ARCHAEOLOGICAL AND HISTORICAL ASPECTS OF CHANGE IN THE SOLENT COASTLINE

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Following the initial drowning of the Solent valley in the Mesolithic period and the subsequent post-glacial rise in sea level which lasted into Neolithic times, a further rise of approximately 5m in sea level has occurred in the Southampton area (Oakley, 1943). Such a rise is of sufficient amplitude to have inundated a strip of coastal plain approximately 800m wide, with the resultant loss and destruction of archaeological material such that any conclusions must be based on evidence from marginal sites, chance finds and historical tradition.

The earliest evidence for inundation is to be found in the distribution of Mesolithic settlements which, by the occurrence of tranchets on both sides of the submerged channel, were riverine sites based on the ancient Solent River (Rankine, 1956). Many early fishing settlements must have been abandoned to flooding although the only evidence for this has come from dredging activities. For example, in 1887 a quartzite macehead with hour-glass perforation was found 6m below the mud during the construction of the Ocean Dock, while some flint flakes and a stiletto-like bone (Rankine, 1956), variously described as a needle (Shore and Elwes, 1889) or a dagger (Dawkins, 1900) were also discovered. However, these finds have since been lost, and it is not clear whether they were found in association. Furthermore, an unpatinated flint flake showing no secondary flaking was found in 1930 at a depth of 5.5m beneath the Southampton Corporation Baths (Godwin and Godwin, 1940). There is no evidence of further prehistoric settlement of the low-lying coastal areas, and the suggestion made by Sumner (1917) that the Solent Valley was dry and inhabited during the Bronze Age has been discounted. This theory was based entirely upon the misidentification of the Mesolithic macehead as belonging to the Bronze Age period (Dawkins, 1900).

Traditionally there was a land connection between the Isle of Wight and the mainland as late as 90 B.C. Diodorus Siculus refers to the island of Ictis, which is assumed to be the Isle of Wight, where "during the ebb of the tide the intervening space is left dry, and they carry over into this island the tin in abundance in their waggons....... Here, then, the merchants buy the tin from the natives and carry it over to Gaul." Reid (1905) who carried out part of the geological survey of the Isle of Wight, was of the opinion that such a causeway was an outcrop of Bembridge limestone between Yarmouth and Pennington. Irrespective of whether the early tradition regarding Cornish tin is correct, there certainly was a later link between the industry and the Solent. A petition of 1689 refers to the carrying by sea, almost time out of mind, of charcoal from the New Forest to Cornwall for the use of refiners of tin (Cal. S.P.Dom., 1689).

The situation of two major Roman sites in the Solent, Clausentum on the River Itchen and the fort at Porchester, are such as to suggest that little or no change has occurred in the coastline at these points. On the other hand, a Roman building at Gurnard has been destroyed by cliff erosion since 1864 (Witherby, 1962). From Gurnard a supposed Roman road crossed the Island to the Roman fort at Carisbrooke, and on the mainland a suggested Roman road runs down to Lepe (William-Freeman, 1915). Doubts have been expressed as to the Roman dating of this feature, although it is referred to as the great road, "per magnum cheminum", as early as 1218 (New Forest Perambulation, 1218), and it is difficult to put forward any alternative suggestions as to its purpose.

Very little is known of the early associations between the Isle of Wight and the mainland. As early as the 7th century, land on the Island was granted to Winchester (Finberg, 1964), and at the time of the Domesday Survey several detached hides were held by mainland manors (Finn, 1962). It may possibly be that the association originated in a Jutish expansion from the Island in search of grazing land in the New Forest.

Although Shore (1893, 1905) refers to an inundation by the sea about A.D. 419, and to encroachments in south-east Hampshire in the 11th century and at Mayling Island and Alverstoke in the 13/14th century, the continued existence of such features as the mediaeval salterns near Lymington suggest very little permanent loss of land in historic times. Even though the 16th century St Andrew's Castle has now been destroyed, its foundations are still visible on the Hamble foreshore.

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SEDIMENTATION AND SEDIMENT TRANSPORT

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Introduction

The Solent, Southampton Water and their tributary inlets form the drowned remnants of a previously extensive river system (see Section 2) which was incised to at least -45m below present sea level. During the ensuing Flandrian transgression, the Isle of Wight-Purbeck ridge was breached, and this has been followed by fairly rapid erosion during the last few thousand years, of the soft, plateau-gravel covered Tertiary rocks which has released large quantities of clays, sands and gravel. Continuing erosion indicates that an equilibrium configuration has yet to be attained.

The tidal conditions within the area are complicated (see Section 5) with a tidal range that can reach 5m at Southampton. Within the Solent, the currents are dominated by the differing amplitudes and phases at either end and, although following a smooth curve, the currents change direction before high or low water. There is generally only a short period of slack water during the tidal cycle and the currents are almost symmetrical. The small differences that do occur, however, appear to be significant in the sedimentation patterns. In contrast, slack water within Southampton Water and the other inlets coincides with high or low tide, and complicated effects due to a double peak on the flood tide and a double high water at spring tides are present. These factors produce a fast, short duration, ebb flow and a slower, longer flood flow, with a long period of slack water at high tide.

The coastlines of the area are exposed to wave action which is generally from a SW or SE quarter due to the sheltering effect of the Isle of Wight. Maximum surface currents exceed 2m sec^{-1} in the West Solent and 1.5m sec^{-1} in the mouths of inlets such as Portsmouth Harbour.

Thickness of sediment

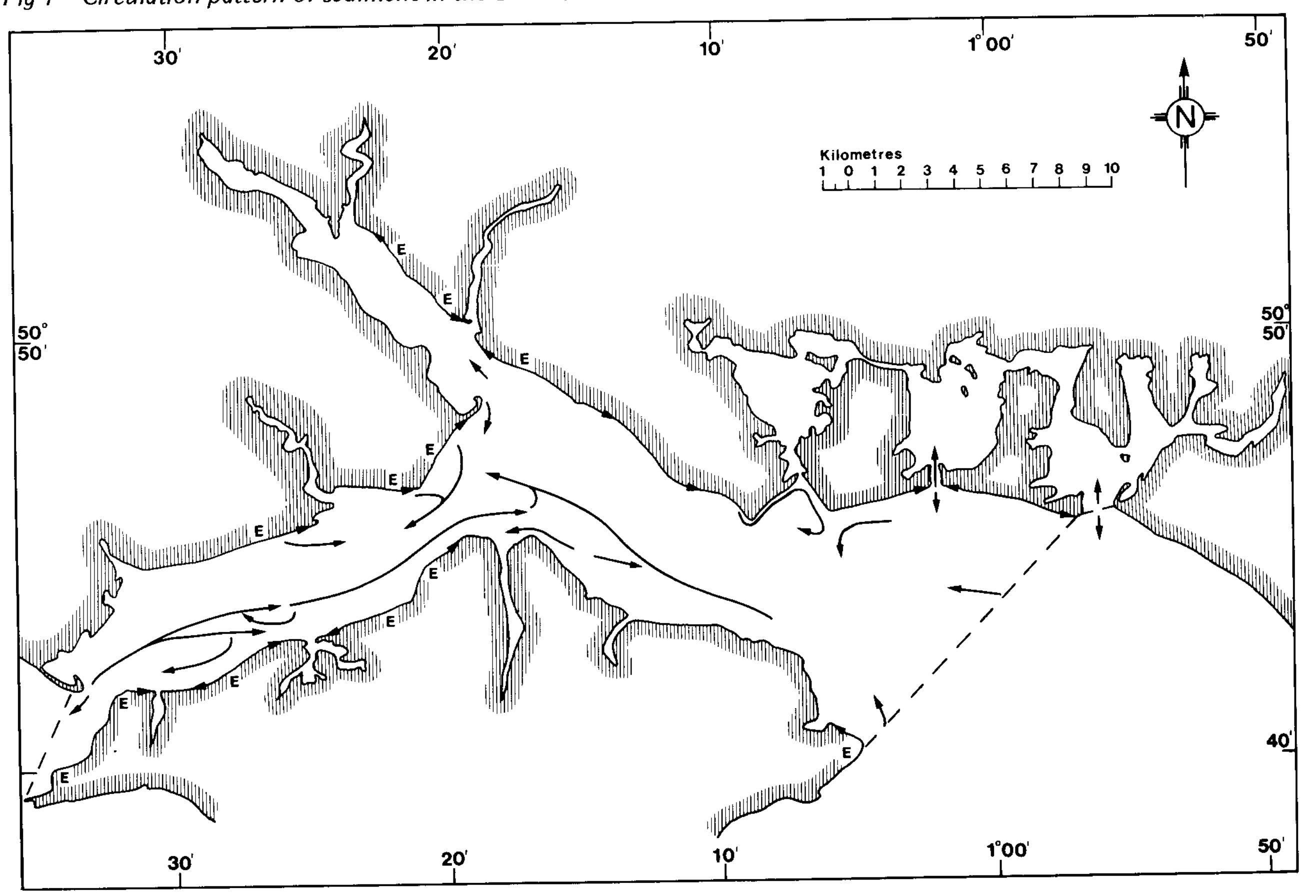
Over most of the Solent area, seismic profiling has shown the sediment to be less than 2m thick. However, bare rock is not very extensive, and occurs only on the steep slopes of the channel in the West Solent, particularly in the vicinity of the Tertiary limestone ledges. The presence of other outcrops is shown by rolled clay fragments in some samples. Thicker sediments occur where the old river valleys have been filled in (Dyer, 1975), especially beneath the Brambles Bank, between the Nab Tower and St Helens Roads and beneath Calshot Spit, where a depth of 25m can be found.

Sedimentary topography

Coastal features indicative of longshore sediment movement are common in the Solent area. Most of the estuaries and inlets have well developed spits (called 'duvers' on the Isle of Wight) which have been derived mostly from material from local cliff erosion (Fig 1), and some of the smaller inlets have been effectively sealed off. Tidal deltas occur at the entrances to Langstone and Chichester Harbours, while elsewhere it seems that the currents across the mouths of the inlets are too strong for deltas to be formed. However, bars are present across smaller inlets with low tidal prism volumes.

There are three main banks within the Solent. The Solent Bank in the West Solent previously had a barchan shape, but is now of much lower relief (Hydraulics Research Station, 1977). The Brambles Bank is an

Fig 1 Circulation pattern of sediment in the Solent. E = Areas of cliff erosion.



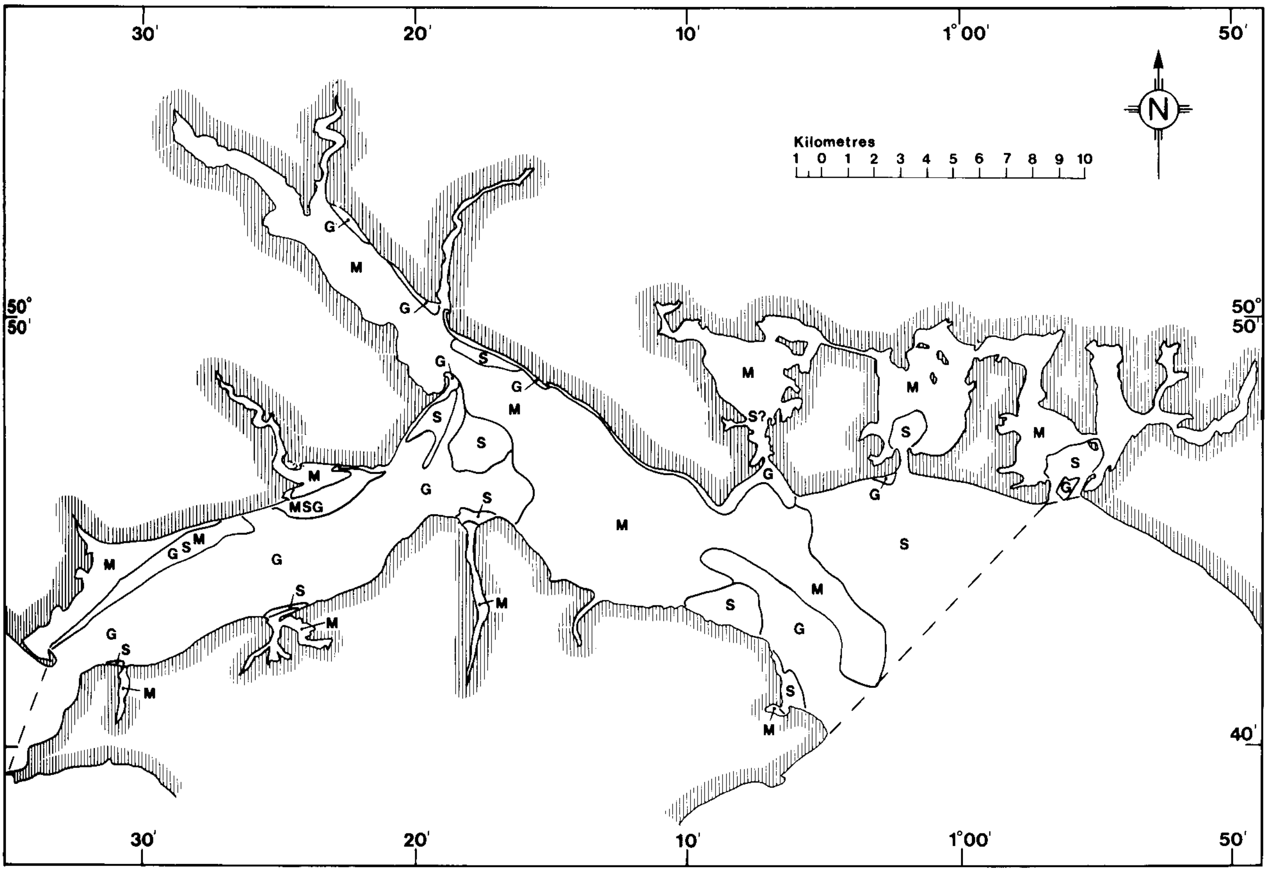


Fig. 2 Distribution of surface sediment types in the Solent. M = Mud, S = Sand, G = Gravel.

extensive shoal area centrally placed at the junction of the East and West Solent and Southampton Water, and appears to be a depositional bank around which sediment is circulating. Ryde Middle Bank is elongated and centrally placed in the deep channel south of the Brambles Bank. It is mainly cut out of Tertiary rock with only a thin sedimentary veneer, and may have considerable influence on the water circulation and sedimentation patterns in the East Solent.

Echo sounding and oblique asdic surveying have provided much information on the detailed topography which is important in the location of the sediment transport paths and in determining the directions of transport. In the West Solent (Dyer, 1971) gravel waves or dunes are extensive and typically 1-2m in height and 10-20m wavelength. The asymmetry of the dunes shows that in several places they are moving in opposite directions on opposite sides of the channel. In addition, they often show a rapid change in direction of movement over short distances. Repeated surveys of certain areas have shown that the basic distribution is stable in the short term, but that minor variations in wavelength occur. Cross channel variation in wavelength was accommodated by the bifurcation of occasional crests within fairly restricted zones which showed variation in position with time. Other variations were consistent with the known presence of loose sand patches moving across the well developed dune pattern beneath.

On Prince Consort Shoal sandwaves up to 7m high and 120m wavelength occur, and elsewhere, such as the entrance to Portsmouth Harbour, small trains of asymmetrical sand and gravel waves are present. In the East Solent the sedimentary topography consists of small irregular and hummocky dunes and narrow trains of sand waves on the edges of the Banks (Lonsdale, 1970).

Linear furrows, aligned with the current flow, occur in Southampton Water (Dyer, 1970a) and appear to be stable features which reform in sediment deposited after dredging. Similar features have been observed on the Outer Bar of Portsmouth Harbour.

The asymmetry of the dunes has been used to postulate the directions of sediment movement (Dyer, 1970b, 1971, 1972a).

Distribution of sediments

Extensive sampling of the sea bed sediments in the Solent has been undertaken with a Shipek grab, and longer cores of the muds in Southampton Water have also been obtained. Standard laboratory examination of the samples has revealed four modes; a gravel mode at 16mm (-4 phi), a coarse sand mode at 0.35m (1.5 phi), a medium sand mode at 0.17mm (2.6 phi) and clay, that in a flocculated state has a fall velocity equivalent to a size of 0.02mm (5.7 phi). Different parts of the area are characterized by certain ranges of particle size (Fig 2), the general pattern of which is similar to that obtained by Barnes *et al.* (1973).

The West Solent is predominantly floored by gravel containing variable proportions of coarse sand (Dyer, 1971). Areas of symmetrical gravel waves contain higher proportions than those of asymmetrical waves, and the probable explanations for this have been discussed by Dyer (1970c, 1972b). The patches of loose sand on the gravel surface are of the coarse sand mode. In shallower water on the northern side of the West Solent, increasing proportions of mud occur and in the littoral zones, especially between Lymington and Hurst Spit, tidal mud flats are extensive. Mud is present almost exclusively in the inlets.

Off Cowes where the tidal currents quickly diminish in strength the importance of gravel diminishes. However, a tongue of gravel extends up the Western Approach Channel towards Calshot Spit and mixed gravel-sand-muds are found in the vicinity of Ryde Middle Bank. The sands on the Bramble Bank are of the medium sand mode and are similar to those on Ryde Sand and in Chichester Bay.

The whole of Southampton Water and much of the East Solent is mud or sandy mud which extends down the channel between Horse Sand and No Mans Land Forts into St Helens Road. The gravels on Sturbridge Shoal are black stained and considered to be a relict gravel terrace, while those off St Helens are highly overgrown with algae. Some relict sand, peats and gravel also occur in Southampton Water. Although some of the mud which fills all of the inlets may come from the rivers, the greatest proportion is probably derived from the sea and enters on the estuarine circulation. Langstone and Chichester Harbours have well established tidal deltas at their mouths which grade from coarse to fine sediment in both inward and outward directions. The deposits comprising Sinah Sands and Sword Bank in Langstone Harbour are sandy and those of Mallard Sands a sandy mud (Dunn, 1972), while in Chichester Harbour, the Winner Bank is gravel and Pilsey Sand composed of sand (Stubbings and Houghton, 1964).

The beaches and the intertidal zones in the Solent area are equally diverse. Although mud flats are extensive on the northern side of the West Solent and the west side of Southampton Water, bare rock and gravel predominate wherever erosion is active (Fig 1).

In the Solent, the grain size of the sediments can be sorted into several modes and skewness and kurtosis measures have been combined. The distribution of these zones and the different grain sizes have been dealt with by Dyer (1971, 1972a) and Lonsdale (1970), who concluded that the extent of the sandy gravels seemed to be significant in the depositional processes of the area. There also appears to be a fairly clear relationship between the mean grain size and the maximum shear stress applied by the tidal currents (Dyer, 1972b), the smaller size material being found under conditions of lower ambient currents.

Shell content

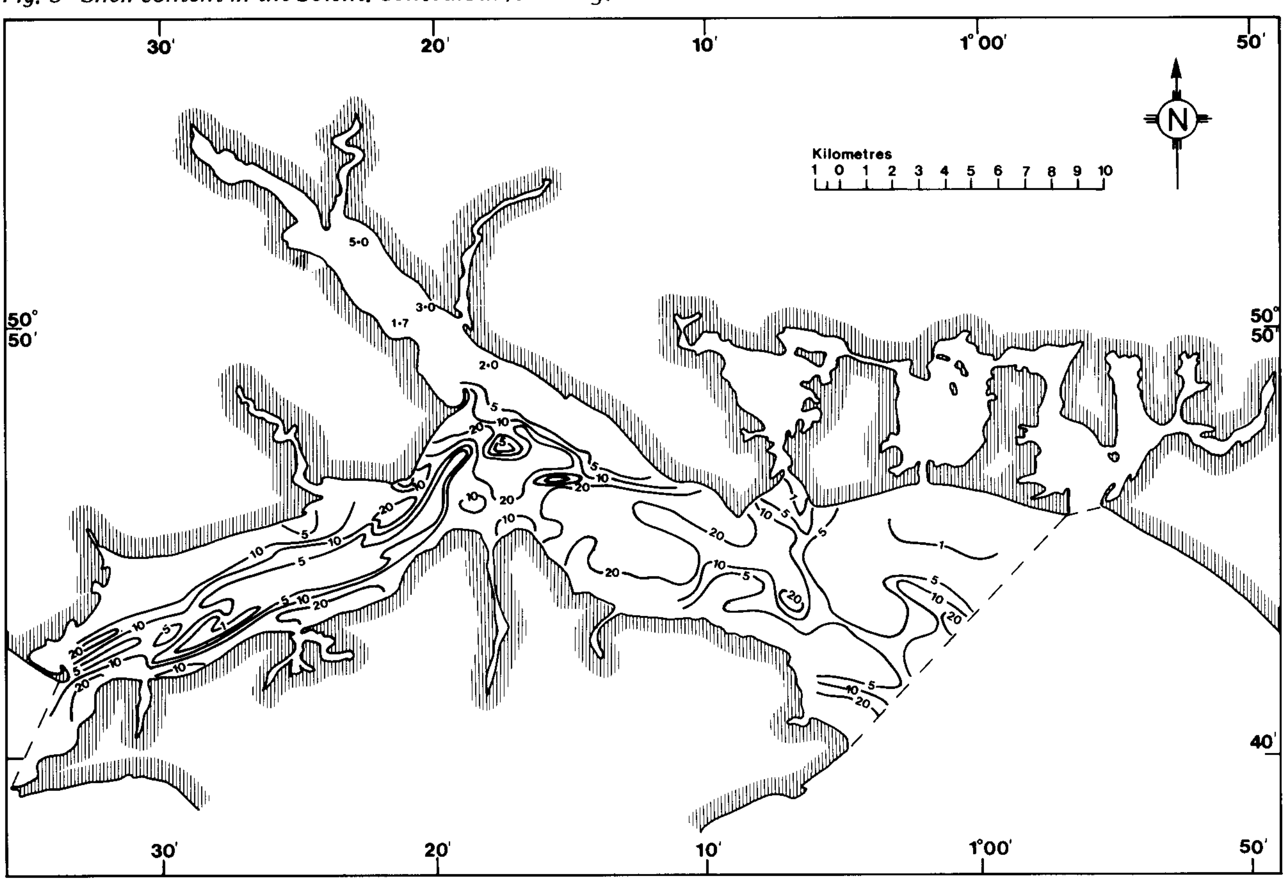
The shell content of the sediments in the area is also variable (Fig. 3). For example, in regions with high current velocities, the content is generally low and consists mainly of broken shells. In contrast, this value is much higher in quieter areas and comprises mostly live animals and complete shells. Muddy areas in the East Solent generally have high shell contents, mostly *Crepidula,* while a few samples from Southampton Water have shown that with the exception of localised shell banks, the muds of estuaries and inlets are likely to be low in shell. Shell banks are particularly apparent on the east side of Southampton Water, near Marchwood Power Station and in inlets where oyster fisheries once existed or are still maintained.

In the West Solent, the percentage of shell appears to be a good indicator of sediment mobility since the smaller gravel particles are clean, while larger particles are increasingly covered with barnacles in areas of less frequent movement (Dyer, 1971).

Mineralogy

The gravels are angular with a shape factor of 0.46, and primarily covered by a light brown iron oxide stain-

Fig. 3 Shell content in the Solent. Contours in % $CaCO_3$.



ing. The sands are of quartz, the coarse mode being well rounded, transparent or milky and often with an iron oxide coating, while the fine fractions are increasingly angular, transparent and with little trace of any surface abrasion. Slag and coke fragments are also fairly common in the East Solent. Two types of opaque heavy minerals are present. Glauconite is common in the West Solent and is probably derived from the Lower Barton Clay exposed in Christchurch Bay (Dyer, 1970b). In the East Solent, limonite predominates, possibly originating from Cretaceous Lower Greensand exposed in Sandown Bay (Dyer, 1972a). The Tertiary clays are mainly composed of illite and montmorillonite (Giles, 1966) although in the Beaulieu River, illite, kaolinite and illite/montmorillonite mixed layer minerals are dominant (Codd, 1972). This kaolinite and the mixed layer clay minerals show increased abundance in the estuary relative to the soils of the drainage area, although no halloysite has been recorded. Skempton (1948), however, stated that a Holocene clay at Gosport contained 30-50% halloysite, the remainder being illite.

Geotechnical properties

The shear strength, Atterberg limits, moisture and organic content of the top 40cm of mud cores taken in Southampton Water have been examined by Dyer (1969, 1972c). These muds were normally consolidated and had near surface shear strengths of about 3-4g cm^{-2} and a surface moisture content of between 120 and 220% dry weight, which considerably exceeds the liquid limit and indicates that they are likely to have a high sensitivity. The plasticity indices and liquid limits categorized the muds as inorganic clays of high plasticity. Chemical determinations of organic content gave values of 2-5% dry weight, while figures provided by ashing were 2 to 3 times greater. Skempton (1948) also presented values for moisture content, shear strengths and Atterberg limits for a Holocene clay deposited at Gosport and tests on similar clays have probably been determined on the samples from the many boreholes in the Fawley and Southampton Docks area.

Sediment movement

The general circulation pattern of sediment (Fig 1), based on such criteria as fining down the transport path, asymmetry of bedforms and other sedimentary characteristics, has been discussed by Lonsdale (1969) and Dyer (1971, 1972a). In the deeper water areas there seems to be a general movement of material into the Solent from either end. From Christchurch Bay in the west, sand and gravel material appears to be transported eastwards, with recirculating eddies, into the deeper water from the beaches of Hurst Spit. The Solent Bank has probably been formed in one of these recirculating eddies, and constitutes a temporary resting point for sediments passing eastwards. It is possible that much of the gravel material has never completed the entire passage from Hurst Spit, but has accumulated because of local erosion of an originally fairly thick gravel sheet which was formed on the bed of the West Solent when it was a river. Gravel transport stops off Cowes and the coarse sand appears to accumulate on Prince Consort Shoal. The medium sand although moving in an anticlockwise direction, accumulates on the Brambles Bank, and the relationship of this process to the flow pattern in the West Solent is discussed in detail by Dyer (1969). Sand and mud also enter from the eastern end of the region. Much of the sand appears to pass northwards into Hayling Bay, with the majority of the remainder accumulating on Ryde Sand. The mud seems to be deposited in the East Solent, and is then carried into the estuaries on the normal estuarine circulation and deposited during the long high water stand. This process is perhaps enhanced by the phase lag between the currents in the Solent and those in the inlets.

In littoral areas and on the beaches, the exposure to wave attack is of the greatest importance. Gravel or bedrock exist on exposed coasts, with mud and sand on the rest. The mouths of the inlets have adjusted their configuration such that longshore transport is towards the inlet on both sides. The coarser sediment is thus swept outwards along the entrance channel and in some instances may recirculate onto the beach. In the West Solent and on the northern side of the East Solent the predominant longshore transport direction is towards the east, resulting in some of this material reaching deeper water. Sediment from Park Shore appears to move offshore toward Middle Lepe Bank and that from Stansore Point probably contributes to westward moving material near East Lepe Buoy. The deposits which move westwards down the Western Approach Channel and in Yarmouth Roads, originate in Stanswood Bay and from erosion at Bouldner, respectively. Finally, Hamilton Bank is supported by eroded material which travels eastwards along the beach from Hook Shore at the mouth of Southampton Water.

Sedimentation rates

(a) *Erosion* There is very little documented evidence on rates of erosion although examination of charts and Ordnance Survey maps could reveal additional information. May (1964) stated that the cliffs at Barton in Christchurch Bay have been receding at 1m y^{-1} since 1895 which would constitute a volume of material in the order of $10^5 m^3\ y^{-1}$ entering the Solent-Christchurch Bay area. Furthermore, the drying line between the Lymington and Beaulieu Rivers has receded 180-360m between 1950 and 1973 (M Ridge, pers. comm.).

(b) *Bedload transport* Net movements of sea features off Stansore Point, based on diver observations averaged over several days, have achieved rates of $8 \times 10^{-5} g\ cm^{-1}\ sec^{-1}$ with a mean value of $8 \times 10^{-7} g\ cm^{-1}\ sec^{-1}$. The cross channel transport rate may be much less, however, since these values may represent only small variations in a larger gross movement. Values obtained from the movement of sand waves in Prince Consort Shoal were $1\text{-}4 \times 10^{-5} g\ cm^{-1}\ sec^{-1}$ (Dyer, 1969).

(c) *Suspended load* Little information is available on the concentrations of suspended sediment. Head (1969) has reported surface and mid-depth concentrations, ranging from 2-50mg l^{-1} for three stations in Southampton Water at high tide over an 18 month period. Highest values occurred at mid-depth at the mouth of the estuary while the lowest concentrations were during the summer. A turbidity maximum is probably present in Southampton Water and this may also occur in other inlets with a sufficiently intense estuarine circulation. Fluid muds have been noted in the basins of Southampton Docks (M Ridge, pers. Comm.).

(d) *Deposition* Although rates of sedimentation of 2-6mm y^{-1} have been calculated semi-empirically in Southampton Water by Dyer (1969), recent geochemical measurements have indicated a value in the order of 1cm y^{-1} (Knapp, pers. comm.). The analysis of dredging rates and hydrographic surveys could provide useful additional information.

(e) *Dredging* Regular maintenance dredging in Southampton Water amounts to about 0.5×10^6 yd^3 y^{-1} (M Ridge, pers. comm.) although the majority comes from the dock area, as only 1×10^5 yd^3 y^{-1} is dredged from the section between dock head and Fawley. Most of the material is pumped into bunds on the salt marshes. There is also considerable commercial dredging of sand and gravel, particularly in the West Solent and landings from the various licensed dredging areas is summarized in Table 1. The effect of the dredging on the local coasts has been assessed by the Hydraulics Research Station (1977).

Acknowledgements

I am grateful to the Crown Estate Commissioners for permission to publish the data in Table 1.

Table 1: Amounts of material (tons) dredged commercially in the Solent

	Solent Banks	*Horse Tail New Grounds*	*Hamilton Bank*	*Longstone Bar*	*Prince Consort Shoal*
1972	1,439,252	401,558	155,553	32,279	25,634
1971	1,098,657	204,753	74,958	32,007	-
1970	1,068,710	160,558	74,908	40,953	-
1969	1,340,523	132,155	100,208	15,823	-
1968	1,334,450	83,500	89,699	27,320	-

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