and O.D. may correspond to the Fawley peat. Submerged forests, in fact, occur around the margins of much of the estuarine system including Southsea (White, 1915), Stokes Bay (Fisher, 1862) and the northern shores of the West Solent (Shore, 1893).

(c) *Holocene history of the estuarine system*

After the last glacial advance the history is largely one of a rising sea-level. During the early Flandrian, the sea began to invade the eastern remains of the Solent river system, initially at a high rate (West, 1972), and submerged many sites of Mesolithic habitation (Draper, 1966). By about 7430 B.P. it had reached -11.5m (Godwin *et al.*, 1958) resulting in the final separation of the Isle of Wight from the Purbeck mainland. In Sub-boreal (Neolithic) times there was probably a standstill or even a temporary regression, when the sea was still more than 3m below O.D. This would account for the spread of land vegetation over the saltmarshes and mud-flats to form the peats and the submerged forests, and perhaps also for much of the submerged shingle in the Spithead which could have originally travelled by longshore drift along former beaches and spits.

After the pause, as in other parts of southern England (Oakley, 1943; West, 1967), the transgression was resumed, at least by Romano-British times (Shore and Elwes, 1889; Shore, 1893). The suggestion that an isthmus across the Solent still linked the Isle of Wight and the mainland at this time (Reid, 1905, 1913) is most unlikely in view of the existence of the deep channel which had been excavated by the "Solent River" and which was now flooded (Steers, 1946). A continuing rise of sea level into historic times may be indicated by evidence on the Isle of Wight (Godwin-Austen, 1857). Flooding combined with wave erosion has taken place on shores facing open stretches of water, particularly near Lee-on-Solent and Portsmouth. At the same time in areas sheltered from waves, particularly those driven by the prevailing southwesterly winds, organic-rich silty clays were laid down forming tidal mud-flats and saltmarshes. Sedimentation has often kept pace with rising sea level (Hodson and West, 1972) such that, as the estuary has extended, the proportion of very shallow areas has gradually increased.

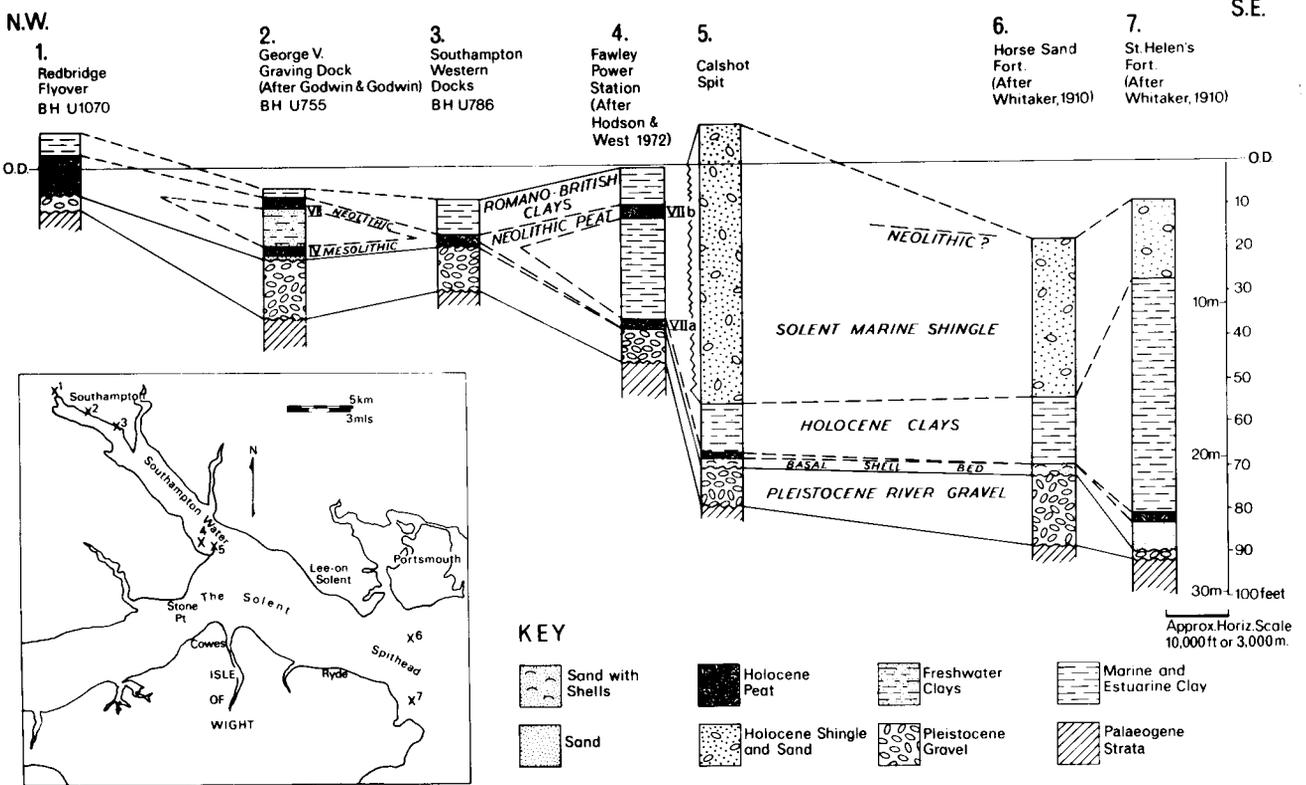


Fig. 8 Quaternary sequences in Southampton Water, the East Solent and the Spithead, with approximate correlations.

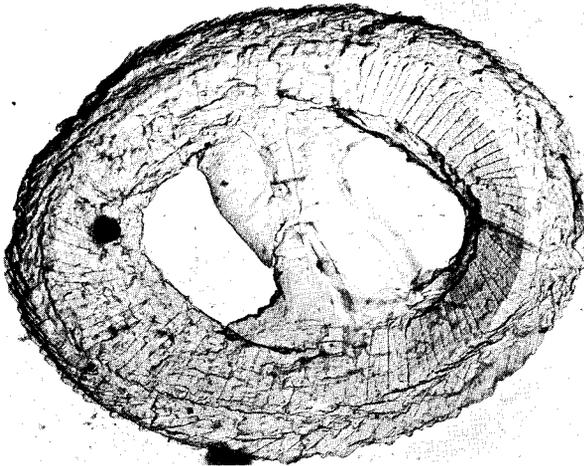


Fig. 9 Above: Coccolith, *Transversopontis obliquipons* (Deflandre) from the Selsey Member of the Bracklesham Formation (see Hodson and West, 1970) at Fawley. T.E.M. :X 10280.

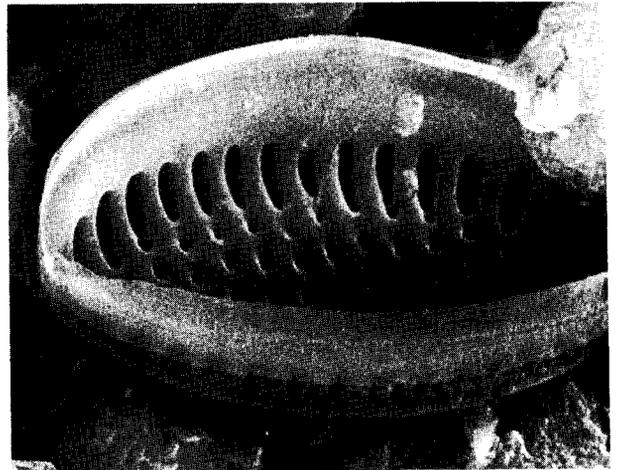


Fig. 10a ▲

Fig. 10b ▼

Fig. 10a, b Diatoms from estuarine mud from the excavations of Fawley Power Station S.E.M. X 2630. See Goss in Hodson and West (1972) for details of diatoms from this locality.

The search for oil and geothermal energy

Petroleum exploration, particularly geophysical, has taken place in recent years around the Solent estuarine system. It follows the major oil discoveries which have been made in Bridport Sands (Lias) and Triassic strata, the Wytch Farm and Wareham areas in Dorset (Anon., 1978), within traps formed by upfaulted north dipping blocks concealed beneath nearly horizontal Cretaceous and Palaeogene strata (Dorset County Council, 1979).

Thick Jurassic sequences with oil source rocks, underlie Poole and Christchurch Bays between the Dorset oil fields and the estuarine system (Terris and Bullerwell, 1965). Porous reservoir rocks probably exist at depth in the Solent area but it is not yet known whether there are appropriate fault traps or whether hydrocarbons have been retained. A major concealed fault associated with the Dorset oil fields may extend eastwards to the Isle of Wight (Western Gazette, 12 May 1978) and could enter the estuarine area. It is possible that the minor structures at the surface in the northern part of the Isle of Wight may give clues to the position of deeper structures.

No commercially useful quantities of oil have yet been reported from boreholes at Portsdown (Tait and Kent, 1958) and Arreton, Isle of Wight, (Falcon and Kent, 1960) on either side of the Solent, although the initial boreholes did not penetrate deep into the New Red Sandstone. The geophysical surveys have been undertaken for oil companies in the New Forest, the Romsey and Chandlers Ford areas, the region of the Portsdown-Swaythling Anticline, the adjacent Channel seafloor and elsewhere in the vicinity of the estuaries. If the results are eventually published they would throw much light on the geological structure of the area.

A deep borehole to Permo-Triassic strata at depths of about 4,000m at Marchwood Power Station has just commenced at the time of writing and should provide exciting new information on the strata at depth under the basin. It should soon be known whether the New Red strata are sufficiently permeable for extraction of hot water and whether there is much salt or other evaporites present. If it is successful but hot saline water emerges, the brines might be reinjected down a parallel borehole thus avoiding pollution problems. Much scientific data of various types will undoubtedly come from this first deep borehole in the centre of the basin, whatever the economic value.

Future investigations

Some comments are made with regard to useful future investigations. Some of the deficiencies in research may soon be rectified, however, and it should be stressed that these comments apply only at present, October 1979. One aspect of research that will probably advance quite rapidly is the search for oil and hot water in this area. The investigations will probably continue, at least until more boreholes provide definite information as to prospects. It is unfortunate that there will probably be an appreciable delay in most cases, however, before the results are published.

With regard to the shallow strata, it is not easy to isolate problems of the geology of the estuaries from problems of the geology of the surrounding region, and most of these are beyond the scope of this brief survey. It is of course obvious that the strata beneath the estuaries are less well known than those of the weathered exposures at the margins.

Further investigations on the succession and distribution of Palaeogene deposits would provide valuable

information for civil engineering purposes, and systematic compilation of existing borehole data and study of samples would enable the construction of a large scale map of the "solid geology" of the floor of the estuarine system. Similarly a detailed map, including information on thicknesses, for Quaternary deposits, would also be of considerable practical value.

The history of the estuarine system throughout the Quaternary is still very poorly understood. As knowledge of the Pleistocene advances, in general, the implications regarding the Solent area will need investigation. Current arguments about a hypothetical glacial "Lake Solent" obviously need to be resolved. Lacking at present are adequate sedimentological and clay mineralogical data on Pleistocene brickearths, interglacial deposits and gravels.

Holocene deposits throughout the estuarine system have not yet been adequately investigated. In addition to more pollen-analysis and carbon-dating, geochemical and sedimentological studies would be of value for determining the origin and history of the Holocene deposits, as these would provide a better understanding of the Flandrian Transgression in southern England. Of potential economic importance are the marine shingle deposits of Holocene age, and their distribution, thicknesses and origin warrant investigation.

Of the various parts of the estuarine system, the West Solent in particular is very poorly known. The very rapid coastal recession of Christchurch Bay of up to 1m per annum (Codrington, 1870; Barton, 1973), means that the western entrance is changing appreciably. The Holocene history of the landward moving (and now dangerously narrow) Hurst Spit will undoubtedly be the subject of much future research. The detailed relationship of the salt marshes and their underlying Holocene muds on the north shore of the West Solent to the gravel of the spit is not known, although here in particular the sediments probably provide an important record of the Flandrian transgression into the former river valley.

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REFERENCES

Advisory Committee on Sand and Gravel (1950). Part 5 Wessex, pp 43. H.M.S.O. London.
Anderson, F.W. (1933). The new docks excavations, Southampton. *Pap. Proc. Hampsh. Fid. Club*, 12, 169-176.
Anon (1978). U.K. production booms onshore too. *International Petroleum Times*, May 15th, 1978, p.8.
ApSimon, A., Gamble, C. and Shackley, D.M. (1977).

Pleistocene raised beaches on Portsdown. *Proc. Hants. Field Club Archaeol. Soc.*, 33, 17-32.
Barker, D. (1972). The ostracods. *Appendix* to Hodson and West: The Holocene deposits of Fawley, Hampshire and the development of Southampton Water. *Proc. Geol. Ass.*, 83, 438.
Barker, D. (1974). Eocene ostracods from the Fawley Transmission Tunnel. *Proc. Geol. Ass.*, 85, 387-389.

- Barton, M.E. (1973). The degradation of the Barton Clay cliffs of Hampshire. *Q. Jl. Engng. Geol.*, 6, 423-440.
- Barton, M.E. (1978). Engineering geology applied to dock and harbour engineering in Southampton Water. Read at Regional meeting of the Engineering Group of the Geol. Soc., Lond., 21pp.
- Bone, D.A. and James, J.P. (1975). Report of field meeting to Chichester Harbour, Sussex. *Tertiary Times*, 2/3, 99-100.
- Bowen, D.Q. (1979) Quaternary correlations. *Nature*, 277, 171-172.
- Bristow, H.W. (1862). The Geology of the Isle of Wight. *Mem. Geol. Surv. U.K.*, pp. xix + 138.
- Bristow, H.W., Reid, C. and Strahan, A. (1889). The Geology of the Isle of Wight (2nd Edition). *Mem. Geol. Surv. U.K.*, pp xiv + 349.
- Brown, R.C., Gilbertson, D.D., Green, C.O. and Keen, D.H. (1975). Stratigraphy and environmental significance of Pleistocene deposits at Stone, Hampshire. *Proc. Geol. Ass.*, 86, 349-363.
- Brydone, R.M. (1912). *The stratigraphy of the Chalk of Hants*, p.p. 116 and map. Duiiau, London.
- Buchan, S., Robbie, J.A., Butler, A.J., Holmes, S.C.A. and Morris, L.S.O. (1942). Water supply from underground sources of Reading, Southampton district. *Geol. Surv. U.K., Wartime Pamphlet*, No. 15, Part 6, pp. 63.
- Burnett, A.D. and Fookes, P.G. (1974). A regional engineering study of the London Clay in the London and Hampshire Basins. *Q. Jl. Engng. Geol.*, 7, 257-295.
- Bury, H. (1927). The rivers of the Hampshire Basin. *Pap. Proc. Hampsh. Fld. Club*, 10, 1-11.
- Chatwin, C.P. (1960). British Regional Geology: The Hampshire Basin and Adjoining Areas (3rd Edition) *Mem. Geol. Surv. U.K.*, pp iv + 99. (New edition, revised by Melville, is in press).
- Churchill, D.M. (1965). The displacement of deposits formed at sea-level 6500 years ago in southern Britain. *Quaternaria* 7, 239-249.
- Codrington, T. (1870). On the superficial deposits of the south of Hampshire and the Isle of Wight. *Quart. Jl. geol. Soc., Lond.*, 26, 528-551.
- Cooper, J. (1976). British Tertiary stratigraphical and rock terms formal and informal, additional to Curry, 1958, *Lexique Stratigraphique International*; with a stratigraphical table. *Tertiary Research Group, Special Paper* No. 1.
- Costa, L.I. and Downie, C. (1976). The distribution of the dinoflagellate *Wetzeliella* in the Palaeogene of North-Western Europe. *Palaeontology*, 19, 591-614.
- Curry, D. (1966). Problems of correlation in the Anglo-Paris-Belgium Basin. *Proc. Geol. Ass.*, 77, 437-467.
- Curry, D., Adams, C.G., Boulter, M.C., Dilley, F.C., Eames, F.E., Funnell, B.M., Wellis, M.K. (1978). A correlation of Tertiary rocks in the British Isles. *Geol. Soc. Lond*, Special Report, No. 12, 72pp.
- Curry, D., Hodson, F. and West, I.M. (1968). The Eocene succession in the Fawley Transmission Tunnel. *Proc. Geol. Ass.* 79, 179-206.
- Curry, D., Daley, B., Edwards, N., Middlemiss, F.A., Stinton, F.C. and Wright, C.W. (1972). The Isle of Wight. *Geologists' Association Guides* No. 25 (3rd edition), pp27.
- Curry, D., King, A.D., King, C. and Stinton, F.C. (1977). The Bracklesham Beds (Eocene) of Bracklesham Bay and Selsey, Sussex. *Proc. geol. Ass.*, 88, 243-254.
- Daley, D. (1972). Macroinvertebrate assemblages from the Bembridge Marls (Oligocene) of the Isle of Wight, England, and their environmental significance. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 11, 11-32.
- Daley, B., Edwards, N. and Insole, A.N. (1979). Lithostratigraphical nomenclature of the English Palaeogene succession. *Geol. Mag.*, 116, 65-66.
- Devoy, R.J.N. (1972). *Environmental changes in the Solent area during the Flandrian Era*. Unpublished dissertation for the B.A. Honours Degree in Geography. University of Durham, pp 47.
- Dingwall, R.G. (1971). The structural and stratigraphical geology of a portion of the eastern English Channel. *Inst. Geol. Sci., Report 71/8* pp.vii + 24.
- Dingwall, R.G. (1975). Sub-bottom infilled channels in an area of the eastern English Channel. *Phil. Trans. R. Soc. A.* 279, 233-241.
- Dorset County Council (1979). Goathorn Peninsula Report of Working Party on the environmental implications of an exploration well site for oil or gas. 72pp.
- Draper, J.C. (1966). Mesolithic distribution in south-east Hampshire. (*Pap. Proc. Hampsh. Fld Club*, 23, 110-119.
- Dunham, K. and Smith, A.J. (organisers) (1975). A discussion on the Geology of the English Channel. *Phil. Trans. R. Soc. A.* 279, 1-295. (An important symposium with 85 papers including a bibliography).
- Dyer, K.R. (1971). The distribution and movement of sediment in the Solent, southern England. *Mar. Geol.*, 11, 175-187.
- Dyer, K.R. (1972). Recent sedimentation in the Solent area. *Mem. Bur. Rech. Geol. Min.*, No. 79, 271-280.
- Dyer, K.R. (1975). The buried channels of the "Solent River", southern England. *Proc. Geol. Ass.*, 86, 239-245.
- Dyer, K.R., Hamilton, N. and Pingree, R.D. (1969). A seismic refraction line across the Solent. *Geol. Mag.*, 106, 92-95.
- Eaton, G.L. (1971). The use of microplankton in resolving stratigraphical problems in the Eocene of the Isle of Wight. *Q. Jl. geol. Soc. Lond.*, 127, 281-282.
- Eaton, G.L. (1976). Dinoflagellate cysts from the Bracklesham Beds (Eocene) of the Isle of Wight, Southern England. *Bull. Brit. Mus. (Nat. Hist.)*, *Geology*, 26, No. 6, 230-332.
- Edmunds, F.H. (1928). Wells and Springs of Sussex. *Mem. Geol. Surv. U.K.*, pp viii + 263.
- Edwards, N. (1971). Stratigraphy and correlation of the Headon, Osborne, Bembridge and Hempstead Beds (Palaeogene), Hampshire Basin - a bibliography (1814-1970). *J. Soc. Biblioph. nat. Hist.*, 6, 50-60.
- Evans, C. (1873). Geology of the neighbourhood of Portsmouth and Ryde. *Proc. Geol. Ass.*, 2, 61-76, 149-174.
- Evans, G. (1979). Quaternary transgressions and regressions. *Jl. geol. Soc. Lond.*, 136, 125-132.
- Everard, C.E. (1954a). The Solent river: a geomorphological study. *Trans. Inst. Br. Geogr.*, 20, 41-58.
- Everard, C.E. (1954b). Submerged gravel and peat in Southampton Water. *Pap. Proc. Hampsh. Fld Club*, 18, 263-285.
- Falcon, N.L. and Kent, P.E. (1960). Geological Results of Petroleum Exploration in Britain 1945-1957. *Geological Society of London, Memoir* No. 2, 56pp.
- Fisher, G.C. (1973). Brickearth and its influence on the character of soil, in the south-east New Forest. *Pap. Proc. Hampsh. Fld Club*, 28, 99-109.
- Fisher, O. (1862). On the Bracklesham Beds of the Isle of Wight basin. *Q. Jl. geol. Soc. Lond.*, 18, 65-94.
- Fox, W.D. (1862). When and how was the Isle of Wight separated from the mainland? *Geologist*, 5, 452.
- Gilkes, R. (1968a). Clay mineral provinces in the Tertiary sediments of the Hampshire Basin. *Clay Miner.*, 7, 351-361.

- Gilkes, R. (1968b). Clay mineralogy of selected specimens from the Transmission Tunnel excavations. *Appendix to Curry, Hodson and West: The Eocene succession in the Fawley Transmission Tunnel. Proc. Geol. Ass.*, 79, 203-206.
- Gilkes, R. (1978). On the clay mineralogy of Upper Eocene and Oligocene sediments in the Hampshire Basin. *Proc. Geol. Ass.*, 89, 43-56.
- Godwin, G. and Godwin, M.E. (1940). Submerged peat at Southampton; data for the study of Postglacial history. *New Phytol.* 39, 303-307.
- Godwin, G. and Switzer, V.R. (1966). Cambridge University natural radiocarbon measurements V111. *Radiocarbon*, 8, 390-400.
- Godwin, G., Suggate, R.P. and Willis, E.G. (1958). Radiocarbon dating of the eustatic rise in ocean level. *Nature, Lond.* 181, 1518-1519.
- Godwin-Austen, R.A.C. (1857). On the Tertiary deposits of the Sussex coast. *Q. Jl. geol. Soc. Lond.*, 13, 40-47.
- Goss, C. (1972). The diatoms. *Appendix to Hodson and West: The Holocene deposits of Fawley, Hampshire and the development of Southampton Water. Proc. Geol. Ass.*, 83, 439-444.
- Hamilton, D., Hommeril, P., Larsonneur, C. and Smith, A.J. (1975) Geological bibliography for the English Channel (Part 2). *Phil. Trans. R. Soc.*, A.279, 289-295.
- Hodgson, J.M. (1964). The low-level Pleistocene marine sands and gravels of the west Sussex coastal plain. *Proc. Geol. Ass.*, 75, 547-561.
- Hodson, F. and Shelford, P.H. (1964). Geology, In "A Survey of Southampton and its Region" (F.J. Monkhouse, ed.) pp 15-36. British Association for the Advancement of Science, Southampton.
- Hodson, F. and West, I.M. (1970). Calcareous nannoplankton from an Upper Bracklesham horizon at Fawley, Hampshire. *Revue Micropaleont.*, 13, 165-187.
- Hodson, F. and West, I.M. (1972). The Holocene deposits of Fawley, Hampshire and the development of Southampton Water. *Proc. Geol. Ass.* 83, 421-444.
- Hooley, R.W. (1905). Excavations on the site of the Electric Light Works, Southampton, May 1903. *Pap. Proc. Hampsh. Fld. Club*, 5, 47-52.
- James, H. (1847). On a section exposed by the excavation at the new steam basin in Portsmouth Dockyard. *Q. Jl. geol. Soc. Lond.*, 3, 249-251.
- Johnson, J.P. (1901). The Pleistocene fauna of West Wittering. *Proc. Geol. Ass.*, 17, 261-264.
- Keen, M.C. (1977). Ostracod assemblages and the depositional environments of the Headon, Osborne and Bembridge (Upper Eocene) of the Hampshire Basin. *Palaeontology*, 20, 405-445.
- Kellaway, G.A. (1971). Glaciation and the stones of Stonehenge. *Nature, Lond.*, 232, 30-35.
- Kellaway, G.A., Redding, J.H., Shephard-Thorn, E.R. and Destombes, J.P. (1975). The Quaternary history of the English Channel. *Phil. Trans. R. Soc.*, A.279, 189-218.
- Kemp, D.J. (1976). Account of excavations into the Campanile Bed (Eocene, Selsey Formation) at Stubbington, Hants. *Tertiary Research* 1, 41-45.
- Kemp, J.T. (1890). The tufaceous deposits of the Test and Itchen. *Pap. Proc. Hampsh. Fld Club*, 1, 83-89.
- Kidson, C. and Bowen, D.Q. (1976). Some comments on the history of the English Channel. *Quaternary Newsletter* (Quaternary Research Association), No. 18, 8-10.
- King, A.D. & King, C. 1977. The stratigraphy of the Earnley 'division' (Bracklesham Group) at Copythorne, Hampshire. *Tertiary Res.*, 1, 115-118.
- Lucas, C.S. (1972). Report on Pleistocene deposits in Newtown nature reserve. *Proc. Isle Wight nat. Hist. Archaeol. Soc.*, 6, 401-404.
- Marsland, A. and Butler, M.E. (1967). Strength measurements on stiff fissured Barton Clay from Fawley (Hampshire), *Proc. Geotechnical Conf., Oslo*, 1, 139-145.
- Martin, E.C. (1938). The Littlehampton and Portsdown Chalk inliers and their relation to the raised beaches of West Sussex. *Proc. Geol. Ass.*, 49, 198-212.
- Meyer, C.J.A. (1871). On the Lower Tertiary deposits recently exposed at Portsmouth. *Q. Jl. geol. Soc. Lond.*, 27, 74-89.
- Mitchell, G.F., Penny, L.F., Shotton, F.W. and West, R.G. (1973). A correlation of Quaternary deposits in the British Isles. *Geol. Soc. Lond. Special Report* No. 4 pp 99.
- Murray, J.W. and Wright, C.A. (1974). Palaeogene foraminiferida and palaeoecology, Hampshire and Paris Basins and the English Channel. *Special Papers in Palaeontology*, No. 14, pp. iv + 129. Palaeont. Ass. London.
- Oakley, K.P. (1943). A note on the postglacial submergence of the Solent margin. *Proc. Prehist. Soc. N.S.*, 9, 56-59.
- Odin, G.S., Curry, D. and Hunziker, J.C. (1978). Radiometric dates from NW European glauconites and the Palaeogene time-scale. *Jl. geol. Soc. Lond.*, 135, pp 481-497.
- Palmer, L.S. and Cooke, J.H. (1923). The Pleistocene deposits of the Portsmouth district and their relation to man. *Proc. Geol. Ass.*, 34, 253-282.
- Prestwich, J. (1854). On the structure of the strata between the London Clay and the Chalk in the London and Hampshire Tertiary Systems. Part II. The Woolwich and Reading Series. *Q. Jl. geol. Soc. Lond.*, 10, 75-170.
- Prestwich, J. (1872). On the presence of a raised beach at Portsdown Hill near Portsmouth and on the occurrence of a flint implement at a high level at Downton. *Q. Jl. geol. Soc. Lond.*, 28, 38-41.
- Prestwich, J. (1892). The raised beaches and "head" or pebble-drift of the south of England. *Q. Jl. geol. Soc. Lond.*, 48, 263-343.
- Reid, C. (1892). The Pleistocene deposits of the Sussex coast and their equivalents in other districts. *Q. Jl. Geol. Soc. Lond.*, 48, 344-361.
- Reid, C. (1905). The island of Ictis. *Archaeologia*, 59, 218-288.
- Reid, C. (1913). *Submerged Forests*, pp. viii + 129, University Press, Cambridge.
- Reid, C. and Whitaker, W. (1902). The Geology of the Country around Southampton. *Mem. Geol. Surv. U.K.*, pp iv + 30.
- Shore, T.W. (1893). Hampshire mudlands and other alluvium. *Pap. Proc. Hampsh. Fld. Club*, 2, 181-200.
- Shore, T.W. (1905). The origin of Southampton Water. *Pap. Proc. Hampsh. Fld Club* 5, 1-25.
- Shore, T.W. and Elwes, J.W. (1889). The new dock excavations at Southampton. *Pap. Proc. Hampsh. Fld Club*, 1, 43-56.
- Small, R.J. (1964). Geomorphology, In "A Survey of Southampton and its Region" (F.J. Monkhouse, ed.), pp. 37-50. British Association for the Advancement of Science, Southampton.
- Smith, A.J., Hamilton, D., Williams, D.N. and Hommeril, P. (1972). Bibliographie géologique de la Manche, *Mém. Bur. Reconn. Geol. Min.*, No. 79, 303-323.
- Steers, J.A. (1946). *The Coastline of England and Wales*, pp xix + 644. University Press, Cambridge.

- Stinton, F.C. (1975). Fish otoliths from the English Eocene. *Palaeontogr. Soc. (Monogr.)* : (1), pp. 1-56.
- Stinton, F.C. and Curry, D. (1979). Lithostratigraphical nomenclature of the English Palaeogene succession. *Geol. Mag.*, 116, 66-67.
- Swanson, E.H. (1970). Pleistocene geochronology in the New Forest, Hampshire. *Bull. Inst. Archaeol.*, Nos. 8 & 9, for 1968-69. 55-100.
- Tait, A.H. and Kent, P.E. (1958). Deep boreholes at Portsdown and Henfield. *Technical Publications of the British Petroleum Company Ltd.*, London, 41pp.
- Terris, A.O. and Bullerwell, W. (1965). Investigations into the underground structure of southern England. *Advancement of Science*, Aug. 1965, 232-252.
- Tillotson, E. (1974). Earthquakes, explosions and the deep underground structure of the United Kingdom. *J. Earth Sci.*, 8, 353-364.
- Tremlett, W.E. (1965). The evolution of the Beaulieu drainage system in the south-east New Forest. *Pap. Proc. Hampsh. Fld Club*, 23, 48-59.
- West, R.G. (1967). The Quaternary of the British Isles. In *"The Quaternary"* Vol. 2 (K. Randama, ed.), 1-87. Wiley, New York.
- West, R.G. (1972). Relative land-sea-level changes in southeastern England during the Pleistocene. *Phil. Trans. R. Soc.*, A272, 87-97.
- West, R.G. and Sparks, B.W. (1960). Coastal interglacial deposits of the English Channel. *Phil. Trans. R. Soc.*, B. 243, 95-133.
- Whitaker, W. (1873). List of works on the Geology, Mineralogy and Palaeontology of the Hampshire Basin. *Journal of Proceedings of the Winchester and Hampshire Scientific Literary Society* 1875, 108-127.
- Whitaker, W. (1910). The Water Supply of Hampshire. *Mem. Geol. Surv. U.K.*, pp. v + 252.
- White, H.J.O. (1915). The Geology of the Country near Lymington and Portsmouth. *Mem. Geol. Surv. U.K.*, pp. v + 78.
- White, H.J.O. (1921). A Short Account of the Geology of the Isle of Wight. *Mem. Geol. Surv. U.K.*, pp. v + 219 (reprinted in 1968).
- Wooldridge, S.W. and Linton, D.L. (1955). *Structure, Surface and Drainage in south-east England*, pp. viii + 176. Philip, London (reprinted in 1964).
- Wrigley, A. (1934). A Lutetian fauna at Southampton docks. *Proc. Geol. Ass.*, 45, 1-16.
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