GEOLOGIE EN MIJNBOUW VOLUME 55 (3-4), p. 131-146 1976

MAJOR FLANDRIAN TRANSGRESSIVE CYCLES, SEDIMENTATION AND PALAEOGEOGRAPHY IN THE COASTAL ZONE OF ESSEX, ENGLAND

J.T. GREENSMITH and E.V. TUCKER[1].

ABSTRACT

The 36 m thick succession rests discordantly on sub-aerially weathered Pleistocene and older strata and comprises 3 major marine transgressive cycles.

The lower 2 are confined to the vicinity of deep Pleistocene channels whereas the 3rd, possibly initiated c. 7500 B.P. extends across the whole coastal zone.

Each cycle consists of a lower division of clays and silts with thin coarser deposits towards the base and an upper division of sands and sandy gravels.

The contact between the two divisions is often erosional or sharp.

Landward displacement of the main lithofacies is most pronounced during episodes of relatively rapid rise in sea level, as in the U.S.A. and Holland. At certain levels reached by the rising sea extensive bodies of relict Pleistocene sediment became avoiable for marine reworking.

The persistence of lagoon, marsh, beach, chenier, barrier, tidal flat and channel lithotopes through the succession in conjunction with 12 radiocarbon dates allow general palaeogeographic deductions to be drawn, more especially for c. 7500, c. 4000 and c. 1350 B.P.

INTRODUCTION

The Quaternary deposits of southeast Essex in the coastal zone between the Colne and Thames estuaries rest on a strongly dissected, terraced Pleistocene surface eroded in Eocene London Clay.

They consist of Pleistocene fluvial sands and gravels, brickearths and loess, intermittently capping the Clay, succeeded unconformably by Flandrian estuarine and shallow water marine deposits which are predominantly clays, silts and sands.

Collectively, the Quaternary sediments reach thicknesses in excess of 40 m, more especially in the network of buried channels which exists beneath the present coastal zone (fig. 1).

The Flandrian succession at depth is typified by rapid Lithefacies changes analogous to the complex changes exhibited on the present tidal flat areas (Greensmith and

The Flandrian succession at depth is typified by rapid lithofacies changes analogous to the complex changes exhibited on the present tidal flat areas (Greensmith and Tucker, 1975). Hence, correlation at depth is difficult. The base of the succession usually consists of reworked sandy gravels. The bases for deductions about Flandrian sedimentation are data from surface outcrop, well records and some 130 boreholes recently drilled (1969-74) on behalf of the Roskill Commission and Maplin Development Authority. The majority of the recent boreholes were sited in the intertidal zone on Maplin Sands and they provide the most important source of information on which interpretations are based.

THE FLANDRIAN SUCCESSION

The succession reaches a known thickness of 36 m and shows a marked variation when traced laterally, thinning out to zero metres along the inner reaches of the major estuaries. Fundamentally, this variation reflects the inundation of the multi-terraced Pleistocene terrain by a westwards extension of the southern North Sea during the last 12000 years. The greatest thicknesses of strata are found in and immediately adjacent to the deep channels carved by the Pleistocene rivers. As the Flandrian sea spread to higher altitudes, approaching present mean sea level at c 5000 B.P., so did the Pleistocene deposits become subject to marine reworking over an increasingly wide area.

The boundary between the in-place Pleistocene and the unconformable Flandrian deposits is generally ill-defined. In the inter-channel tracts it resides within the top 5 m of the basal sandy gravels, whereas in the channel areas this figure may be exceeded. Below the unconformity the finer sediments are strongly compacted and there is an absence of drifted plant debris. At the position of the unconformity partly gleyed, gray-green soil profiles are sometimes preserved. Gentle inundation of the weathered Pleistocene surface is indicated. Above the unconformity there is an abundance of shelly fauna and plant debris in the comparatively unlithified sediments.

---

[1] Department of Geology, Queen Mary College, Mile End Road, London, E1 4NS.

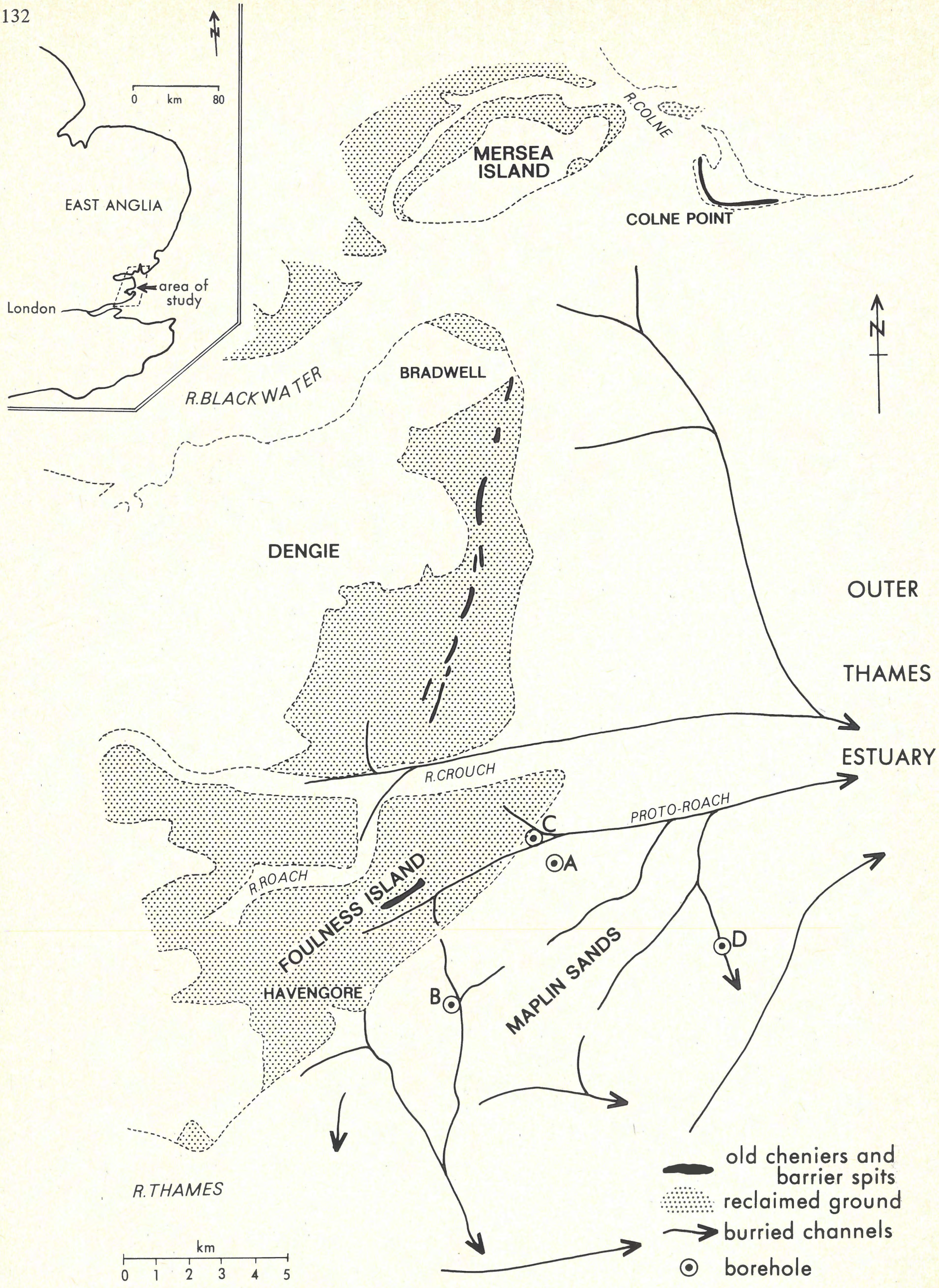


Fig. 1
The Essex coastal zone. The unshaded land areas are London Clay irregularly mantled by Pleistocene deposits.

Beneath parts of Foulness Island and Maplin Sands basal sandy gravels are totally absent, due to non-deposition or subsequent erosion, and relatively uncompacted Flandrian clayey silts rest either directly on firm, brown London Clay or on a layer, up to several metres thick, of reworked, brecciated and silt-adulterated brown Clay.

A. *Major Depositional Cycles*

Major Flandrian cycles are recognissable as repetitive transgressive units, averaging 9 m in thickness, and separable into two main lithological divisions. The lower division is dominated by lagoonal, marsh and tidal flat silty clays and clayey silts. Thin and lenticular beds of shelly beach and beach barrier sands and gravels occur at the base. The upper division consists of tidal flat and subtidal sands and sandy gravels and commonly rests with sharp contact on the underlying beds.

The interchannel tracts and channel margins are characterised by one to three such cycles (figs. 2 and 3). Successions thicker than 18 m are usually multicyclic. In the deep channel successions cyclicity is not readily identifiable, probably because the channels were persistently occupied by the sea and subject to perpetual reworking of the bed load.

Generally, the cycles of deposition are at their thickest towards the eastern and northeastern flanks of Maplin Sands where the deepest channels are located. The 3rd (uppermost) cycle eventually gave deposition across the entire present coastal zone; it may have been instituted at or just before 7500 B.P. In the channels the cycle attains thicknesses of up to 24 m as compared with up to 21 m in the interchannel areas (fig. 4). The sand upper division is thickest in the channels (up to 18 m) and presently outcrops widely in the intertidal zone. The clayey silt lower division is thickest in the interchannel areas (up to 11.5 m. whereas in the channels the maximum thickness is 8.5 m.) It outcrops widely on Foulness Island and adjacent islands, and on the Dengie peninsula.

B. *Lithology*

(i) Silts and Clays. – The deposits dominating the lower division of the major cycles are soft clayey silts which are commonly finely laminated; the laminae are 1-2 mm thick. Sorting is poor (fig. 5). Certain beds are predominantly clays in which silt partings occur sporadically. Colours vary from gray-green, gray, brown to black, the differences reflecting the amount of included calcureous matter and compressed peatified debris. Peat fragments up to 200 mm long have been detected along with seed pods, both in association with laminae disturbed by fine rootlet traces. Ocasionally, the fragments are concentrated into silt-rich peats and peaty silts as much as 15 cm thick. One such deposit at -18.3 m Ordnance Datum, Newlyn beneath Foulness Island is dated at 7516 ± 250 B.P., another on Dengie flats at c./ -2.0 m O.D. at 4959 ± 65 B.P. Two seams on Mersea Island just below mean high water mark give dates of 173 ± 60 and 118 ± 48 B.P. (Greensmith and Tucker, 1973a, 1973b).

The deposits dominating the lower division of the major cycles are soft clayey silts which are commonly finely laminated; the laminae are 1-2 mm thick. Sorting is poor (fig. 5). Certain beds are predominantly clays in which silt partings occur sporadically. Colours vary from gray-green, gray, brown to black, the differences reflecting the amount of included calcareous matter and compressed peatified debris. Peat fragments up to 200 mm long have been detected along with seed pods, both in association with laminae disturbed by fine rootlet traces. Ocasionally, the fragments are concentrated into silt-rich peats and peaty silts as much as 15 cm thick. One such deposit at -18.3 m Ordnance Datum, Newlyn beneath Foulness Island is dated at 7516±250 B.P., another on Dengie flats at c. -2.0 m O.D. at 4959±65 B.P. Two seams on Mersea Island just below mean high water mark give dates of 173±60 and 118±48 B.P. (Greensmith and Tucker, 1973a, 1973b).

Mineralogically the fine grained deposits are a mixture of quartz (25-60 per cent by volume and mainly angular in shape), clay minerals (20-50 per cent) and carbonates (0-20 per cent) with subordinate iron oxides (0-1 per cent), iron sulphides (0-0.5 per cent), calcium phosphates (0.1 per cent), organic carbon (0-3 per cent except for peat seams) and gypsum (0-1 per cent). A few fresh, angular grains of oligoclase and microcline feldspar occur intermittently.

The clay minerals are dominated by mica (illite) which forms 50-80 per cent of the clay fraction. Kaolinite varies between 3-20 per cent and montmorillonite between 1-30 per cent. Fresh to slightly altered green grains closely resembling glauconite are occasionally present. The higher proportions of montmorillonite are usually found where the Flandrian succession abuts London Clay. In these close positions the variety and proportion of clay minerals is so akin to that of the London Clay that a substantial contribution must have come from that source.

Variably comminuted shell debris largely accounts for the carbonate content, the calcite – aragonite ratio being about 9. At certain levels, referred to as firm or overconsolidated because of their mechanical properties, the carbonate percentage falls to zero or is very low; dolomite sometimes forms (Greensmith and Tucker, 1971).

In summary, the evidence afforded by the silts and clays suggests a local provenance for the inorganic constituents, in part Tertiary strata but dominantly younger Pleistocene deposits flanking and originally exposed within the Outer Thames estuary area.

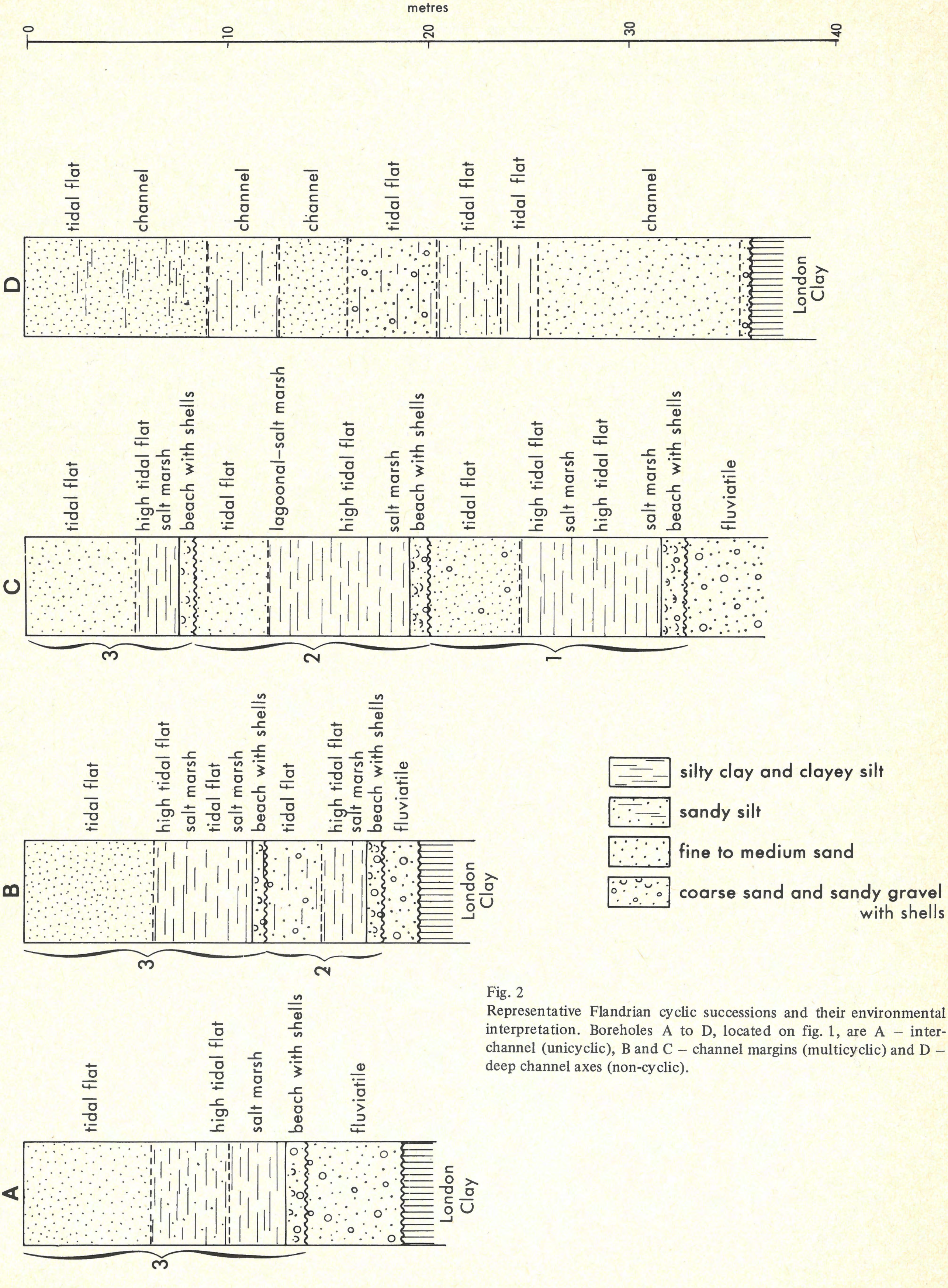


Fig. 2
Representative Flandrian cyclic successions and their environmental interpretation. Boreholes A to D, located on fig. 1, are A – inter-channel (unicyclic), B and C – channel margins (multicyclic) and D – deep channel axes (non-cyclic).

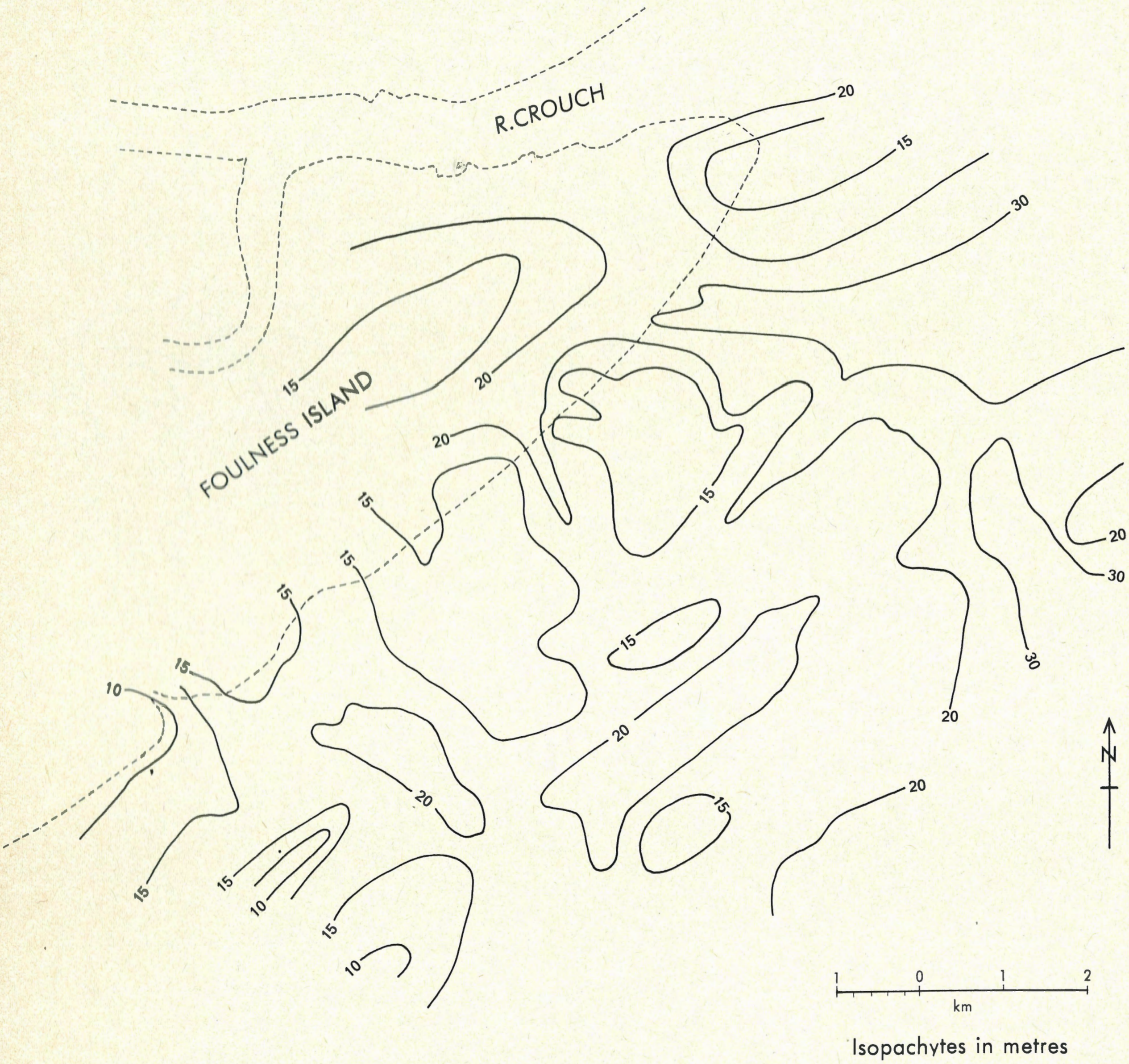


Fig. 3
Isopachytes (approximated) for the cumulative thickness of the 1st, 2nd and 3rd cycles beneath Maplin Sands and Foulness Island.

(ii) Sands and Sandy Gravels. – The deposits dominating the upper division of the major cycles are quartz sands. They are normally fine to medium grained and moderately well sorted (fig. 6A). Silt, clay, pebbles and shell fragments are present in variabele amounts. Indeed, silt and clay forms up to 26 per cent by volume of some layers. At certain depths, such as in the 2nd cycle at -12 to -19 m O.D., the sands are sometimes coarse, pebbly and more properly designated as sandy gravels (fig. 6B). Up to 45 per cent of the coarse sand grains are well rounded, this contrasting with the finer sands where some 52-80 per cent of the grains are very angular to angular. In addition to quartz the sands contain minor amounts of microcline, andesine, oligoclase, glauconite and gypsum. Beg (1967) found garnet, epidote and hornblende within the surface sands and suggested Pleistocene sources. Zircon concentrations, rutile, staurolite, kyanite, tourmaline and barytes were thought to be of Tertiary provenance. The pebbles in the gravels are dominated by light brown to

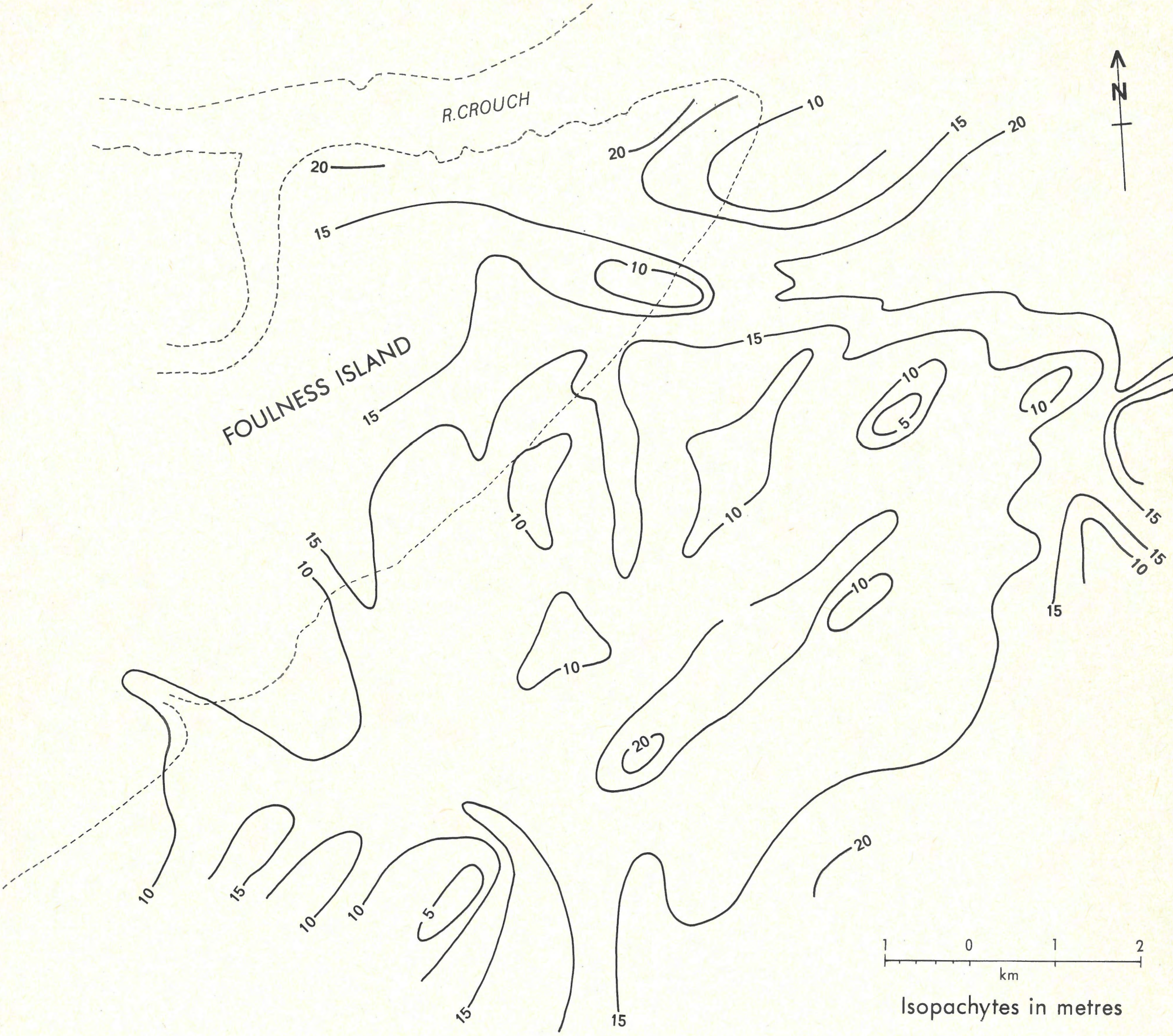


Fig. 4
Isopachytes (approximated) for the 3rd cycle beneath Maplin Sands and Foulness Island. The pattern is similar to that of fig. 3 indicating the depositional control exerted by persistent channels.

mottled gray flints, up to 90 per cent of most samples, dense brown – black flints (c 6 per cent), chertified sandstones (1 – 16 per cent) and vein quartz (up to 6 per cent). A high proportion of the pebbles are now angular with more than one sharp edge and clean faces. This suggests permafrost, periglacial shattering during Pleistocene times and a comparatively mild degree of transport subsequently.

The deposits give little indication at depth of internal bedding and lamination, though occasional sharp contacts, shell- and clay-rich seams and textural changes imply a certain degree of stratification. Likewise, sedimentary structures have not been proven subsurface, though ripple marks, mobile barrier spits and tidal bars characterise the present surface. A very wide range of drifted and worn subtidal and

Fig. 5
Characteristic size frequency distribution of particles in lagoon – marsh – high tidal flat deposits.

intertidal shells are dispersed through the sediments and the matrix is invariably highly calcareous.

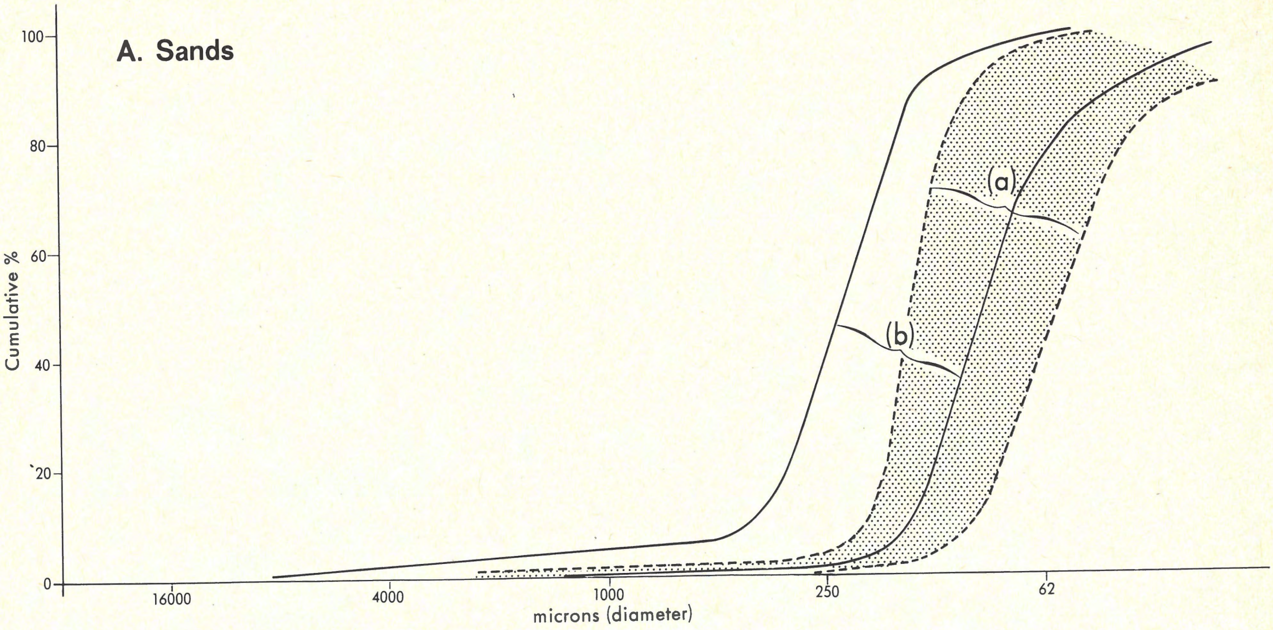
The evidence again indicates local Tertiary and Pleistocene sources for the inorganic detritus, the angular quartz grains probably being derived from the brickearths and loessic beds.

FLANDRIAN ENVIRONMENTS

The distribution of organic materials in the present coastal zone has been recorded in considerable detail over the last 70 years or so (e.g.'s Sorby, 1901; Davis, 1967; Kilenyi, 1969) and a wide variety of species identified. If these organisms are placed into their sedimentological context, then it is possible to recognise four principal environments of deposition (or lithotope associations). Moreover, the lithology and organic content at depth are so similar that the implication must be of a persistence of these principal environments through most of Flandrian times.

A. Salt marsh – Lagoon

These are characterised by silty clays and clayey silts with abundant marsh top vegetation and rootlet disturbance. Oxidation is common in the top 2-3 m of the marsh deposits with the precipitation of limonite and the leaching of calcareous shells. On the higher inner levels of the marsh desiccation and compaction forms firm fissured surfaces. Examples occur at depth near the top of the 2nd and 3rd cycle silt divisions. In some instances the firm layers rest almost directly on beach deposits of greater permeability; a relationship which probably enhances the rate of desiccation of the silts. A feature of the firm layers is their common association with peat-bearing clayey silts carrying an abundance of well-preserved, unworn fresh- and brackish-water mollusc shells, especially *Hydrobia ventrosa, Assiminea sp, Valvata sp* and *Planorbis sp*. Along the seaward edge of the marsh these shells are associated with drifted, worn marine shells.



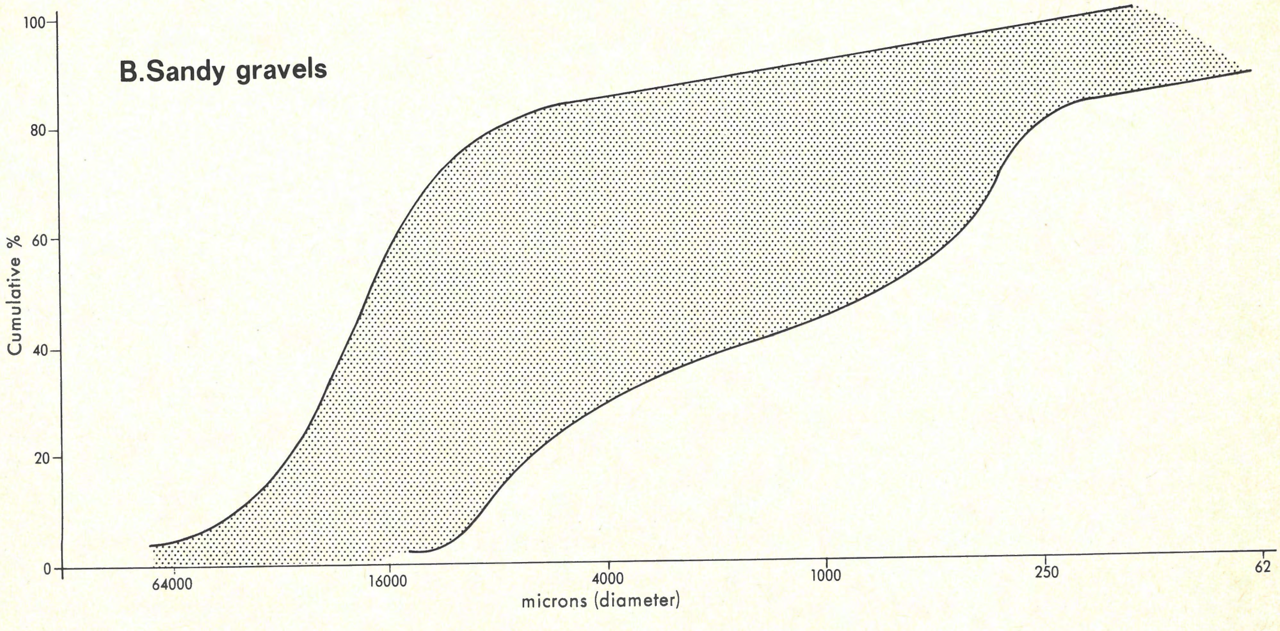


Fig. 6
Characteristic grain size distribution for A – sands and B – sandy gravels. The sands of the 3rd cycle (a) are generally finer grained than those of the 1st and 2nd cycles (b).

Open lagoonal deposits are not readily distinguished from intertidal deposits except in the presence of *Cerastoderma glaucum* (Boyden, 1973). In closed lagoons occupying depressions on the marsh surface and connected to the sea via an intricate network of marsh creeks, the silty clays tend to be very finely and evenly laminated, exhibit desiccation surfaces and fissures and carry no marine shells, except for occasional thin, comminuted marine shell seams formed by wash-over from adjacent marsh-edge cheniers.

B. Beach – Chenier – Barrier-spit

These are discontinuous bodies of shell, sand and gravels abutting and transgressing across the top of high tidal flat and marsh deposits. The faunal constituents are predominantly drifted, worn marine shells, these being mixed with a small proportion of fragile marsh top shells. *Cerastoderma edule* is the most common organic constituent in the modern and ancient bodies where it is associated with *Macoma balthica, Scrobicularia plana, Ostrea edulis, Mytilus edulis, Parvicardium exiguum, Chlamys sp, Abra abra, Spisula sp, Littorina spp, Venerupis sp, Nassarius sp, Balanus sp, Barnea candida, Hydrobia ulvae, Retusa reticularis, Bittium reticulatum, Buccinum undatum*, ostracods, foraminifera, bryozoa and crab pincers. *Gibbula cineraria, Mya arenaria, Crepidula fornicata, Petricola pholadiformis* and *Elminius modestus* are only found in the modern bodies; *Buccinum undatum* is less abundant in the older bodies.

C. Intertidal Flats

The present Essex flats show a lateral zonation from high flat clayey silts with widespread bioturbation to low flat clayey and silty sands and gravels. The zones are very variable in width and, in the northern part of the area, sheets of gravel extend across almost the whole width of the intertidal zone. At the margins of deeper permanent channels the gravels and sands are moulded into asymmetric bars and ridges which have transgressive characteristics. These structures act as temporary sites of accumulation for tidal flat and subtidal shell debris, such as *Cerastoderma edule, Mytilus edulis, Ostrea spp, Venerupis, Nucula, Corbula, Spisula* and *Chlamys*.

Drifted shell debris including *C.edule, Corbula* and *Nucula* is commonly associated with unworn *Hydrobia ulvae* and concentrations of comminuted plant debris in the high tidal flat silts. This association is common in the succession at depth.

D. Channels

The clayey silts, sands and occasional gravels typifying the channels and channel successions carry a fully marine fauna, including *Spisula subtruncata, Corbula* and remains assignable to the Cardiacea, Nuculacea, Mactracea and Pectinacea. The shells are frequently highly fragmented.

DEPOSITIONAL PROCESSES AND CYCLICITY

The processes contributing to the patterns and sequences of deposition in the Flandrian succession are complex, little understood and open to constant review and modification as new facts accumulate. Only selected and general points will be discussed here.

The overall character of the sediments indicates a persistance of depositional processes through Flandrian times similar to those operating at the present day. The present strand-line is intermittently characterised by migratory sand, gravel and shell beaches, ridges, barrier spits and cheniers. Movement occurs predominantly during storm conditions. The beaches, ridges and barrier spits rest on high tidal flat deposits sharply but also override landwards onto adjacent marsh surfaces and older Pleistocene and Tertiary surfaces. Cheniers rest directly on marsh surfaces (Greensmith and Tucker, 1969). Where the various bodies transgress across marsh surfaces the contact is sharp and directly comparable with the ravinement structures described from the eastern seaboard of the U.S.A. (Swift 1968). The junction with Pleistocene deposits, in contrast, is normally diffuse.

Re-emergent marsh faces are quickly eroded on the seaward side of the mobile structures and the sites of erosion become the loci for clay and silt deposition, some of the materials being directly derived from the marsh front. The remainder probably emanates from the suspended load distributed through the normally turbid tidal streams and may have an offshore provenance (Sheldon, 1968).

The high flat clays and silts grade laterally towards low flat sands and gravels, a gradation ascribed, in part, to hydraulic differential processes including 'settling-lag' and 'scour-lag' (Van Straaten and Kuenen, 1957; Evans, 1965). Pertinent to these sorting processes are water velocities across the tidal zones during calm conditions. Bottom flood-tide currents reach speeds of 30-50 cms/sec whereas ebb-tide currents only reach 20-30 cms/sec (Talbot, 1967).

At present there is a progressive translation of the main lithofacies landwards. A significant contributory factor in this displacement appears to be a relative rise in sea level and consequent marine transgression, for which there is considerable evidence. The present transgressive episode is the youngest of a relatively minor series of such episodes which collectively constitute the Flandrian Transgression. The 3rd transgressive cycle contains within it evidence for at least five minor transgressive episodes interspersed with periods of reduced (or negative) rates of sea level rise. The latter periods seem to have been times of marine regression and are represented by the seaward extention of marshes (peat layers) and more widespread development of supratidal overconsolidated layers and partly gleyed soils (Greensmith and Tucker, 1973a). Major facies displacement landward ceased or was retarded during these regressions.

In broad terms the Essex succession resembles the Flandrian coarsening-upwards clastic marine transgressive sequences of coastal Delaware and the interdeltaic coastal areas of the Gulf of Mexico (Nelson and Bray, 1970; Kraft, 1971). The last 3500 years at Huston Bay in Florida has witnessed the deposition of a sequence of swamp silty peats passing upwards sharply into shelly quartz silts and sands. This Florida sequence, similar to parts of the Essex succession, is interpreted as a marine transgressive sequence caused by rising sea level (Scholl, 1964). There are also similarities to the coastal succession of Holland where a whole sequence of environments migrated landwards during Flandrian times (Van Straaten, 1965; Eisma, 1968; de Jong, 1971).

In all these comparable regions it is clear that Pleistocene sources have contributed largely to the Flandrian sediments and that the pre-Flandrian relief played an important role in the ultimate dispersal of those sediments. Thedifferences in detail from one region to another reflect a wide range of local factors including the delicate balance between deposition and erosion induced, in part, by the availability of source materials in the coastal zone and rates of sea level change. In the Essex situation it appears that there have been episodic increased rates of tectonically-controlled subsidence interspersed with diminished rates, superimposed onto the eustatic Flandrian Transgression, and these major and minor episodes have contributed significantly to the periodicity of sedimentation.

FLANDRIAN PALAEOGEOGRAPHY

Rapid lateral facies changes, the drifted nature of the bulk of the faunal and floral elements and the few radiogenic dates currently available (table 1) preclude the drawing of anything but very generalized palaeogeographic (or lithotope distribution) maps. Most environmental detail, including radiocarbon dates, has accumulated on the sediments post-dating c. 8000 B.P. and for those reasons the three maps constructed are for an arbitrary period spanning 250 years at around 7500, 4000 and 1350 B.P.

A. c. 7500 B.P.

Prior to 7500 B.P. the evidence suggests extension of the sea along pre-existing Pleistocene channels, with the accumulation in the deeper parts of at least 15 m of silts, sands and gravels. The 1st transgressive cycle reached its end in this period and the 2nd cycle was about to terminate. The end stages involved extensive reworking of sandy gravels capping what seems to be a bench carved into London Clay at a depth varying from -15 m O.D. beneath Foulness Island to -25 m below the outher fringes of Maplin Sands. While the age and origin of this bench must remain conjectural at present, there is a possibility that it was cut by the sea during the Paudorf Interstadial (c. 30000 B.P.) when sea levels in the North Sea may have reached about -15 m O.D. (D'Olier, 1972). The stripping off of the deposits resting on the Paudorf (?) bench exposed more of the London Clay on Foulness Island and on the Dengie penincula (fig. 7).

LOCALITY	BRITISH NAT.GRID	O.D. (Newlyn)	SAMPLE	DATE (B.P.)
E. Mersea	TM/ 062141	+ 1.6 m	peat	118 ± 48
E. Mersea	TM/ 058139	+ 1.0 m	peat	173 ± 60
Dengie	TM/ 012995	+ 1.6 m	shell	645 ± 100
Dengie	TR/ 016994	+ 1.2 m	shell	1265 ± 100
Dengie	TR/ 021028	+ 1.0 m	shell	1340 ± 100
Foulness	TR/ 018943	– 5.5 to – 8.3 m	shell	3580 ± 175
Foulness	TR/ 029940	– 5.0 to – 7.5 m	shell	4350 ± 210
Dengie	TM/ 043093	c.–2 m	peat	4959 ± 65
Foulness	TR/ 050940	–11.5 to –13.0 m	shell	5650 ± 240
Maplin	TR/ 018943	–12.5 to –13.5 m	shell	6620 ± 100
Foulness	TR/ 029940	–18.3 m	peat	7516 ± 250
Oaze deep, Outer Thames	TR/ 070810	–25.7 m	shell	11900 ± 540

TABLE 1
Radiocarbon dates in Essex Flandrian succession

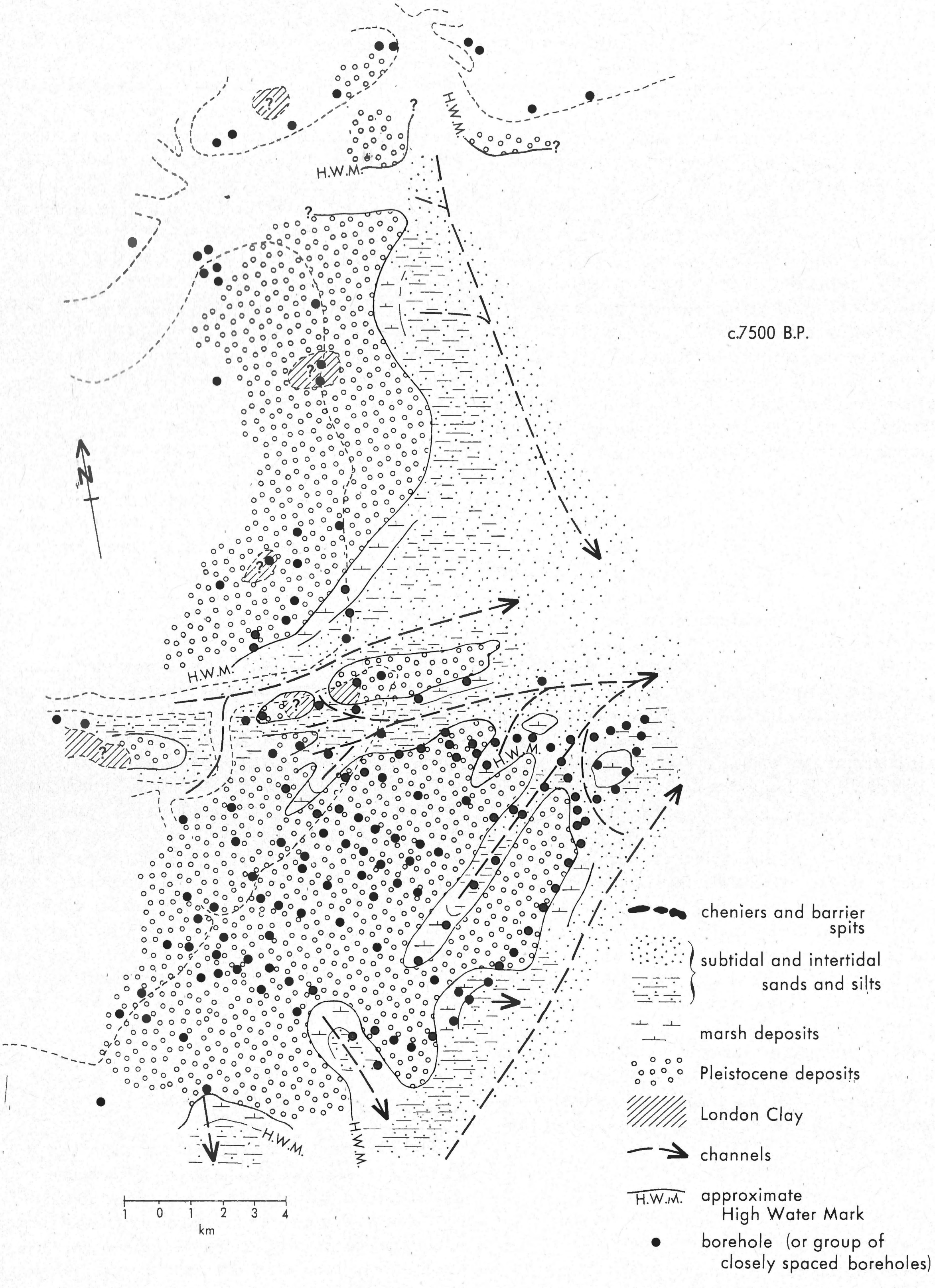


Fig. 7
Generalised palaeogeographic map c. 7500 B.P.

By 7500 B.P. marshes existed along the flanks of the main channels and occupied shallow embayments, though probably they were not extensive. There is evidence that active marsh erosion was taking place producing peaty silts of the type which characterises present day marsh fronts.

A network of channels existed beneath the middle tracts of Maplin Sands draining mainly southeastwards and southwards from the vicinity of Havengore Creek. There is no evidence to show whether this network linked through northwestwards into the middle-upper reaches of an ancestral river Roach. The main channel of the river Crouch appears to have had a through connection beneath Foulness Island to the main proto-Roach channel. The proto-Roach channel also had feeder channels at its head directed towards the position of the higher reaches of the ancestral Roach.

Towards the northern end of the coastal zone it is probable that the sea had not penetrated much beyond the mouths of the Blackwater and Colne channels. Brickearths, loess and terrace gravels figured prominently on the land surface.

B. c. 4000 B.P.

By 4000 B.P. wide tracts of the coastal zone comprised salt marshes (fig. 8). An intricate network of major and minor channels existed and, in some of the deepest channels, fine sands representing the upper division of the 3rd transgressive cycle were already being deposited. The marked influence of the gravel-mantled Paudorf (?) bench had virtually ceased by 6500 B.P. due to burial under a comparatively thick mantle of clayey silt. This mantle extended across the intertidal zone and occupied considerable lengths of the channels; it constitutes the lower division of the 3rd cycle.

The increased rate of fine sediment injection into the coastal zone may also have been influenced by the greater availability of brickearth, loess and London Clay materials as the sea rose to higher levels. Sea level may have risen almost to present mean sea level by 4959 B.P. and there is evidence for marine transgression until at least 4000 B.P. as witnessed by the formation of cheniers on the site of Foulness Island and the Dengie peninsula. Willis (1961) records a very marked marine transgressive episode in the Fenlands, in northern East Anglia, between 4680 – 4285 B.P. The later stages of this period of marine transgressions probably saw the progressive withdrawal of early Bronze Age Man from coastal sites (Akeroyd, 1972).

C. c. 1350 B.P.

In Romano-British times, spanning 2000 – 1750 B.P., river mouth forts were built and salt works established or re-established in the coastal zone adjacent to high water mark (Smith, 1918). Marine regression or stillstand conditions are indicated. But soon after the evidence suggests a relatively rapid marine transgression across these sites of human activity, as at Bradwell-on-Sea and East Mersea (Greensmith and Tucker, 1973a). The progress of this transgression is marked by the formation of shell, sand and gravel cheniers and barrier spits, now seen at outcrop on Foulness Island, the Dengie peninsula and at Colne Point (fig. 9) (Greensmith and Tucker, 1975, fig. 10.5). The peak period for the formation of these structures probably spanned 1550 – 1250 B.P., which suggests that this transgressive episode persisted for a greater length of time than in the Fenlands, where it terminated c. 1450 B.P. (Willis, ibid). There is no doubt that the Essex transgression is of the same general age not only of that of the Fenlands but also of the main post-Roman transgressions in Somerset and Holland. Eustatic control is implied.

D. Changes since c. 1250 B.P.

The evidence indicates a number of minor phases of marine transgression and regression. Resting on the firm Romano-British occupation surface at Mersea Island and elsewhere are thin high tidal flat sequences carrying peat seams. The latter, dated at 173±60 and 118±48 B.P. at East Mersea, represent episodes of marsh extension (Greensmith et al, 1972).

Certain creeks draining from the Dengie marshes appear to have remained in open communication with the sea, or may even have been enlarged during transgressive episodes, as suggested by the presence of unworn *Cerastoderma glaucum* valves. Some of these have been dated at 645±100 B.P.

However, reclamation since the 13th Century has complicated and obscured much fine detail. The proto-Roach and other channels beneath Maplin Sands, and probably the Dengie Flats, are now completely choked by sand and silt fill as a consequence of man's activities. Nonetheless, it can be deduced that the last 100 years or so has witnessed the initiation of another episode of marine transgression. Marsh erosion is widespread throughout the coastal zone and a further major series of shell, sand and gravel cheniers and barrier spits has been formed.

CONCLUSIONS

The Flandrian succession is a prime example of a marine transgressive sequence developed as a consequence of sea level rise. At certain periods the rate of rise appears to have been enhanced either due to increased differential subsidence or eustatic change, or a combination of both. At these times the lithofacies zone were, and are, displaced landwards relatively rapidly, as expressed by transgressive shell, sand and gravel beaches, barrier spits, cheniers and intertidal bars resting with varying degrees of discordance on finer grained

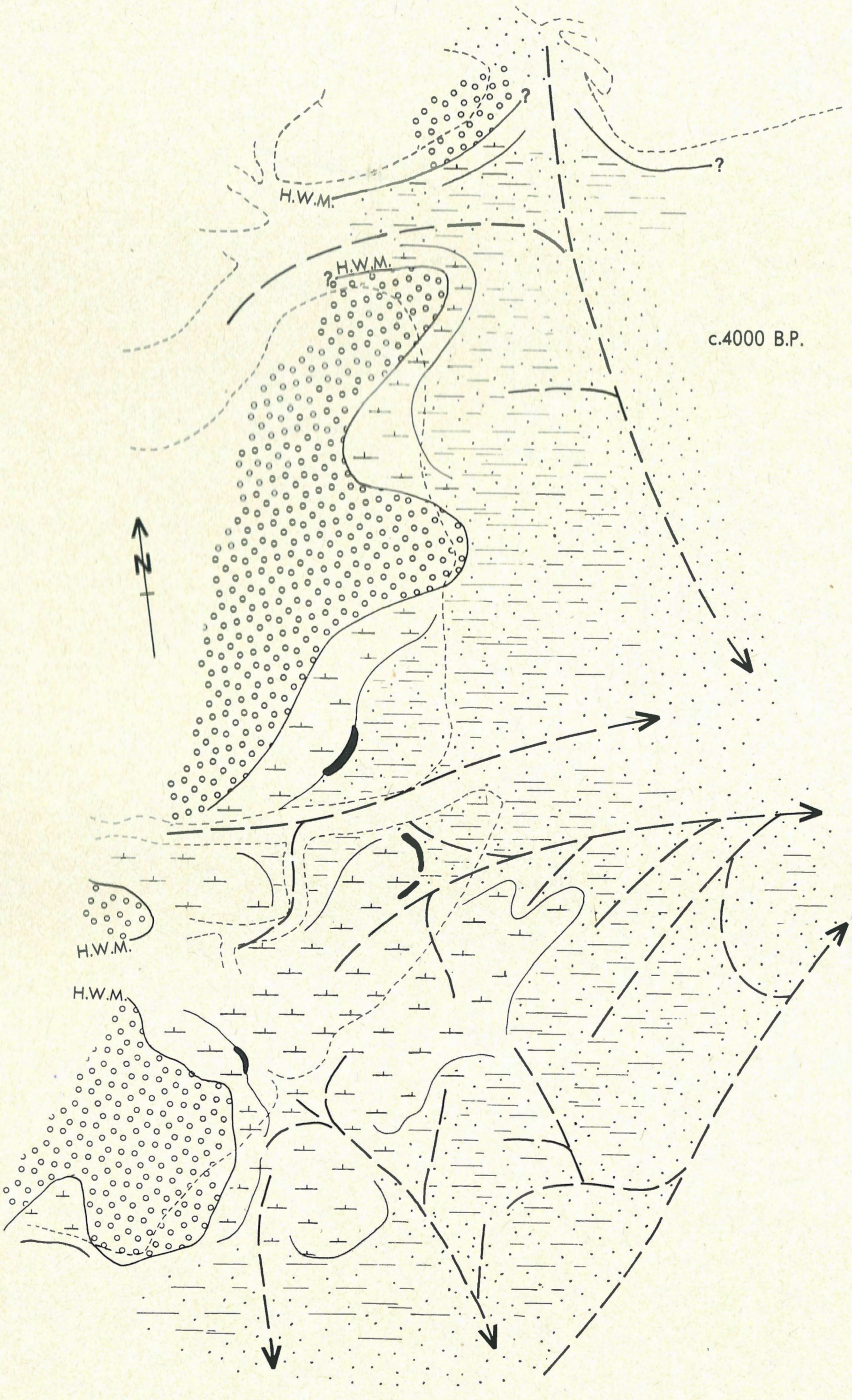


Fig. 8
Generalised palaeogeographic map c. 4000 B.P. Map symbols as for fig. 7.

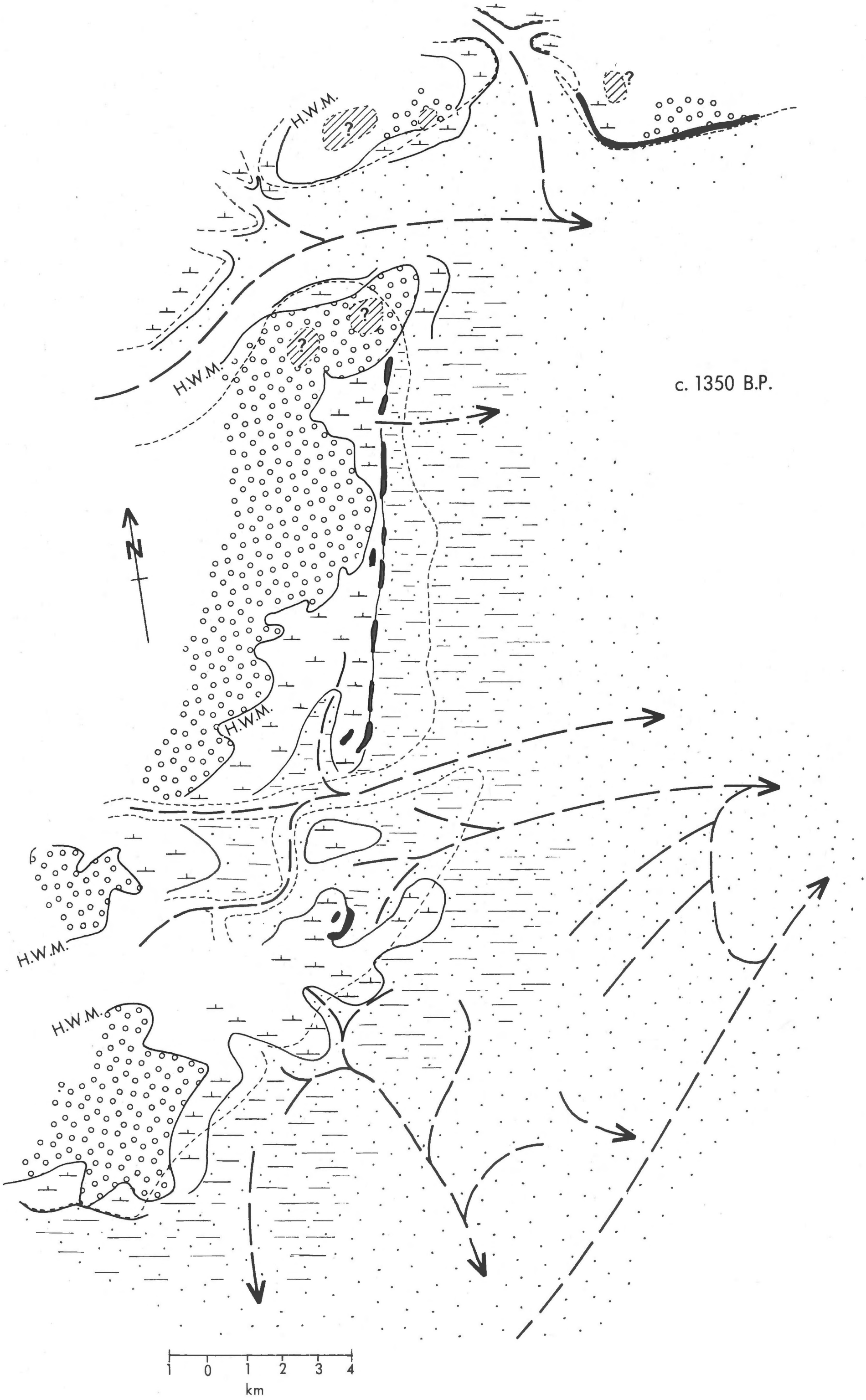


Fig. 9
Generalised palaeogeographic map c. 1350 B.P. Map symbols as for fig. 7.

lagoonal, marsh and tidal flat deposits. During episodes of reduced rates of sea level rise or stillstand landward encroachment of the facies diminished or ceased.

The bulk of the organic and inorganic constitents in the succession is of local Outer Thames origin and predominantly derived from Pleistocene fluvial terraces and the London Clay. It is possible that off-shore Pleistocene boulder clays are contributing to the present deposits (Sheldon, 1968).

The distribution of the terrace deposits and their increased availability at certain stages of sea level rise seem to be a relevant factor in the development of the three-fold major cyclicity. The coarse deposits (up to 11.8 m residual thickness) mantling the Paudorf (?) bench contributed significantly to the upper division of the 2nd cycle and the terrace deposits straddling present mean sea level appear to have contributed considerably to the 3rd cycle if, as seems feasible, mean sea level closely approached modern sea level at c. 5000 B.P. (cf. Jelgersma, 1966; de Jong, 1971; Fairbridge, 1975). The fine grained nature of most of the sands in the 3rd cycle, compared with earlier cycles, and the dominance of silt particles in the finer deposits suggest that the southeast Essex brickearths and loesses were a very important source at this stage (Gruhn, Bryan and Moss, 1974).

The present evidence indicates that the Flandrian Transgression has not ceased in the Essex coastal zone. If relative sea level continues to rise in the area, as it appears to be doing, then it would be anticipated, given no human interference, that the present lithofacies would migrate bodily even further towards the hinterland, so extending the influence of the 3rd cycle.

ACKNOWLEDGEMENTS

Many people have contributed data on which this work is based among whom we would particularly like to mention Peter Martin of Rendel, Palmer and Tritton, Gunter Tuch of British Airports Authority and G.G. Pickton of the Department of the Environment. The radiocarbon dates were obtained through the auspices of Professor F.W. Shotton and Roger Williams of Birmingham University and Peter Sabine and Albert Horton of the Institute of Geological Sciences. Dr. R.G. West commented helpfully on the peat seam dated at 4959 B.P. though the inferences made are entirely those of the authors. The chemical and certain mineralogical information was supplied by Stuart Adams and Bill French of Queen Mary College. Mrs. Jean Fyffe drew all the figures.

REFERENCES

Akeroyd, A.V. (1972) – Archaeological and historical evidence for subsidence in southern Britain. Phil. Trans. R. Soc. Lond. A, 272, P. 151-169.

Beg, I.R. (1967) – Petrological and environmental aspects of the sediments of the Thames Estuary. Unpub. Ph. D. Thesis, Univ. London.

Boyden, C. (1973) – Observations on the shell morphology of two species of cockle *Cerastoderma edule* and *C. glaucum*. Zoo. J. Linnean Soc., 52 p. 269-292.

Davis, D.S. (1967) – The marine fauna of the Blackwater estuary and adjacent waters, Essex. Essex Naturalist, 32, p. 2-61.

D'Olier, B. (1972) – Subsidence and sea-level rise in the Thames Estuary. Phil. Trans. R. Soc. Lond., A, 272, p. 121-130.

Eisma, D. (1968) – Composition, origin and distribution of Dutch coastal sands between Hoek van Holland and the Island of Vlieland. Netherl. J. Sea Research, 4, p. 123-267.

Evans, G, (1965) – Intertidal flat sediments and their environments of deposition in the Wash. Quart. J. Geol. Soc. Lond., 121, p. 209-245.

Fairbridge, R.W. (1975) – Holocene sea level and the marginal bulge hypothesis. (Abstr) 56th Ann. Meeting Amer. Geophys. Union. 3 p.

Greensmith, J.T., R.G. Blezard, C.R. Bristow, R. Markham and E.V. Tucker (1972) – The Estuarine Region of Suffolk and Essex. Geol. Assoc. Lond., Field Guide no. 12, 41 p.

Greensmith, J.T. and E.V. Tucker (1969) – The origin of Holocene shell deposits in the chenier plain facies of Essex (Great Britain). Marine Geol., 7, p. 403-425.

——, (1971) – Overconsolidation in some fine-grained sediments; its nature, genesis and value in interpreting the history of certain English Quaternary deposits. Geol. en Mijnb., 50, p. 743-748.

——, (1973a) – Holocene transgressions and regressions on the Essex coast, Outer Thames Estuary. Geol. en Mijnb., 52, p. 193-202.

——, (1973b) – Peat balls in late-Holocene sediments of Essex, England. J. Sediment. Petrol., 43, p. 894-897.

——, (1975) – Dynamic structures in the Holocene chenier plain setting of Essex, England. Nearshore Sediment Dynamics and Sedimentation. Wiley, London, p. 251-270.

Gruhn, R., A.L. Bryan and A.J. Moss (1974) – A contribution to Pleistocene chronology in Southeast Essex, England. Quatern. Research, 4, p. 53-71.

Jelgersma, S. (1966) – Sealevel changes during the last 10,000 years. Royal Meteor. Soc. Proc., Internat. Symp. on World Climate from 8000 to O B.C., p. 54-71.

Jong, J.D. de (1971) – The scenery of the Netherlands against the background of Holocene geology; a review of the recent literature. Rev. Geogr. Phys. Geol. Dynam., 13, p. 143-162.

Kilenyi, T.I. (1969) – The problems of Ostracod ecology in the Thames Estuary. The Taxonomy, Morphology and Ecology of Recent Ostracoda. Oliver and Boyd, Edinburgh, p. 251-265.

Kraft, J.C. (1971) – Sedimentary facies patterns and geologic history of a Holocene marine transgression. Geol. Soc. Amer. Bull., 82, 2131-2158.

Nelson, H.F. and E.E. Bray (1970) – Stratigraphy and history of the Holocene sediments in the Sabine-High Island area, Gulf of Mexico. Deltaic Sedimentation: Modern and Ancient, Soc. Econ. Pal. Min., Spec. Pub. no 15, p. 48-77.

Scholl, D.W. (1964) – Recent sedimentary record in mangrove swamps and rise in sea level over the southwestern coast of Florida: part 2. Marine Geol., 2, p. 343-364.

Sheldon, R.W. (1968) – Sedimentation in the estuary of the River Crouch, Essex, England. Limnol. and Oceanogr., 13, p. 72-83.

Smith, R.A. (1918) – Essex red hills as salt-works. Proc. Soc. Antiq., 30, p. 36-54.

Sorby, H.C. (1901) – On the variation in numbers and habitat of marine animals on the coast of Essex during the last 10 or 12 years. Essex Naturalist, 12, p. 17-23.

Straaten, L.M.J.U. van (1965) – Coastal barrier deposits in South- and North-Holland, in particular in the areas around Scheveningen and IJmuiden. Meded. Geol. Sticht., NS 17, p. 41-75.

——, and P.H. Kuenen (1957) – Accumulation of fine grained sediments in the Dutch Wadden Sea. Geol. en Mijnb., 19, p. 329-354.

Swift, D.J. (1968) – Coastal erosion and transgressive stratigraphy. J. Geology, 76, 444-456.

Talbot, J.W. (1967) – The hydrography of the estuary of the River Blackwater. H.M.S.O., London, 92 p.

Willis, E.H. (1961) – Marine transgression sequences in the English Fenlands. Ann. New York Acad. Sci., 95. p. 368-376.