Cored material from the Fleet: some initial inferences

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Recent research into the Fleet sediments has been prompted by the unique geomorphological relationship of the lagoon with Chesil Beach. The sediments which floor the Fleet represent a sediment trap implying an infill from the Portland Harbour area, and not from the west ahead of an advancing Chesil (Poole, 1966). Of 25 planned, some 23 boreholes were sunk (1990 to 1993) to a maximum depth of -5.62 m OD, and 21 cores analysed for their stratigraphical composition. This includes petrology, mineralogy, geochemistry, magnetic susceptibility, using modern techniques of laser granulometry, scanning electron microscopy and EDAX analyses, mineral magnetic analyses (molspin magnetometer and pulse magnetiser), calcimetry, and wet and dry bulk densities. Two cores (4 and 6) have been analysed in greater detail, on which some radiocarbon dating of peat and other organic remains has been done, together with the examination, classification, and analyses of ostracods and diatoms. A pollen analysis has yet to be completed. Further radiocarbon dating of cores over the longitudinal cross section is also planned which should confirm the believed diachronous nature of the sedimentary deposition. Stratigraphic horizons in the lateral and longitudinal cross sections have been tentatively constructed and are offered herewith. From these, inferences are drawn regarding the sedimentary infill and evolutionary history of the Fleet Lagoon, and of Chesil Beach itself.

Introduction

Whilst it is not intended in this paper to review the past literature on the evolutionary history of the Fleet, some reference to it must however be made. The Victorians (into the early part of the twentieth century) seemed unable or unwilling to agree on whether the Fleet was 'an erosional' or a 'depositional' feature. However, it was Codrington (1870) who strongly averred that whatever else the Fleet might be deemed to be, it was essentially accretional in character. Fisher's (1873) notion of a fluvial origin, was rejected outright; at least for some years, until temporarily resurrected again by Baden-Powell in 1930, and then dropped. Codrington (1870) was doubtless right in his appraisal of the Fleet as an accretional feature as far as its sedimentary infill was concerned. But the nineteenth century geographers, and many since, have failed to recognise that for the Fleet to exist at all at present sea levels, the area upon which those accretionary deposits lie must once have been an erosional feature, *ceteris paribus*. So to a certain extent, proponents of such opposing views, were in part both correct.

For such recognition not to have been articulated in the then literature implies that Chesil beach was an offshore bar or barrier (regardless of derivation or provenance), which advanced with rising sea levels eastwards across Lyme Bay, and impounded the Fleet ahead of it. Poole (1966) has since argued convincingly that the bed of the present Fleet was virtually dry land until Chesil had almost reached its present position. My researches into the Fleet sediments are consistent with such an hypothesis, and suggest that the bed of the Fleet was dry land (albeit probably at times marshy) during much of the Holocene, and its sedimentary infill was from the Portland Harbour area.

The Flandrian transgression during the last 10,000 years has produced in the Fleet both a shallow water (non-pelagic) carbonate environment, and a siliclastic one. As both environments are not incompatible, the Fleet exhibits characteristics from both categories. Nevertheless, there are some very important differences and contrasts in emphasis to be identified, arising largely because of the local origins of many carbonate grains. The greatest source for carbonate grains is the warm shallow photic zone of a littoral marine environment (Leeder, 1982). But for clastics (or terrigenous grains) the abundance of such will depend upon their availability from the source area, their mechanical durability and chemical stability (Folk, 1974), much of the Fleet clastic grain infill being derived from elsewhere, i.e. allochthonous. Before examining the sedimentary data from the Fleet it is thus important to list the major differences between carbonate and siliclastic sediments, viz:

CARBONATE SEDIMENTS	SILICLASTIC SEDIMENTS
Majority of sediments occur in shallow tropical environments.	Sediments occur worldwide and at all depths.
Majority of sediments are marine.	Sediments are both terrestrial and marine.
Grain size of sediments generally reflects the original size of calcified hard parts.	Grain size of sediments reflects the hydraulic energy in the environment.
Presence of lime mud often indicates prolific growth of algae, the calcified portions of which are mud size crystal aggregates.	Presence of mud indicates settling out from suspension
Sediment type often changes over time in response to evolution.	Sediment grains remain virtually unchanged throughout geological time.
Shallow water lime / sand bodies result primarily from localised physicochemical or biological fixation of carbonate.	Shallow water sand bodies result from the interaction of currents and waves.
Localised accretions of sediments without accompanying change in hydraulic regime alter the character of surrounding sedimentary environments.	Changes in the sedimentary environments are generally brought about by widespread changes in the hydraulic regime.
Sediments are commonly cemented on the sea floor.	Sediments remain unconsolidated in the depositional environment and on the sea floor.
Periodic exposure of sediments during deposition results in intensive diagenesis, especially cementation and recrystallisation.	Period exposure of sediments during deposition leaves deposits relatively unaffected (duricrusts excepted.)

The Fleet sediments are thus examined within the above relevant parameters, and my researches into them have the following three aims:

1. To determine as far as possible by coring, the composition and nature of the Fleet sediments;

2. To infer and determine as far as possible from core evidence any changes in relative sea levels and associated environmental conditions during the Flandrian marine transgression;

3. To seek evidence from the Fleet area sediments of possible or likely indicators of the late evolutionary history of the Chesil Beach, and with which it must be identified.

The sedimentary infill of the Fleet therefore suggests a palaeoenvironment which lends itself to analysis, but is complicated by its evolutionary history as a lagoon exhibiting both estuarine and marine sedimentary characteristics, to say little of anthropogenic influences and activities from littoral settlements during oscillating Flandrian relative sea level rises, e.g. World War 2 'bouncing bombs' and other anthropogenic scrap iron etc.

Any general stratigraphic picture emerging needs much qualification before discussion, namely:

1. That core sections only inform, with any precision, details of the stratigraphic column through which the core has passed. As such, core data analyses can only represent a series of pin-pointed sedimentary infill sequences (*sensu stricto*) and which may still not accurately represent given areas or depths, or dating.

2. Unless and until the technology for analyses of in situ sediments becomes both viable and available to researches such as mine, sediment or depositional areas not cored between boreholes can only be inferred, and any statements made therefrom, or when related to specific cores, must be regarded as being somewhat circumspect. These are major caveats, and any interpretative conclusions must be made within their constraints.

Firstly, 23 cores made in a lagoonal area of some 5 square kilometres can only be regarded as being a somewhat frugal sample, and far from the theoretical ideal. Coring on a 1 square metre sampling graticule might be possible given sufficient time, resources and money, but my research facilities are rather more modest. Even so, a longitudinal cross section of cores (with the unavoidable inferences) has been made from Berry Knap almost to Ferry Bridge, together with six lateral cross sections from Chesil to the Fleet shore. Deeper coring is now planned as the outcome of the encouraging results and data already secured. Also evidence from previous coring done for the CEGB has been made available, and this augments and enhances that from my 23 cores. The position of these borings is shown in Figure 1, while sediments found within selected borings are given in Figure 2A and 2B.

Secondly, only a relatively dense areal pattern of boreholes of adequate depth can indicate the likely sequential pattern of deposition. Single or widely separated borehole data must therefore be treated with reserve in this regard also. The interpretation of the processes of sedimentation has in the past been somewhat hidebound by the concept that at any instant in geological time, sediment was raining down everywhere and thus was preserving simultaneously different contemporaneous environments and also, obeying implicitly the laws of superposition. A result of these ideas is the traditional 'layer cake' stratigraphy (Ager, 1993). This concept may well be valid in the ocean depths at present day, but it most certainly does not apply to the super-shallow Fleet lagoon during the Holocene.

The above notion does not take into account the possibility - even likelihood - that the infill will occur on anything but a flat or horizontal bedrock or substrate, or the behaviour of differing fluid dynamics arising from differing sediments of differing grain sizes deposited within differing environmental conditions. Time planes are not necessarily parallel with lithological boundaries, so that often sedimentary deposits are diachronous. For example, deltaic or progradational infill

exhibiting foreset beds are (*ceteris paribus*) time-transgressive, as is usually demonstrated by Walther's law (Leeder, 1982). From my core data, radiocarbon dating and other evidence seem to confirm such a characteristic time-transgressive sedimentary infill into the Fleet from the Portland Harbour or SE direction. From the study of the stratigraphical and petrological data so far, this seems to preclude accretionary patterns from any other direction, e.g. from the north-west.

An exhaustive search at the Bodleian Library at Oxford and in the British Library in London for reliable historical map evidence of a breach in Chesil Beach near the Swannery at Abbotsbury has proved totally negative. Such evidence, if valid, would indicate a sedimentary infill from the NW, with a wholly different pattern from that revealed by my cores. Whilst the maps of Kipp (1607) and Moll (1724) both show open access to the sea at Abbotsbury, the earlier map of Saxton (1575) shows a continuous shingle ridge from Portland to Burton cliffs. It would seem that a marked degree of cartographic licence typifies such historical maps, and the Dorset County Archivist in a personal communication suggests that no remotely accurate survey of Chesil Beach was done before the nineteenth century, and mapped therefrom. However, it is necessary to be somewhat definitive regarding the notion of a 'breach' in Chesil sufficient to produce an infill pattern dissimilar to that from the SE; there is of course much evidence of washovers and crestal lowering and retreat from high tidal and meteorological forcing, an example being the great 1824 gale with severe inundation and damage at Fleet and Abbotsbury (Coode, 1853; Groves 1875; Carr and Blackley 1974; Carr and Seaward 1990, 1991), but of a barrier breach typified by those in the Baltic, off Southern Mexico, or off Ninety Mile Beach, East Gippsland, Australia, there appears to be no evidence.

Whilst inference between cores is regrettably unavoidable, caution must also be exercised in inferring rates of sedimentation in the vertical column of the core; compaction is differential both vertically and horizontally, and it varies widely between clastic and non-clastic deposits. For example, the peat layer compaction can be as much as 80% to 90% of its 'original' thickness whilst sands can be compressed by as little as 2% of their original depth (Jelgersma, 1961).

Therefore it is necessary to consider horizons least susceptible to changes in levels due to the progressive accumulation of overburden; these are organic horizons in contact with an underlying mineral substrate. Conversely, horizons most susceptible to change of level are such organic horizons in contact with overlying mineral deposits, as well as any similar deposits that overlie deeper peat beds.

The bedrock geology of the Fleet spans the Weymouth anticline and coring has therefore been into sediments overlying Cornbrash, Forest Marble, Fuller's Earth, Forest Marble, Cornbrash, Oxford Clay, Corallian Limestone, and Kimmeridge Clay, respectively, from NW to SE. From experience with the use of the Livingstone piston corer an increasing resistance at progressively shallower core depths from NW to SE, suggests stiffer sediments lying upon bedrock at a shallower depth OD. The more resistant Corallian outcrop in the Wyke Regis area is the probable explanation for this apparent slope upwards SE along the Fleet substrate.

Detailed core data is offered on cores 1 to 5 and 6x, 6 and 6y, all in the West Fleet and more than 5 metres in depth. The lowest sediment in core 4 (from *circa* -4.50 m to -5.27) was a very stiff light grey clay containing organic particles, and similarly occurring in core 6 at slightly less depth of between -4.10 m and -5.24 m on which overlies some 18 cm of interdigitated sands and clays. Such was the resistance in this material to piston coring, even when using 2 x 1 ton ratchetted pulley blocks that at times the raft was raised out of the water. This layer appears common along the Fleet at decreasing depths south-eastwards, and it would seem to be of solifluction derivation, and has a significant magnetic susceptibility. It must also be recognised that magnetic intensity of the sediments and palaeo-climate may be fundamentally linked, since sediment characteristics may be partly controlled by climate. This appears consistent with characteristic environmental conditions at the very beginning of the Holocene or Flandrian, by for example, the in-

washing of minerogenic material and dissolved iron (Berglund and Malmer, 1971), and this may be explained as an initial stage of intensive leaching during a very unstable climate.

However, instead of a great diversity and high intensity of various physical processes in the cold climate in the early Holocene, modern research and analyses of the period from 10,000 to 8,000 years BP, suggest a great stabilisation due to deep infiltration of melt water, and plant cover, much higher concentrations of humic acids and increasing leaching processes, but depending on the nature of dissolved salts in the substrate.

This lower sediment in the Fleet is thus likely to be the result of the foregoing conditions; the petrology and mineralogy revealed by the Scanning Electron Microscope and EDAX suggest it to be not of marine derivation but containing much reworked terrestrial material incorporating well-humified organic fragments.

There appears to be a cyclical pattern of peat layer deposition between sand layers, lenses, and interdigitated silty clays and clayey silts, there being for example six clearly defined peat layers in core 6, and five in core 4. Marine transgression thus appears to have been intermittent in so far as the peat deposits (both *Phragmites* and more halophytic varieties), suggest former land surfaces under episodes of negative tendency, either stillstand or regression. However, caution must be exercised relating a sequence of peat overlain by marine clays to a change in sea level. Such peat beds may accumulate close to mid-tide level behind barriers such as mini-shingle spits or dunes (these being both possible in a palaeo-Fleet), which can break down, exposing the peats to a full tidal range and burying them with marine sediment without any change in sea level (Churchill, 1965).

In some cases a substantial compacted peat layer, (for example, core 6) of some 0.86 m thick, is found immediately overlain by a macro and micro shell assemblage; this may or may not be the result of a catastrophic event by storm or tsunami, or neither. Here another *caveat* is necessary: no research has yet attempted to establish unequivocally on stratigraphical, sedimentological, and/or palaeoecological grounds, the means by which the two such different processes of storm surges and tsunami waves might be distinguished in coastal sedimentary sequences arising from the resultant coastal flooding (Foster et al, 1991).

Nevertheless, the peat layer immediately below the shell assemblage (-2.92 metres to -3.09 metres OD) has been radiocarbon dated to 4540 ±70 years BP and hazel (*Corylus*) wood within the same peat layer a little lower down at -3.52 metres to -3.56 metres OD, similarly dated to 4800 ±100 years BP. A third sample from peat at -4.30 metres produced a date of 4840 ±70 years BP. With only three radiocarbon dates to hand at the moment, one is somewhat hesitant to attempt to relate these data to other similarly dated peats found elsewhere in UK coastal environments. So far, what can be said of the Fleet pattern of the peat deposition based on the present amount of coring evidence, is that it appears discontinuous, or patchy, at various levels, but occurring repeatedly in thin layers from -3 metres OD to -1 metre OD, with increasing areal deposition south-eastwards into the East Fleet, and this pattern disappears only on the approach to the tidally-scoured Narrows.

The occurrence of peat from -5.30 metres OD (core 6) to -2.60 metres OD (core 15) with interdigitated marine clays and sands nevertheless suggests both regressive and transgressive overlaps respectively; although the apparent cyclicity of the peat and sand layers and their relative shallow depths in the East Fleet, suggest that they may be tidally derived and controlled where such tidal ranges and wave energy are the greatest. However, this anomaly is further compounded by the CEGB core evidence of peat layers in the East Fleet area at -3 metres OD to -5.5 metres OD, and at variance with the pattern of the shallower peats referred to above in core 15. However this only confirms the view that the Fleet peat deposition is a complex one both areally and in depth sequences, and the likely results of both positive and negative tendencies, together with an increasingly significant tidal control with rising relative sea levels. As rising sea levels bring with them an increasing sediment supply, this will affect conditions of burial of both non-clastic and clastic sediments.

So until far more boreholes are sunk, only a tentative (and thereby simplistic) assessment of this aspect of the palaeo-organic deposition pattern can be made. To some extent this is true also of the depositional pattern of the clastic sediments, namely the sands, silts and clays.

Samples of the sands taken from the Portland Harbour CEGB boreholes sunk *circa* 1964, have been compared with those from the Fleet, and subjected to the same petrological and mineralogical analyses. The borehole logs of the CEGB corings (Rendel Palmer and Tritton, Consulting Engineers) describe most of these sand layers as being "grey Fine Marine Clay" and having layer thicknesses of as much as 10 m. Whilst thicknesses of sand layers in the Fleet are at maximum barely 0.5 metre they are nevertheless characterised by their grey colour, and quite unlike (in this respect), those found on present day beaches at Ferrybridge, Sandsfoot, Weymouth, Church Ope Cove, and Portland Bill. Moreover, when compared with sand samples collected from offshore Chesil and the Shambles bank, a similar difference is apparent, i.e. all the latter exhibit a golden colour, markedly absent from the Fleet sands. Traces of yellowish or golden sands only appear in cores taken in the East Fleet, i.e. cores 15, 21, 25, 26, 27 and 28, and within - 1 metre OD. This suggests a relatively recent spread of present day beach sands into the Fleet.

A factor thought to produce the yellowish or golden colour is the presence of ferruginous grain material, markedly absent from the Fleet sand deposits, and not widely present in the Portland Harbour CEGB cored sands. An analysis so far of the Portland Harbour and Fleet sands by laser granulometer and scanning electron microscope, indicate that they are petrologically and mineralogically similar, having a likely common provenance.

The 'black' component of the Fleet and Portland Harbour sand appears to be chert or flint (probably from the cherty series of the Portland limestone, so well exemplified at Blacknor on the west side of Portland, and at Church Ope Cove on the east side), and the 'white' is quartz, so common to most sands. An analysis of the Corallian limestone at Wyke Regis exhibited a high proportion of quartz grains, and this could well be (*sensu stricto*) a source of the 'white' component of the Fleet and Portland Harbour sand deposit.

Whilst the SEM reveals much of the mode of transport and past erosional- and depositional-history of sand grains, together with the help of EDAX analysis, these can indicate a likely provenance. However, quartz (because of its commonness), can be derived from almost anywhere. The Fleet and Portland Harbour quartz grains are very angular (Powers scale 0.12 - 0.17) and it is initially tempting to infer that these grains have not travelled very far or been in the sea for very long, or both, and therefore of local or nearby derivation. However, it is well known that quartz grains can be transported over vast distances displaying negligible edge abrasion (Folk, 1974; Bull, 1981). It is therefore inadvisable to assume a wholly local source of sediment component for these 'grey' sands, particularly from a sandstone or calcareous sandstone, such quartz grains may have been reworked many times, and still remained angular or even very angular. Nevertheless the Corallian quartz grains are likely to be one (possibly major) source of supply.

A similar caveat may well apply to the black chert component, the nearby Portland limestone cherty series being a most likely source, but by no means to the exclusion of others. Chert is physically virtually indestructible and its 98% componental composition of Chesil exemplifies this. Sand streams from the east into Weymouth Bay have been identified by Stride (1963) moved by palaeotidal currents offshore. These have abraded the sea-bed of soft sandstones and Jurassic clays by frictional contact to such an extent that trenches have been cut, some near Weymouth are up to 15 miles long, and more than a mile wide.

It is likely also that chert and flint from the Dorset chalk has been moved south and west in the lee of Portland/Chesil during rising Flandrian relative sea levels, which made the inundation and infill of the Portland Harbour area possible from the east. This then is a possible mechanism and a possible area of provenance to account for some of the chert component of the Fleet "grey" sands. SEM examinations of the chert grains show a similar pattern of angularity with that of the quartz.

The finer grain sizes in the Fleet silts and clays exhibit a similar composition, are characteristically grey in colour and probably are similarly derived. The sands, silty clays and clayey silts are interdigitated up the core columns in a similar manner from the deepest cores in the West Fleet, 6, 6x, 6y, to the shallowest core 26, in the East Fleet. Because of the present inability to core deeper in the extreme East Fleet (believed due to the less-eroded Corallian bed rock), we know nothing of any recent sedimentary infill deeper than *circa* -2 metres OD. An attempt with different coring equipment is to be made in this area in September 1993, in the hope of coring deeper to reveal more Flandrian sediments, in which case it may indicate that it is the stiffness of the lower sedimentary layers rather than the believed shallow depth bedrock, which is the operational problem. A further coring is planned in the Spring of 1994 using a percussion corer (including a possible core into Burton Mere) to define more exactly the likely nature and surface depth profile of the Fleet bedrock.

I am grateful to D.R. Seaward Esq. for his identification and analysis of the shells obtained from the cores, together with Dr J. Whittaker of the British Museum, for his identification and analysis of the ostracoda, and to Dr S. Juggins of University College, London for similar work on diatoms. A pollen analysis has been planned for November 1993. When these aspects of the work are completed they will doubtless throw much light upon the palaeo-ecology and on the bio-stratigraphy of the Fleet sediments related to the litho-stratigraphy, both being the product of oscillating sea levels and a tidal regime.

Conclusions

From the above paragraph it is self evident that no positive conclusion can be drawn from the present incomplete data. However the preliminary findings do raise more questions than they appear to answer, and this alone should endorse the validity of the research. The reader is referred to the line core diagrams and maps produced with this paper.

Acknowledgements

I am most grateful to the following for their unstinted help:

Mr. D.R. Seaward for shell analysis.
Dr J. Whittaker for Ostracoda analysis.
Dr S. Juggins for Diatom analysis.
Ilchester Estates, for access, logistical and financial support, particularly Mr Edward Green, and Mr John Fair.
O.C. Royal Engineers, Bridging Camp, Wyke Regis, for raft towage and hoist gear.
Mr Neville Copperthwaite for use of platform barge.
Mr Peter Mowlam for logistical support and repair facilities.
To members of the Fleet Study Group, for their support and advice, notably from Dr Alan Carr and Mr Geoffrey Poole.
Mr Reg Perry of Portland for obtaining sand samples at Church Ope Cove, and Portland Bill.
The Royal Navy for obtaining sand samples from the Shambles bank.
My Departmental colleagues from the School of Geography, University of Oxford, for academic, psychological and physical support, bravely assisted by Miss Nicola Goss from the Department of Geography at Birmingham University.

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Figure 1. Core transect locations, Fleet lagoon, Chesil Beach, Dorset

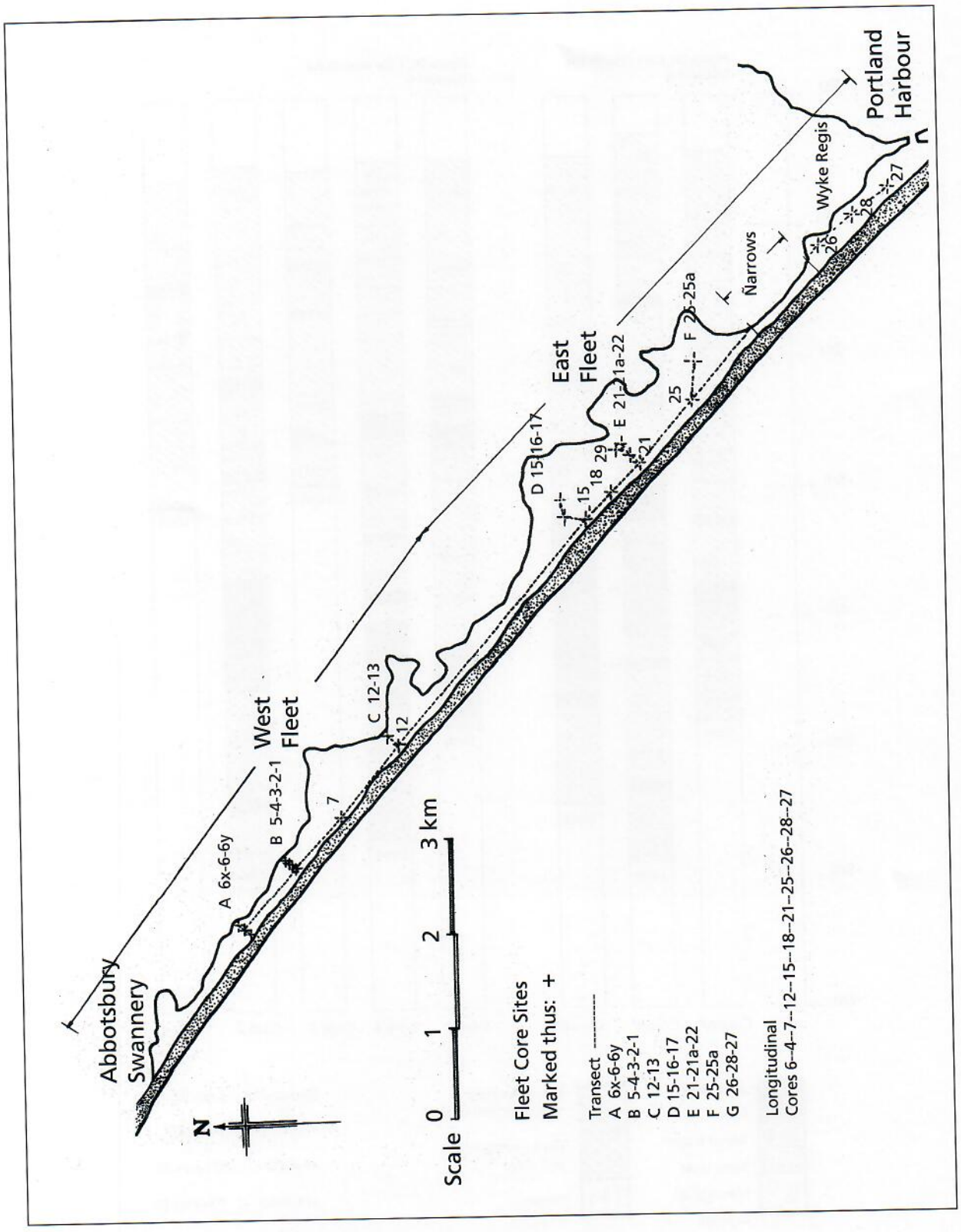
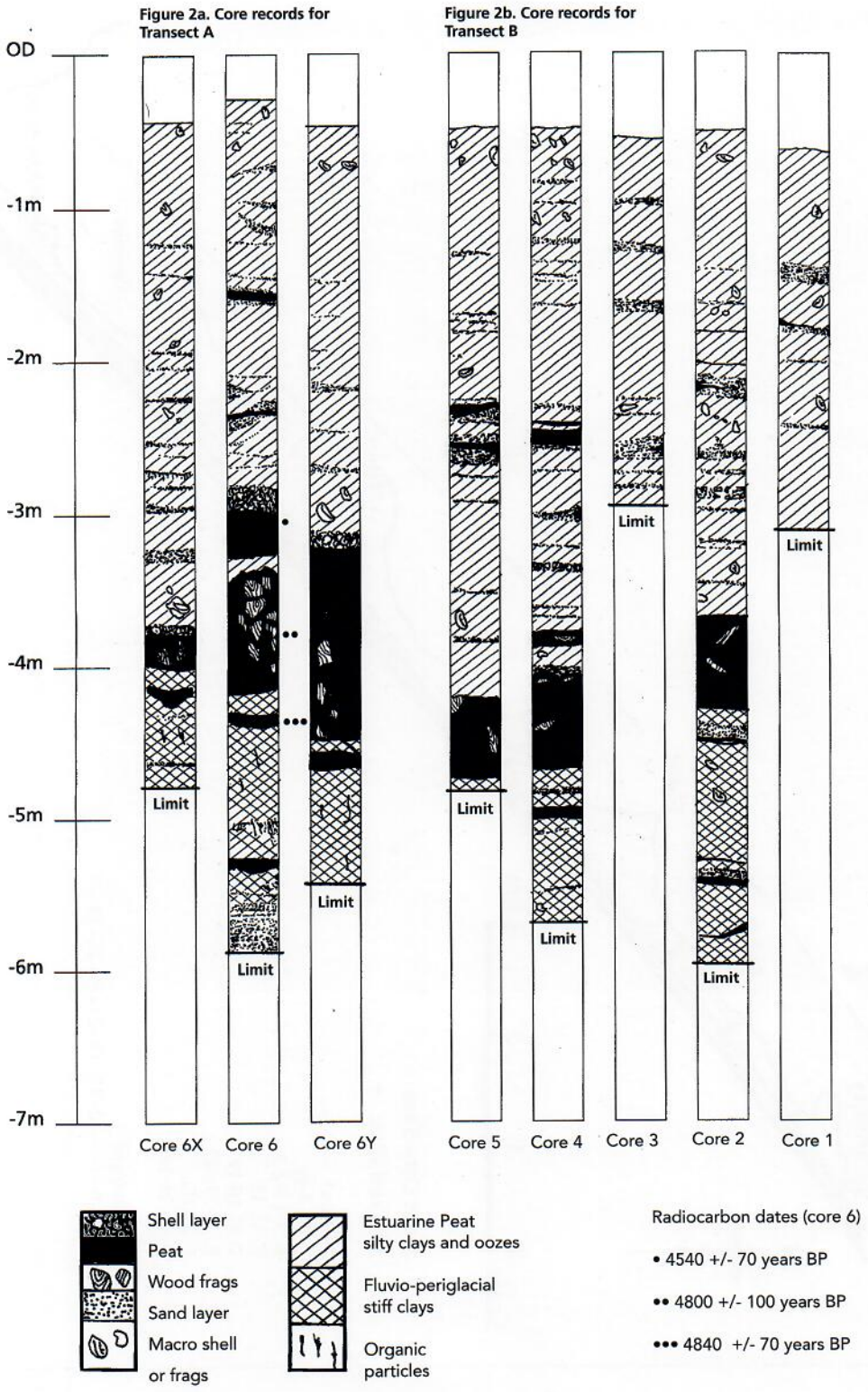
Figure 2. Transects A and B