FLANDRIAN SEA LEVEL CHANGES AND VEGETATIONAL HISTORY OF THE LOWER THAMES ESTUARY

By R. J. N. DEVOY†

Sub-department of Quaternary Research, Botany School, University of Cambridge, Downing Street, Cambridge CB2 3EA, U.K.

(*Communicated by R. G. West, F.R.S. – Received* 20 *October* 1977)

[Pullouts 1–16]

CONTENTS

† Present address: Department of Geography, University College, Cork, Eire.

A biostratigraphic study, investigating the interleaved Flandrian biogenic and inorganic deposits of the lower Thames Estuary, has been carried out between central London and the Isle of Grain. The vegetational and environmental history, showing the relation of the biogenic deposits to former sea level has been deduced from pollen, diatom and other microfossil studies. Radiocarbon dating has been used to establish an objective chronology. From this evidence the height of relative sea level movements, seen in marine transgression and regression surfaces, have been determined. These are plotted against time to show the rate of relative sea level change and subsidence trends for the Thames Estuary and southern England. Diatom studies show the early importance of marine and brackish water influences, at the beginning of Flandrian sedimentation in the Thames. Pollen and macrofossil analyses demonstrate the strong local effects of the saltmarsh and fen environment upon the vegetational history. The rise of *Alnus* pollen is seen to occur before 8100 years B.P., probably reflecting local physiographic conditions and valley flooding consequent upon the rising sea level. Elements of the regional vegetation development are recorded however, with the *Ulmus* and *Tilia* pollen declines shown. Five regression phases (Tilbury I–V), represented by the biogenic deposits and four marine transgressions (Thames I–IV), together with the possible existence of a fifth (Thames V), are recognized. The relative sea level for mean high water mark of spring tides (m.h.w.s.t.) is shown to rise at about 8500 B.P. from −26.5 m O.D. to above present Ordnance Datum (Newlyn) by about 1750 years B.P. Relative sea level curves for the Thames during Flandrian times correlate well with the form and rate of relative sea level changes shown for northwest Europe. Plotting these graphs against each other has allowed subsidence trends to be shown. Within the Thames, possible differential downwarping of approximately 1.5 m has been identified between Crossness and Tilbury for the Flandrian. The regional trends of west to east and north to south downwarping are supported. The amount of subsidence for southeast England, formerly given as 6.1 m since 6500 B.P., is not confirmed. The figure for the Thames area relative to the Bristol Channel lies closer to 2–3 m since 7000 B.P., although rates of downwarping vary with the type of environment studied, making generalizations tenuous. Sea level only shows relative subsidence trends and is not as yet seen to provide an accurate fixed datum from which one can give precise figures for land subsidence.

1. Introduction

The lower Thames Estuary is defined here as the area between central London eastwards to the Isle of Sheppey. The limits of the lower Thames Estuary are bounded by the Ordnance Survey grid squares TQ 050 and 300 in the east and west and by grid squares TQ 000 and 600 in the north and south (figure 1). Within the area, most of the land lies below the 100 m contour, with the Chalk and London Clay formations forming zones of high ground. Four main physiographic units are recognized:

(1) The flood plain north and south of the River Thames, lying between mean low water mark of spring tides (m.l.w.s.t.) and the 10 m contour. (This unit includes the alluvium of the Thames tributary streams.)

(2) The chalk upland south of the river, rising to above 60 m O.D.

(3) The raised and mostly sub-horizontal clay zones of southeast Essex.

(4) The clay uplands of north Kent, from Higham and High Halstow to the Isle of Grain.

The solid geology of the area is represented by Cretaceous, Palaeocene and Eocene rocks (figure 2). North of the river Eocene sediments predominate; they are represented by the clays, loams, sands and pebble beds of the lower London tertiaries, with extensive areas of London Clay. The latter formation commonly occurs south of the river, giving way in the west beyond Cliffe, to exposures of the Upper Chalk. Structurally the area forms part of the much larger syncline of the London Basin. The rocks dip gently from west to east, before merging into the deeper and active southern North Sea syncline (d'Olier 1972). An idea of the dip can be gained from recent deep boreholes in the area. At Barking Creek mouth in the west, the chalk surface was met at −26.6 m O.D., compared with −153 m O.D. some 30 km to the east at Sheerness. No major faults occur, although many minor folds and faults are known, with northwest–southeast trending anticlines occurring across the course of the Thames (Sherlock 1962; Conway & McCann 1972; Lake, Ellison, Henson & Conway 1975).

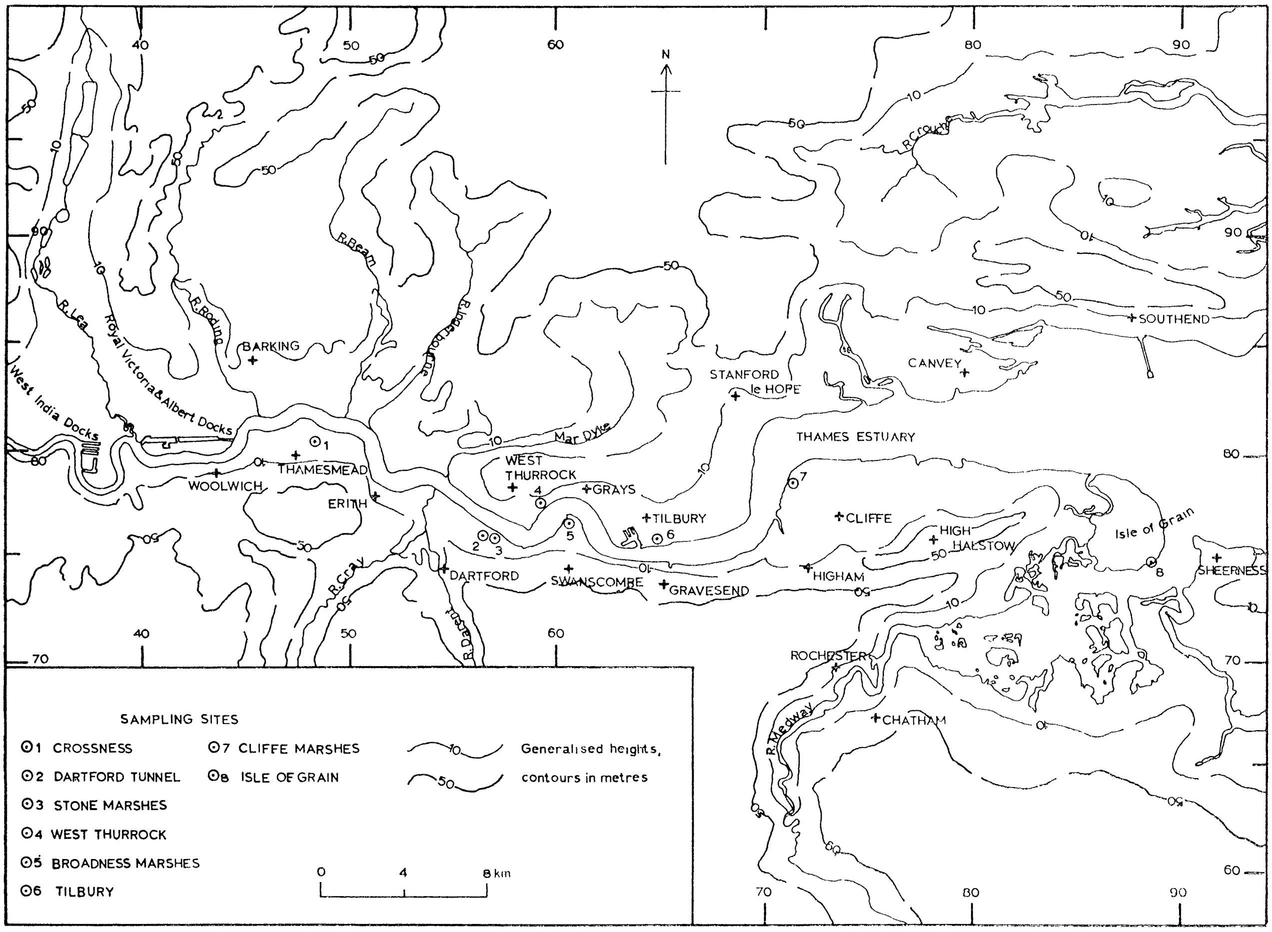


FIGURE 1. Topographical map of the lower Thames, showing site location.

Pleistocene deposits form the major characteristic geomorphic features apparent today (Wooldridge 1927, 1957, 1960; Wooldridge & Linton 1955; Zeuner 1954, 1959). The deposits may be grouped under five headings: river terrace sequences, head, brickearth, alluvium and boulder clay (till). Subsequent deformation by weathering and mass movement results in a complex picture which makes recognition of each deposit and chronological appraisal of them difficult. Landsliding and slip features are common, particularly in the submerged Flandrian†

† The term Flandrian is used here to describe the last 10000 radiocarbon years of the British Quaternary, as defined by Mitchell, Penny, Shotton & West (1973). The lack of a type site in Flanders and problems of stratigraphic correlation (Paepe *et al.* 1976) are however, recognized. Until a further precise definition is made, this term is still preferred.

sequences. The silts and clays of Stone, Cooling and Cliffe marshes display such features, ranging in size from a few metres up to a kilometre in width (Kirby 1969). Similar large landslips are associated with the abandoned cliff in the London Clay at Hadleigh, Essex (Hutchinson & Gostelow 1976).

Known deposits of the early Pleistocene are sparse or absent from the area. The earliest are represented by exposures of chalky boulder clay of Anglian age, found at Hornchurch and further north at South Hanningfield, Essex (Mitchell *et al.* 1973). Deposits which are

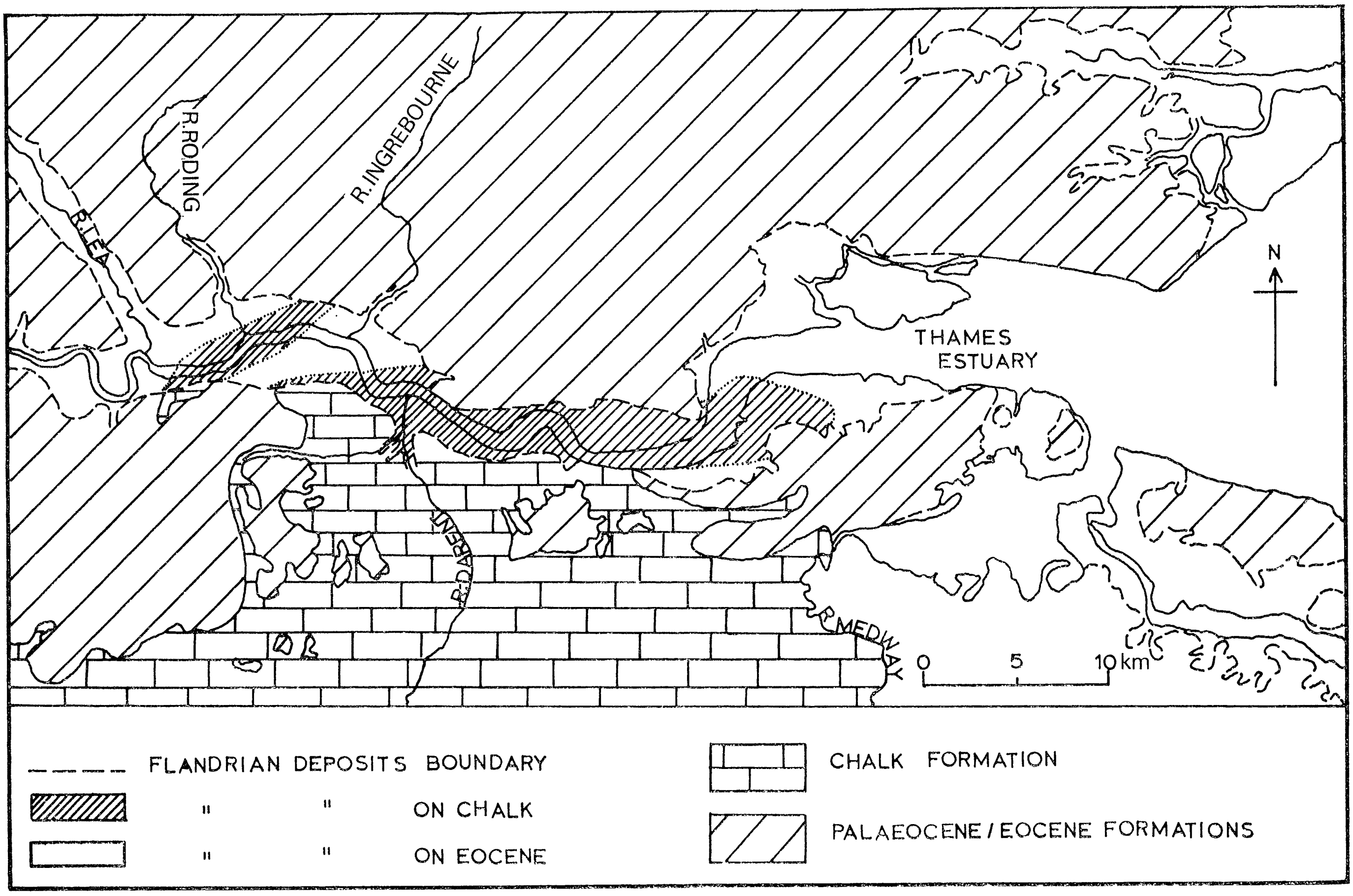


FIGURE 2. Generalized geological map of the lower Thames area.

of apparent equivalent age to the Crag deposits of East Anglia (Shephard-Thorn 1975) lie outside this area, in the Weald. These form the focus for controversy centring upon either a marine origin or an aeolian and fluvio-glacial origin, as proposed by Wooldridge & Linton (1955) and Kellaway, Redding, Shephard-Thorn & Destombes (1975) respectively.

The Thames river terrace sequences are composed of sand and gravels in association with brickearth. Their formation is best explained by increased aggradation, consequent upon sea level rises during stages of the Pleistocene (West 1968). However, their present height is not entirely explicable by such glacio-eustatic sea level fluctuations. For example, the Boyn Hill Terrace reaches to above 30 m whilst higher levels are encountered with earlier terraces upstream, requiring base level heights in excess of Flint's (1971) maximum potential sea level rise of *ca.* 43 m. Positive structural movements and changes in the geodetic sea surface (Mörner 1976*a*) over the last million years, may both form elements in the explanation of their height. Four terraces are identified with two buried channel phases and collectively referred to as stage III in the Thames terrace sequences (West 1968): Boyn Hill, Taplow, Upper Floodplain and Lower Floodplain. On reaching the lower Thames, the altitudinal differences are often slight and the deposits confused, making differentiation and application of the scheme difficult. Dating has depended upon height differences and principally upon archaeological, palaeobotanical and faunal evidence. The archaeological finds of flint artifacts, bones and occupation levels, however, are often derived and therefore not *in situ* (Wymer 1968); this reduces the reliability of such information. The use of palaeobotanical techniques with evidence from faunal assemblages provides a better chronological yardstick (Stuart 1974; Carreck 1976). Thus the Boyn Hill Terrace is equated with the Hoxnian interglacial and the Taplow Terrace containing a cold fauna is probably Wolstonian in age. The Upper Floodplain Terrace, from which a number of sites have been studied, notably at Ilford (West 1964), Aveley (West 1969) and Trafalgar Square (Franks 1960), developed during the Ipswichian. Sutcliffe (1976) in support of Zeuner (1954), disagrees with this dating and stratigraphic interpretation in the lower Thames. Instead, two distinct terraces are identified here, incorporating deposits equivalent to those of the Taplow and Upper Floodplain Terraces proper. Differences in the faunal assemblage of each terrace are used to support identification of a further warm phase after the Ipswichian. This distinction is questionable, given the ambiguous height data, structural movements in the area and lack of clear substantiating stratigraphic and palaeobotanical evidence elsewhere in Britain. Explanation of the stratigraphy for these Ipswichian deposits may lie with two contrasting episodes of increased river/estuarine aggradation, dependent upon changes of sea level (Hollin 1977). The Lower Floodplain phase, forming the lowest terrace, probably developed during early Devensian times as shown by the cold flora and fauna of the Lea Valley Arctic Plant Bed (Godwin 1964). The first buried channel developed during middle Devensian times cutting into these gravel deposits; this channel is now found west of Brentford at a depth of −40 m O.D. This was later infilled and a second buried channel cut to a depth of −30 m O.D. in late Devensian times; this is found at −13 m O.D. at Tilbury and −5 m O.D. at Charing Cross (Lake *et al.* 1975). Infilling of this channel probably started in the Flandrian, consequent upon a rising sea level. Overall, the subject of separation and dating of the Thames terrace sequences is confused and open to further study.

Until recent radiocarbon datings (Welin, Engstrand & Vaczy 1974, 1975; Lake *et al.* 1975), previous research upon the Flandrian sediments was centred upon the work of Whitaker (1889) and Spurrell (1889), together with archaeological material (Akeroyd 1966). Such evidence together with further information upon this and related sea level studies in the British Isles is given elsewhere (Devoy 1977*a*).

2. Techniques of analysis and their application

In the investigation of sea level changes, biostratigraphic analysis is but one source of evidence that may be used. For example, engineering techniques employing shear-strength tests, plasticity and particle size distribution may all be used in interpreting different episodes in the stratigraphy. This approach is demonstrated by Greensmith & Tucker (1971*a*, *b*, 1973) in the identification of over-consolidated horizons, showing the presence of former saltmarsh deposits in the absence of biogenic sequences. However, it is essential to establish as precisely as possible the deposits' relation to their contemporary sea level; without *in situ* development of organic material this is difficult. Nevertheless, even where marine/brackish inorganic and freshwater organic facies alternate and a full range of biostratigraphic techniques can be used, the problem of defining the point of sea level rise and its relation to sediment accumulation remains. For although biogenic growth will be related to a particular point within the tidal range, the deposits may form from below mean sea level (m.s.l.) to above mean high water mark of spring tides m.h.w.s.t. (Jelgersma 1961; West 1968; Tooley 1976). To determine this relation, upon which the curve for relative sea level movement is based, five criteria have been established:

(1) Identification of *in situ* development of the sediments, shown by a gradual stratigraphic change between the organic and inorganic deposits. Where the transition is sharp, reworking or erosion of the sequence may have occurred. A marine transgression contact is defined by the point of upward transition from biogenic to marine/brackish inorganic accumulation. The transition between a biogenic deposit overlying a marine sediment, is recognized as a regression contact for sea level movement.

(2) Analysis of the vegetational changes through the organic sediment and over the transitional areas with the inorganic deposits, using pollen and macrofossil techniques. In the Thames, sediment accumulation at the contact zones is taken to represent approximately the position of m.h.w.s.t. (Tooley 1969). Godwin (1943) noted the occurrence of distinct seral vegetation changes in such interleaved deposits. From open marine/brackish water sedimentation, the vegetation was seen to develop ideally from saltmarsh communities, through *Phragmites* reed-swamp to freshwater dominated communities. Such a sequence was seen to be reversed over a transgression contact. This general ecological picture, more recently supported by Tooley (1969, 1974, 1976), in conjunction with the stratigraphic evidence allows determination of the deposits' height relation with sea level, during the time of formation. It would appear that the intertidal area dominated by the Phragmitetum and saltmarsh communities, as represented by the contact zones, falls within the level at which m.h.w.s.t. are operative (Godwin 1943; Chapman 1964; Ranwell 1972).

(3) Determination of the environment represented by the silts and clays, in support of the vegetation analyses. Such sediments indicate deposition by water action, although the salinity of the water body (whether marine, brackish or freshwater) and thus the relation of the deposits to sea level, is not clear from the stratigraphy alone. Diatoms provide an excellent tool here, as they demonstrate salinity changes well and help pinpoint the transgression and regression contacts more accurately.

(4) Once these transitional points have been established material is taken for ^{14}C dating, providing an objective chronology.

(5) Determination of the correct heights of the transgression and regression contacts by precise levelling to Ordnance Datum, Newlyn. Inaccuracies due to differential compaction and consolidation occur, and the importance of these factors for sea level change has been noted (Royal Netherland Geological and Mining Society 1954; Jelgersma 1961) (see § 11).

(*a*) *Sampling network*

Five principal sites lying both north and south of the river were selected along a west to east transect, following the course of the Thames. Each site is representative of the local marsh stratigraphy, chosen to allow detailed examination of the lithostratigraphy and to establish lateral and chronological correlation of the deposits. This provides a check upon possible river meandering. Each of the five sites is dealt with separately in the following section, starting with Tilbury as the reference (type) site and then proceeding downstream from Crossness to the Isle of Grain.

(*b*) *Methods of coring and levelling*

Sample cores for micro and macrofossil analyses were made with a 10 cm diameter piston corer, providing meter length, undisturbed samples. Undisturbed U-4 cores from a percussive drilling rig provided material for examination from engineering investigations. Additional samples were taken from both 'free face' excavations with 50×10 cm alluminium monolith tins and with a Russian type borer. The Duit's gouge and the Hiller borer were found to be most effective in field examination of the stratigraphy. Levelling has been referred to the Third Geodetic Levelling of England and Wales, Ordnance Datum, Newlyn.

(*c*) *Stratigraphy and nomenclature*

Sections have been constructed from existing records, augmented by hand borings. From these, the sample core can be related to both the local and regional stratigraphy. To clarify the nomenclature of the deposits, the inorganic layers are termed Thames (Th) and numbered from I–V from the gravel base upward, in accordance with stratigraphic procedure (Stratigraphy Committee of the Geological Society of London 1969; Harland *et al.* 1972). The biogenic levels are similarly numbered from I–V, using Tilbury (T) as the type site where the Flandrian sequences were found to be most fully developed. In recording and representation of the stratigraphy, Troels-Smith's scheme (1955) for classification of unconsolidated sediments has been used. Here, the density of the deposit symbols equals the relative proportions of the component elements, based upon a 5 class scale. The original stratigraphic data for each site studied has been deposited in the Royal Society's archives and in the British Library (lending division) and is available for consultation there or by writing for photocopies.

(*d*) *Pollen sampling, preparation and counting*

The biogenic deposits together with the transitional zones into the inorganic sediment were sampled at a regular interval. Further samples were taken at points of interest in the stratigraphy and the pollen sequence. Preparation was made using standard techniques (Faegri & Iversen 1975) and employing Erdtman's acetolysis. Over-representation of the pollen taxa, particularly *Alnus* and Cyperaceae, made establishment of a standard pollen counting sum difficult (Janssen 1959; Wright & Patten 1963; Godwin 1975). Generally, a minimum count of 500 land pollen grains was made, excluding *Alnus*, Cyperaceae, aquatics and pteridophytes. The state of pollen preservation was noted for each spectrum using criteria established by Cushing (1967).

(*e*) *Construction and zonation of diagrams*

Relative pollen diagrams are presented, with the pollen assemblage divided into four broad physiognomic categories: trees, shrubs, herbs and aquatics; pteridophytes form a fifth, separate group. Calculation of an individual taxon is expressed as a percentage sum of total land pollen (t.l.p.) and represented as a bar diagram. This has been redrawn to exclude *Alnus* and Cyperaceae values and the resultant graph is shown as a separate continuous curve. In this fashion an attempt is made to highlight the more regional elements in the pollen assemblages. Tree pollen apart, the pollen taxa are shown in their order of appearance in the pollen record, identified from the base upward. It has not been possible to distinguish between *Corylus avellana* and *Myrica* pollen and these taxa have been presented as *Corylus* type pollen.

To assist analysis of the vegetational composition and to aid dating, local pollen assemblage zones (l.p.z.) have been used in each of the diagrams (West 1970; Huddart & Tooley 1972). The lack of established regional pollen assemblage zones for East Anglia and southeastern England, does not allow use of the chronozone system (West 1970; Hibbert, Switsur and West 1971). Thus reference has been made to the general scheme of pollen assemblage zones (p.z.) for England and Wales (Godwin 1975), following comparison with available regional data. A p.z. VIII has not been recognized in the diagrams due to the local nature of the pollen assemblage and the lack of reliable indicator species, with the exception of *Fagus* and *Acer* pollen.

(*f*) *Diatom analysis*

Samples were taken at regular intervals through the inorganic sediments and over the contact zones with the inorganic deposits, where sampling was more frequent. The biogenic material was found to be barren in diatoms, as were many sampled sequences as a whole in the estuary area.

Laboratory preparation of diatom samples was made in accordance with procedures currently in use in the Diatom Laboratory, Geological Institute, Haarlem, The Netherlands. A minimum count of 600 valves was made at each level. Where a valve was broken but recognizable, it was counted as a 'whole' valve if more than half remained. Identification was made with reference to van der Werff (1958–1974), Hustedt (1927–1966), Cleve-Euler (1951–1953), Hendey (1951, 1964, 1974), Donkin (1971), Patrick & Reimer (1966) and Peragallo (1965). The ecology of the diatoms was established in accordance with van der Werff and Hustedt, with planktonic, epiphytic and benthonic forms recognized. The species were grouped upon a salinity tolerance basis, using two methods. First, the recognition of six salinity groupings shown in the M–B–Z diagram (van der Werff 1958). The number of taxa within each of these groups form a percentage of the total number of species counted. The second, the Halobion diagram (Hustedt 1958), shows the curves for planktonic, benthonic and epiphytic species within five salinity groups. Calculation here is as a percentage of the total individuals counted.

(*g*) *Radiocarbon dating*

All samples were submitted for radiocarbon analysis to the Cambridge Laboratory. They were taken only over a short vertical distance to provide an accurate and specific dating. Piston cores and monoliths were used exclusively for radiometric assays. Care was taken to ensure *in situ* development of the material, freedom from contamination by younger deposits and the absence of leaching. Results are expressed in accordance with the Libby halflife of 5568 years. Where used, tree ring calibration of the radiocarbon data has been made in accordance with Switsur (1973) and Hibbert & Switsur (1976).

3. Tilbury (The World's End)

The World's End site (figure 3) was the closest one available to the sections examined by Churchill 1962–1963, at Tilbury Docks (coordinates for Tilbury Docks 51° 27′ 26″ N; 0° 21′ 54″ E; World's End TQ 64667540: 51° 27′ 14″ N; 0° 22′ 12″ E).

The area examined lies close to the river behind the flood embankments and has undergone extensive development since the nineteenth century. To the west lie Tilbury Docks and railway station with Tilbury Fort to the east. In the immediate area of the boreholes, the ground surface is uniformly at a height of *ca.* 2 m O.D. Borehole SB21/1 was taken 200 m at 317° N from the northwest corner of the World's End public house.

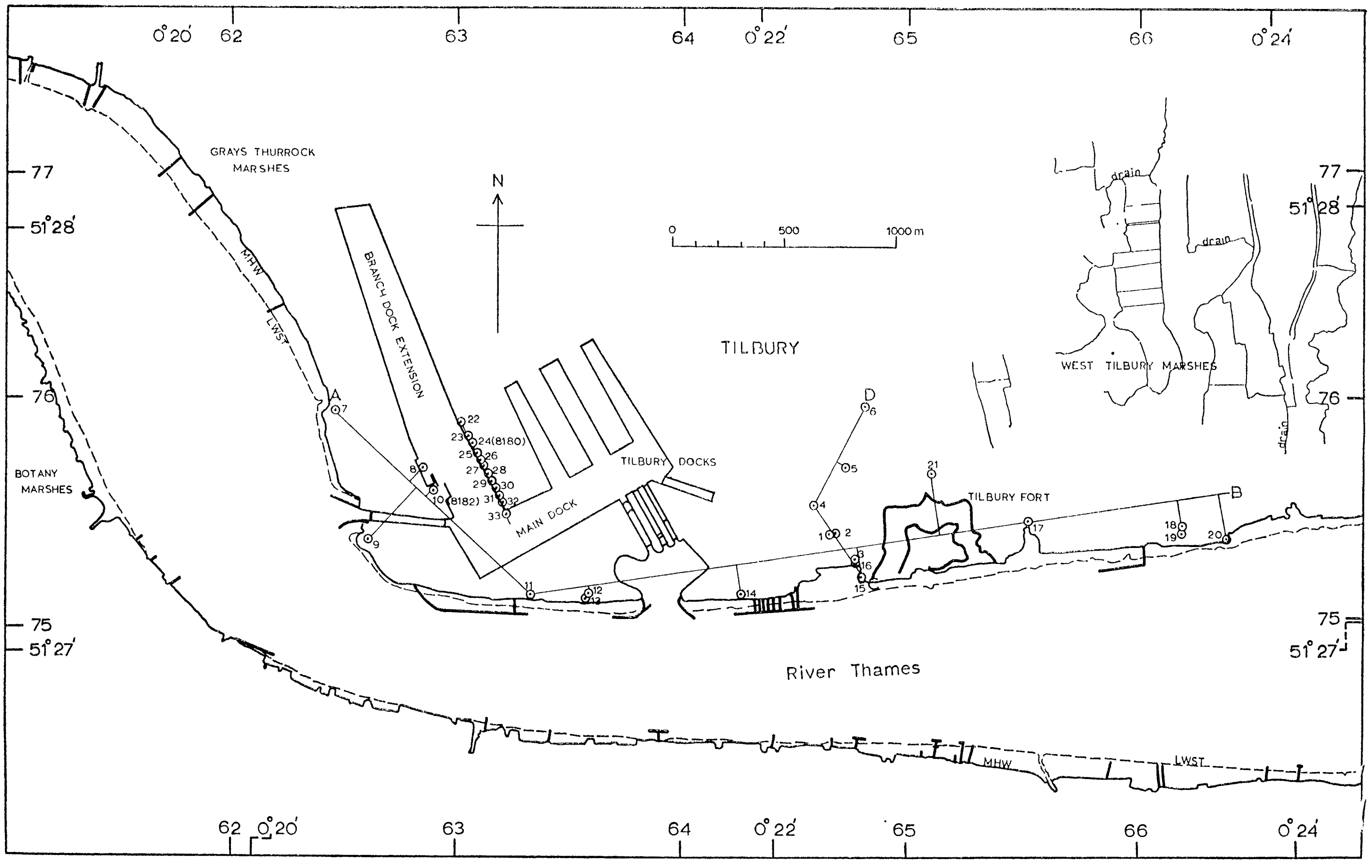


FIGURE 3. Site map of the Tilbury area, showing borehole locations (⊙).

(*a*) *Stratigraphy*

Sections are presented traversing the area from TQ 6244675960 in Grays-Thurrock Marshes to TQ 6617175387 in West Tilbury Marshes (figures 4† and 5), an area whose stratigraphy was described by Churchill (1965) and Godwin, Willis & Switsur (1965). These sections further show a north–south profile (figure 4), containing the sample borehole SB21/1, used for pollen and diatom examination.

Chalk underlies the drift deposits over the whole area, it's surface occurring between −15.5 and −20 m O.D. Above, gravel and sand form a subsurface highland zone immediately inland of the deposits bordering the Thames, in the area of the New Branch Dock (figure 5). The gravel surface occurs at a depth of −9.5 to −10 m O.D.; between boreholes EB21/29 and EB21/33, the surface falls to a depth of below −13.5 m O.D., a height conformable with those found in the main sections (figure 4). Channel features occur in this lower level, exemplified in EB21/30–32 and EB21/22–24. At borehole SB21/5 the gravel rises to −5.7 m

† Figures not in the text are printed on pullouts 1–16.

O.D. (figure 4), with the biogenic and inorganic sequences feathering out against the sand and gravel.

Five biogenic levels interleaved with olive green to blue-grey silt/clays were found. The upper two of these layers, termed Tilbury V and IV were found to be only locally persistent with Tilbury IV, the lower level, most widely developed. These form thin, fibrous, dark brown to black oxidized silty monocot peats with *Phragmites* present *in situ*. Tilbury IV occurs at an average depth of −2 to −2.5 m O.D., varying in thickness between 0.3 to 1.5 m. Tilbury III forms a persistent layer lying between the limits of −4 m at TQ6358075144 and −8.2 m O.D. (figures 4 and 5). By comparison with the Tilbury III levels at sites upstream, lying generally at heights between −1 to −5 m O.D., the deposit is seen to occur in the Tilbury area at consistently lower heights. This confirms the eastward dip of the sequences, also reflected in Tilbury IV, first observed at Broadness (see figure 28). In composition the deposit consists of a fibrous, dark brown monocot peat dominated by the stems and leaves of *Phragmites* and Cyperaceae bedded in a black gyttja matrix. The irregular profile of Tilbury III can best be explained by two main processes. First, by peat growth upon an originally hummocky, uneven clay/silt surface formed by Thames II, resulting from differential deposition rates and second, by erosion of the peat due to channel and creek formation, exemplified between EB21/29–33 (figure 5). The channel described by Churchill (Godwin *et al.* 1965), seen to develop in Tilbury III, can be seen between EB21/24–26.

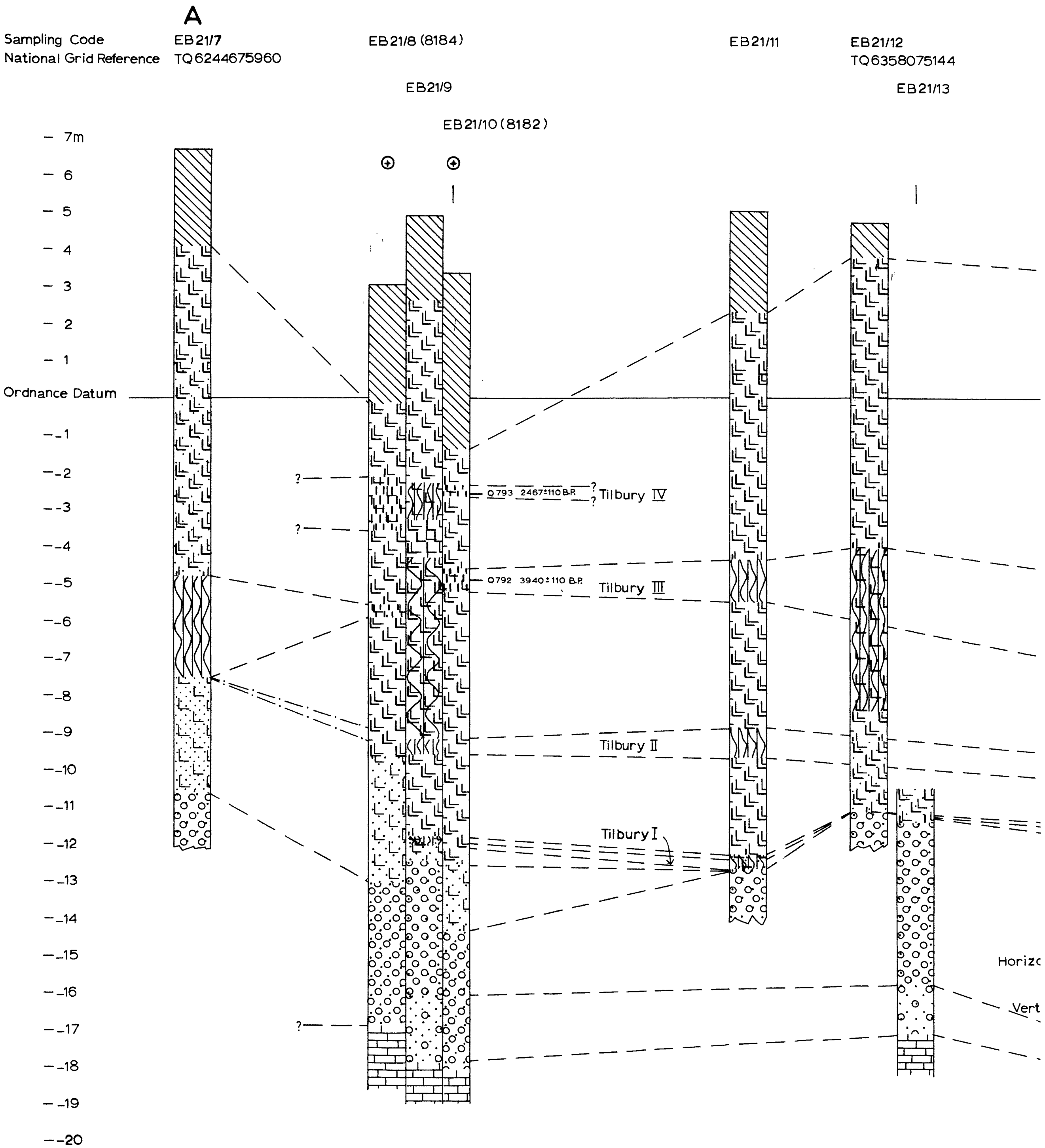
In cross section the sediments of Tilbury II have a more uniform surface, developing upon the clay/silt of Thames I. In EB21/7 the layer appears to merge with Tilbury III as the gravel surface rises. This level occurs between −9 to −11.15 m O.D. at an average depth of −10 to −10.5 m O.D. The basal peat bed in the New Branch Dock between EB21/22–29 may be correlated with Tilbury II. The deposit here forms at a higher level, growing at a later date (figure 5) and in response to the sea level rise of Thames II, but is not in direct relation to the sea level changes shown by the main Tilbury II level (figure 4). Churchill's boreholes 8180, 8182 and 8185 (figure 4) come from this area, and basal samples taken from these for ^{14}C dating and altimetric measurement would not have a direct bearing on the position of sea level at that time. The layer forms a dark brown and compact felted wood peat, changing to a *Phragmites* and Cyperaceae dominated monocot peat in the upper transition zone with Thames II. The biogenic deposit Tilbury I lies between the maximum limits of −12 to −16.5 m O.D. (figures 4 and 5). In EB21/9–11 at higher levels, the layer forms a sand/clay with a black gyttja content approximately 15 cm thick. At lower levels the bed thickens, forming a crumbly wood peat and gyttja deposit with the growth of *Alnus in situ*.

The inorganic sediments interleaving the peats form deposits of an apparent uniform character, composed of olive green/grey clays and silts. The recognition of Tilbury V necessitated the designation of another transgression sequence termed Thames V. However, owing to the local occurrence of the peat the inorganic deposits remain divided into the four main transgressive sequences (Thames I–IV). Fragments and complete shells with ostracods were common at all levels, with *Hydrobia* spp. and *Pseudamnicola confusa* found most frequently (B. W. Conway personal communication). In borehole SB21/6 *Hydrobia* spp. dominated shell marl was identified at −3.5 m O.D. and was correlated with Tilbury III (figure 4). These shell species, typical of brackish estuarine and saltmarsh environments though tolerant of freshwater (McMillan 1968), probably formed in quiet water inland of the main stream.

(*b*) *Pollen analysis*

The sample borehole gives a representative example of the sediments encountered here (see § 2*c*, figure 6). Generally, non-arboreal pollen (n.a.p.) is important at this site, often exceeding 40 % Σ total pollen (t.p.) above 1200 cm, with Gramineae, Cyperaceae and Chenopodiaceae forming the main pollen taxa. Six local pollen assemblage zones are recognized (figure 6):

l.p.z. height from surface (cm)	description
Tf 146–745	Overall dominance of n.a.p. with Gramineae, Cyperaceae and Chenopodiaceae the main herb taxa. Trees are of importance but falling to 25 % Σ t.p. and to 15 % Σ t.p. in the peats. Here Compositae *Bellis* type pollen reaches high values–55 % Σ t.l.p. Rise of *Pteridium aquilinum* curve with appearance of cereal type pollen. *Tilia* values are sporadic now and higher frequencies of *Fagus* and *Acer* pollen.
Te 745–790	Rise of tree pollen with sharp decline of n.a.p. as spore frequencies expand, particularly Filicales with *Thelypteris palustris*, reaching 35 % and 40 % Σ (t.l.p. + pteridophytes) respectively. *Quercus*, *Corylus* type and *Alnus* with *Tilia* are the main tree pollen taxa. *Quercus* maintains persistent frequencies of 30 % Σ t.l.p. while *Alnus* and *Corylus* type expand and decline in this zone. Chenopodiaceae pollen declines to negligible values.
Td 790–850	Non-arboreal pollen rises to dominance, > 50 % Σ t.p., though arboreal pollen (a.p.) frequencies reach 40 % Σ t.p. Gramineae, Cyperaceae and Chenopodiaceae are the main pollen taxa. Aquatics rise toward the top of the zone with a decline of Chenopodiaceae, reaching 10 % Σ t.p. *Alnus* values are low < 5 % Σ t.l.p., with *Quercus*, *Corylus* type and *Tilia* the main tree taxa.
Tc 850–1220	Fall of spores to much lower values with expansion of herb pollen. Gramineae reaches 45 % Σ t.p. at maximum with low but continuous frequencies of Cyperaceae pollen. Chenopodiaceae rises to 10 % Σ t.l.p. with occurrence of saltmarsh taxa, Compositae *Bellis* type, *Plantago maritima*, *Armeria* type and *Artemisia* pollen. *Quercus* and *Corylus* type (> 15 % Σ t.l.p.) with Gramineae, form main pollen taxa.
Tb 1220–1260	Early dominance of tree pollen, replaced by strong rise of n.a.p. with spores from the middle of this zone. Spores reach 90 % Σ t.p. *Quercus*, *Corylus* type, *Alnus* and Gramineae form main pollen taxa. *Alnus*, reaching 65 % Σ t.l.p. at base, with *Corylus* type and *Quercus* are main tree taxa. *Tilia* appears reaching > 5 % Σ t.l.p. Gramineae and Cyperaceae pollen frequencies rise sharply to maxima of 25 % Σ t.l.p. at 1240 cm. Shrubs become richer in taxa, with the appearance of *Cornus sanguinea*, *Rhamnus catharticus* and *Ilex* pollen.
Ta 1550–1545	Dominance of a.p., generally 80 % Σ t.p. *Quercus*, *Corylus* type & *Alnus* are the main tree taxa with *Ulmus* and *Pinus* forming important elements. *Tilia*


A
Sampling Code
National Grid Reference
EB21/7
TQ6244675960
EB21/8 (8184)
EB21/9
EB21/10 (8182)
EB21/11
EB21/12
TQ6358075144
EB21/13
7m
6
5
4
3
2
1
Ordnance Datum
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
-11
-12
-13
-14
-15
-16
-17
-18
-19
-20
Q793 2467±110 B.P.
Tilbury IV
Q792 3940±110 B.P.
Tilbury III
Tilbury II
Tilbury I
Horiz
Vert

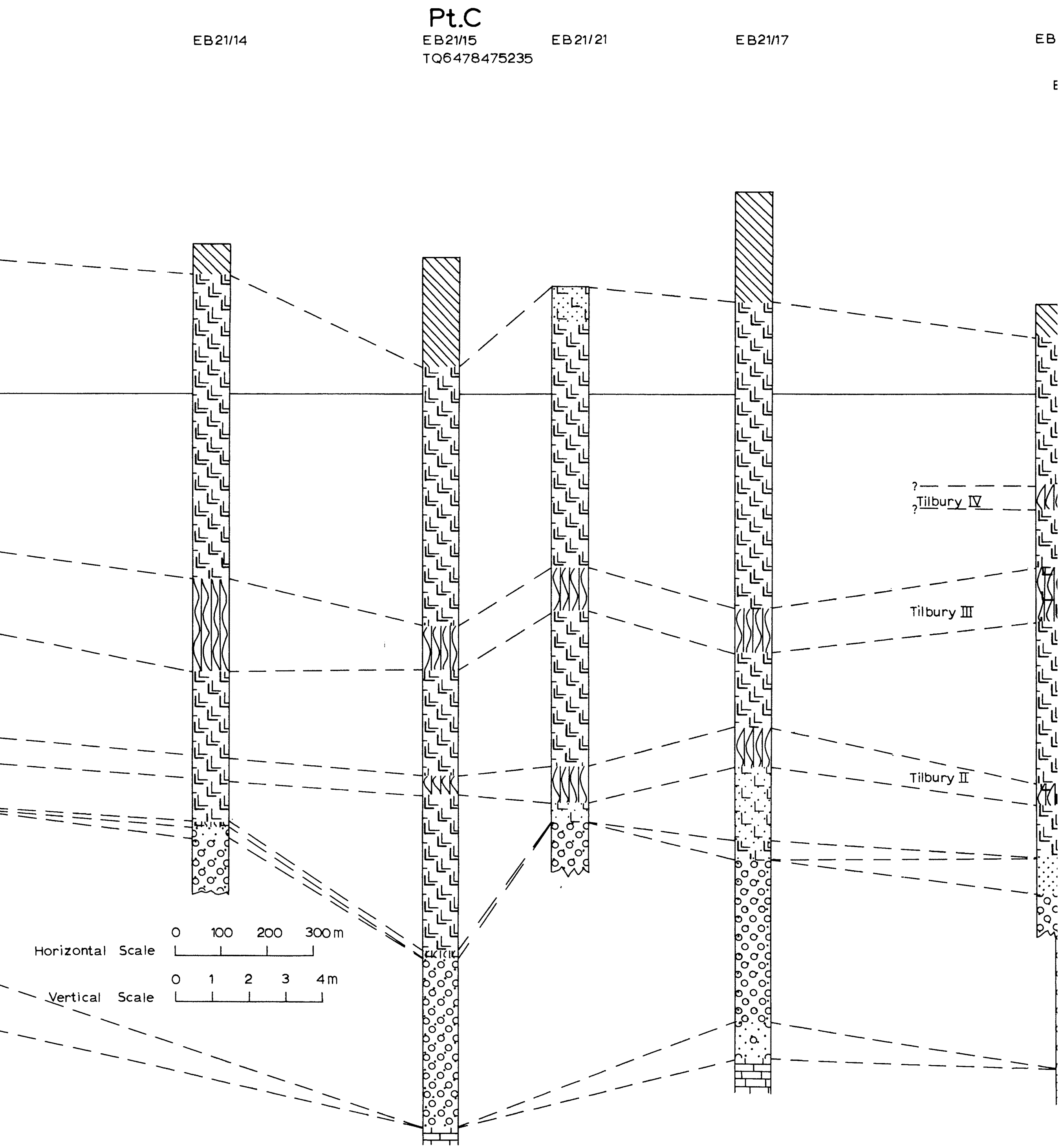
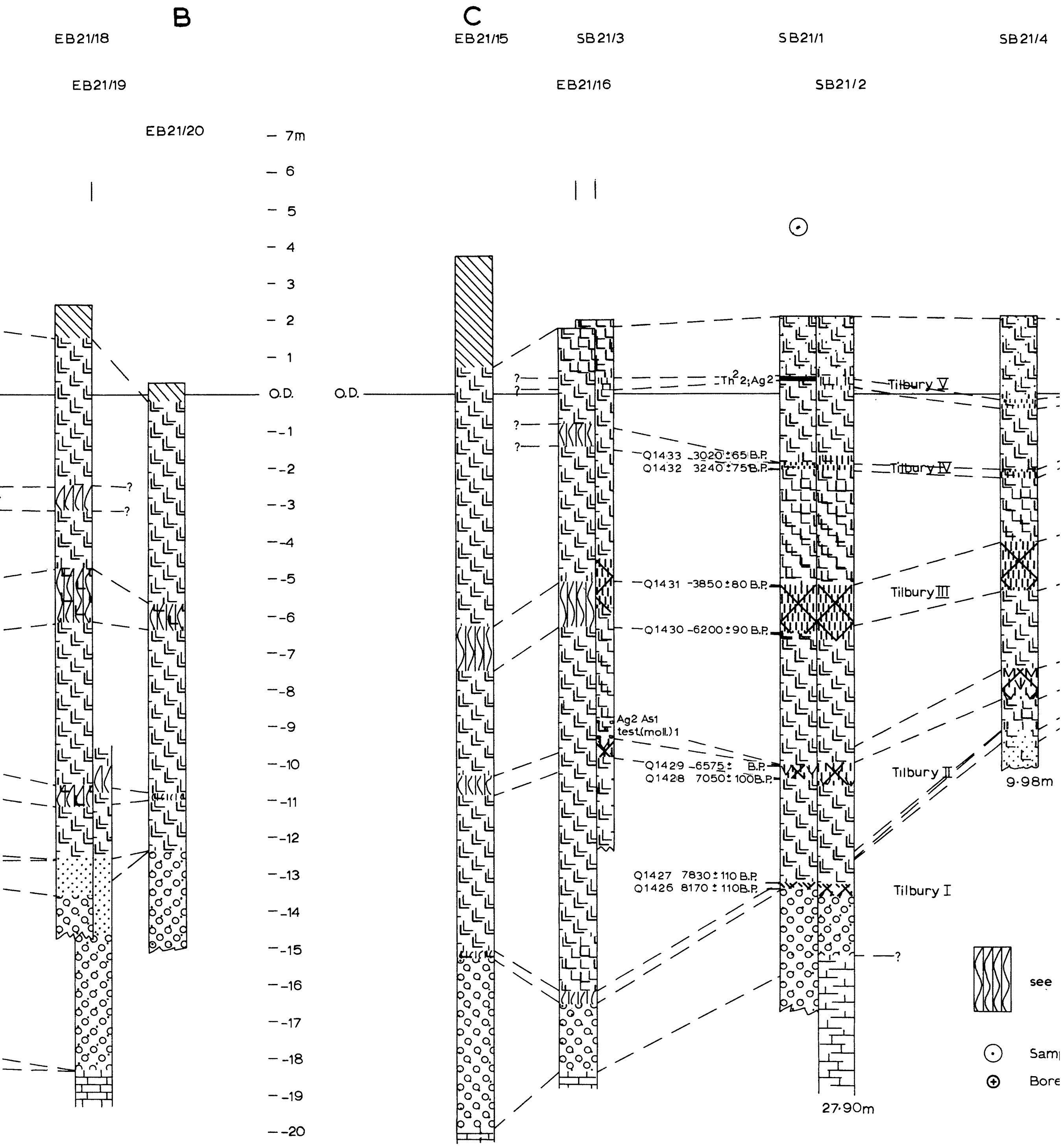
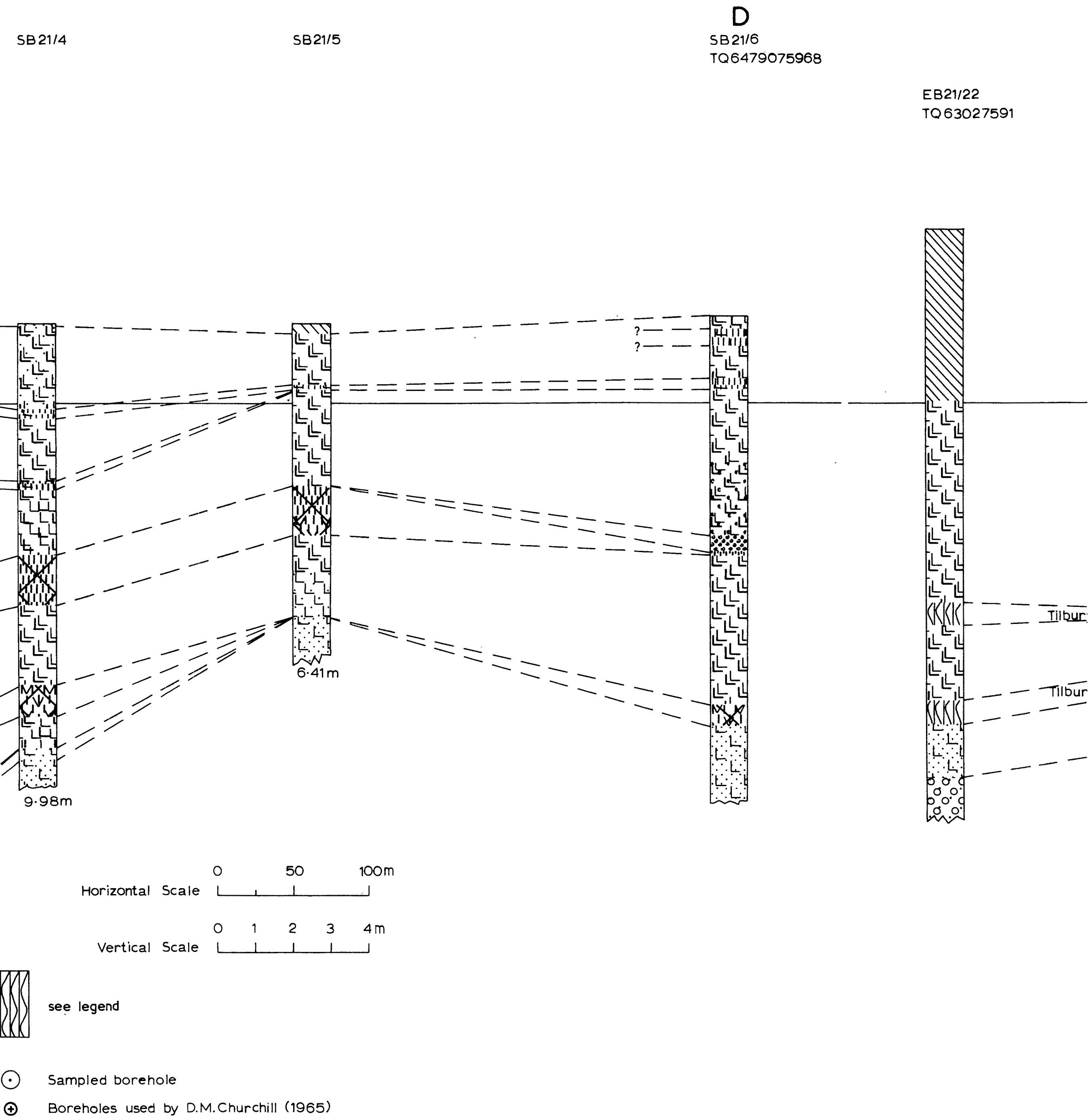


FIGURE 4. Stratigraphic diagram from the Tilbury Docks and West Tilbury Marshes area,
Ltd, the Institute of Geological Sciences, Le Grande Sutcliffe & Co. and the author.
fen peat, which is well humified with a significant gyttja component; branches, twigs
Appropriate Troels-Smith symbols and proportions have been used where the inorganic



shes area, based upon borehole data supplied by Binnie and Partners
e author. The sediment symbol represents a medium brown fibrous
hes, twigs and leaves are common, particularly in Tilbury I and II.
inorganic element in the biogenic deposits exceeded 25 % of the total.


D
SB21/4
SB21/5
SB21/6
TQ6479075968
EB21/22
TQ63027591
?
?
6·41m
9·98m
Tilbur
Tilbur
Horizontal Scale
0
50
100m
Vertical Scale
0
1
2
3
4m
see legend
Sampled borehole
Boreholes used by D.M.Churchill (1965)

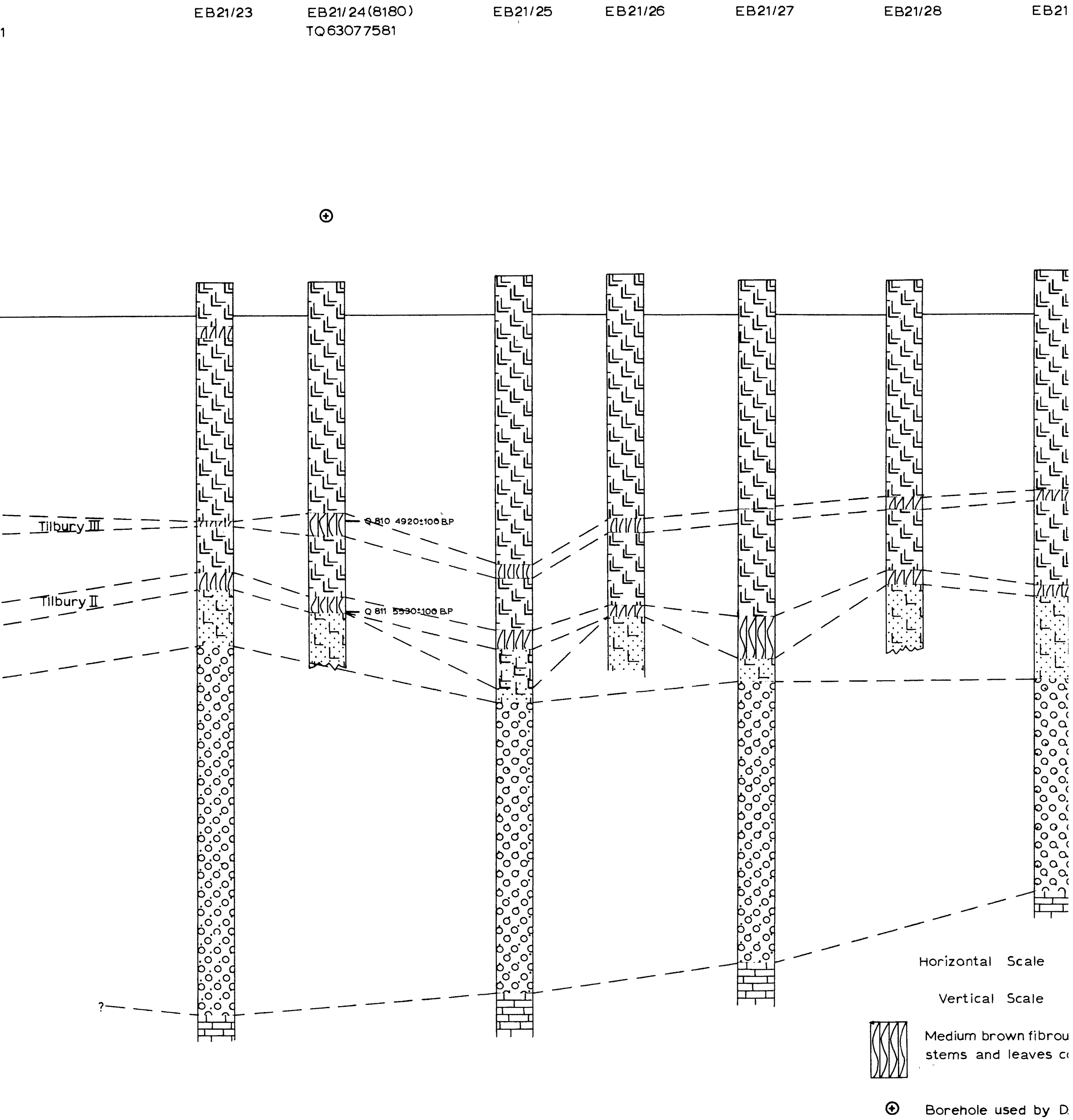
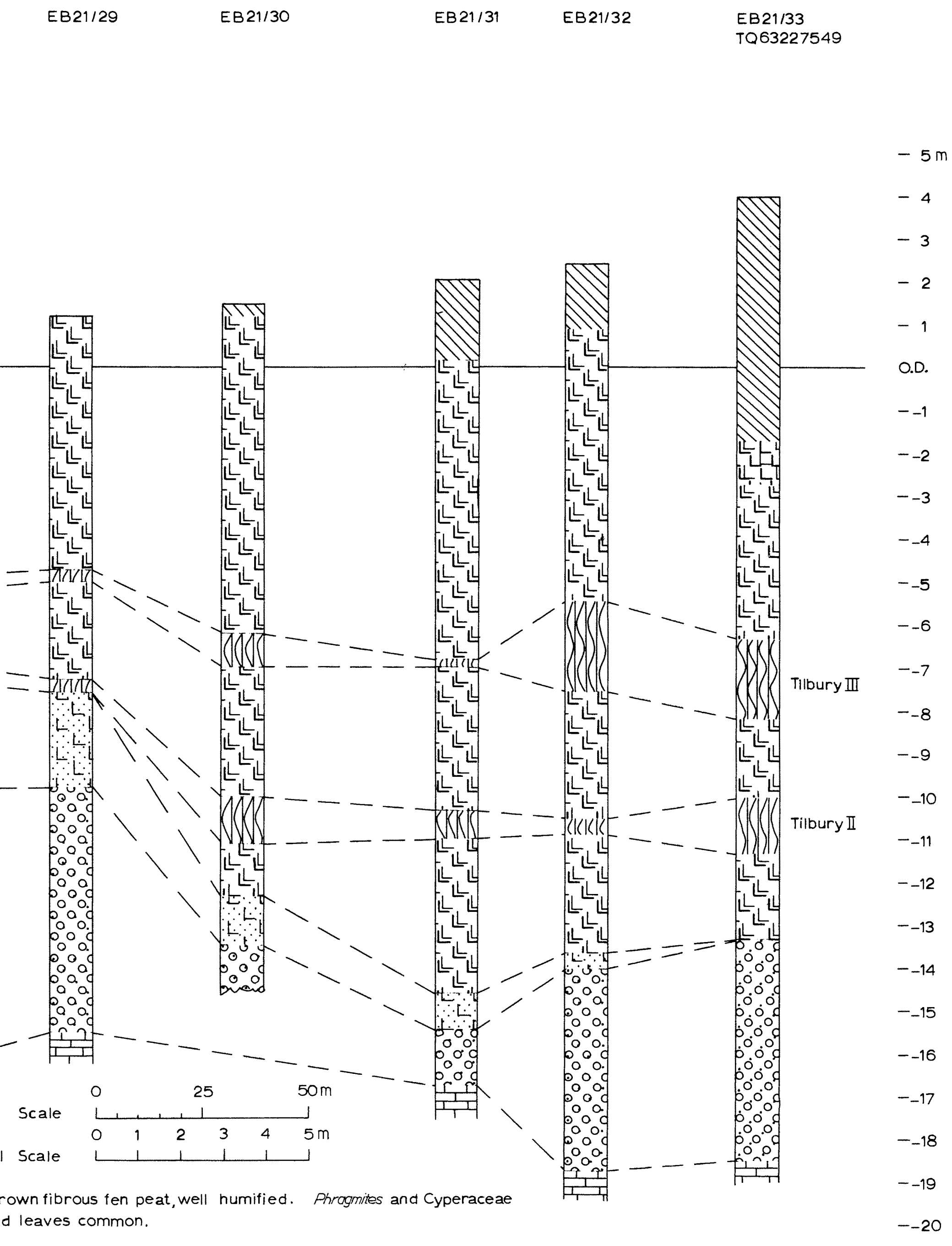


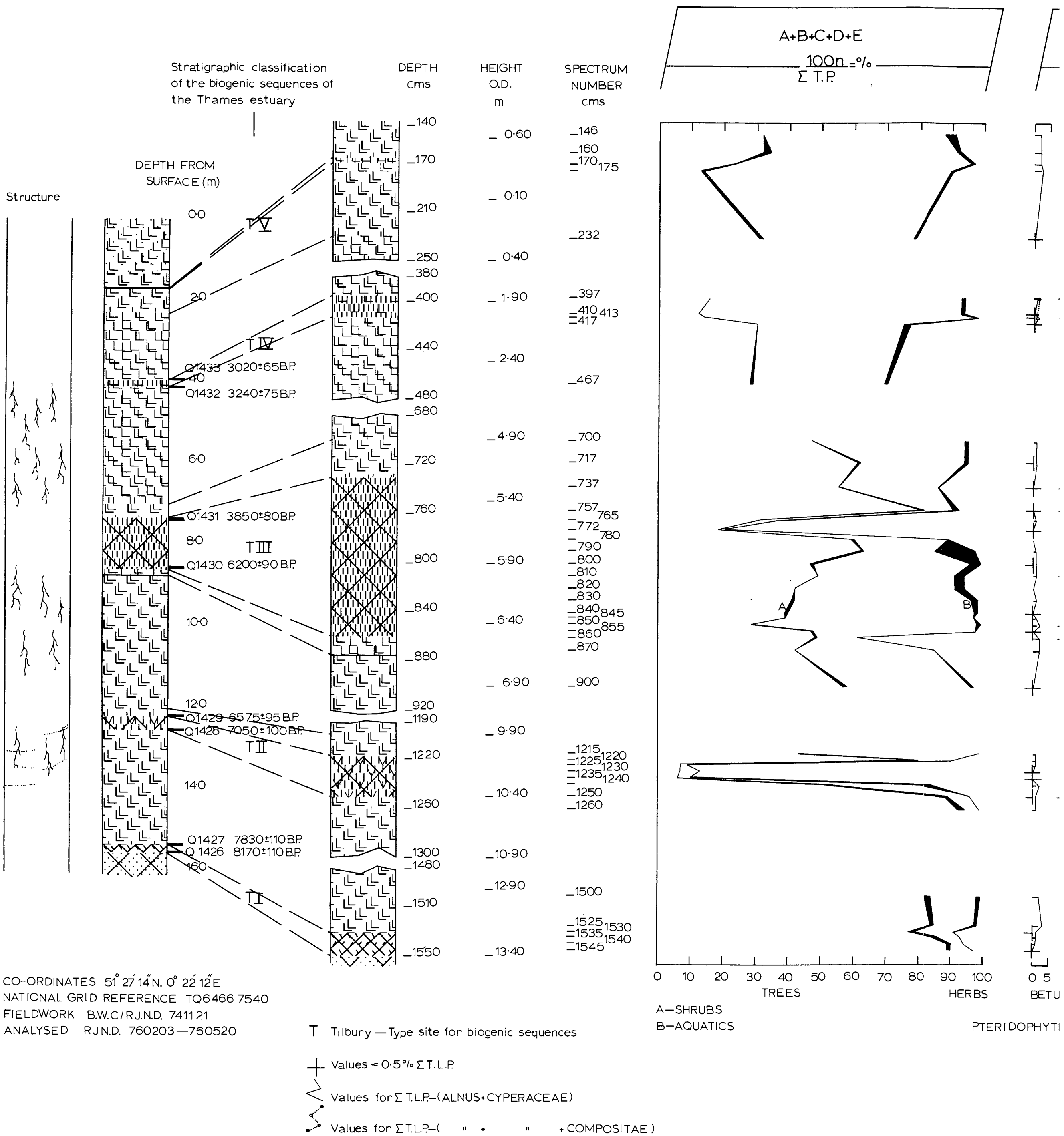
FIGURE 5. Stratigraphic diagram from the New Branch Dock Extension, Tilbury D
borehole data supplied by Soil Mechanics Ltd.

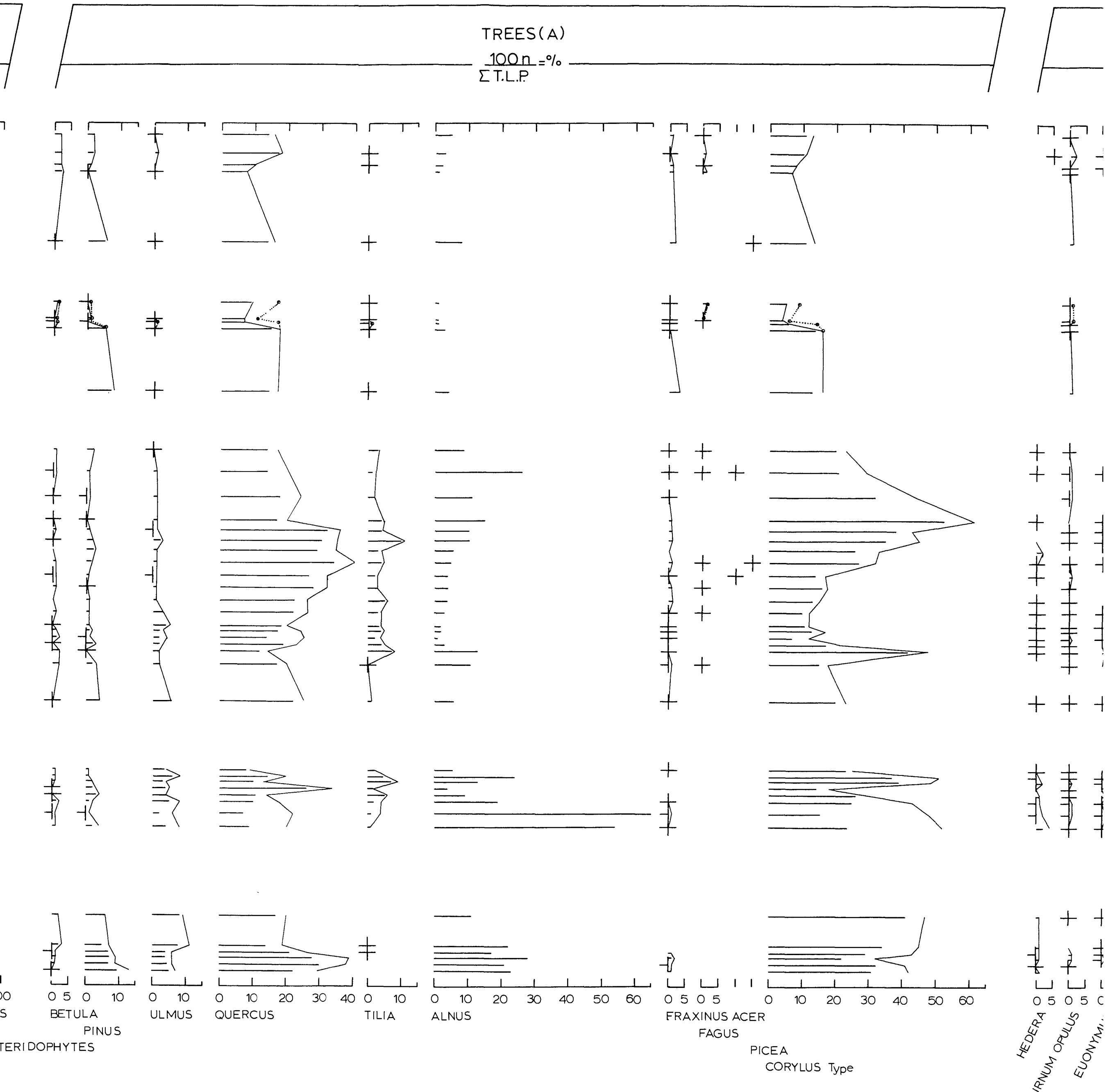


rown fibrous fen peat, well humified. *Phragmites* and Cyperaceae
d leaves common.

used by D.M. Churchill (1965)

Tilbury Docks, based upon


Structure
DEPTH FROM SURFACE (m)
Stratigraphic classification of the biogenic sequences of the Thames estuary
DEPTH cms
HEIGHT O.D. m
SPECTRUM NUMBER cms
A+B+C+D+E
100n/Σ T.P =%
T IV
T III
T II
T I
Q1433 3020±65B.P.
Q1432 3240±75B.P.
Q1431 3850±80B.P.
Q1430 6200±90 B.P.
Q1429 6575±95 B.P.
Q1428 7050±100B.P.
Q1427 7830±110B.P.
Q 1426 8170±110B.P.
TREES
HERBS
BETU
A–SHRUBS
B–AQUATICS
PTERIDOPHYT
CO-ORDINATES 51° 27′ 14″N. 0° 22′ 12″E
NATIONAL GRID REFERENCE TQ6466 7540
FIELDWORK B.W.C/R.J.N.D. 741121
ANALYSED R.J.N.D. 760203—760520
T Tilbury — Type site for biogenic sequences
Values < 0·5% Σ T.L.P.
Values for Σ T.L.P.–(ALNUS+CYPERACEAE)
Values for Σ T.L.P.–(" + " + COMPOSITAE)


TREES (A)
100 n / Σ T.L.P. = %
BETULA
PINUS
PTERIDOPHYTES
ULMUS
QUERCUS
TILIA
ALNUS
FRAXINUS ACER
FAGUS
PICEA
CORYLUS Type
HEDERA
VIBURNUM OPULUS

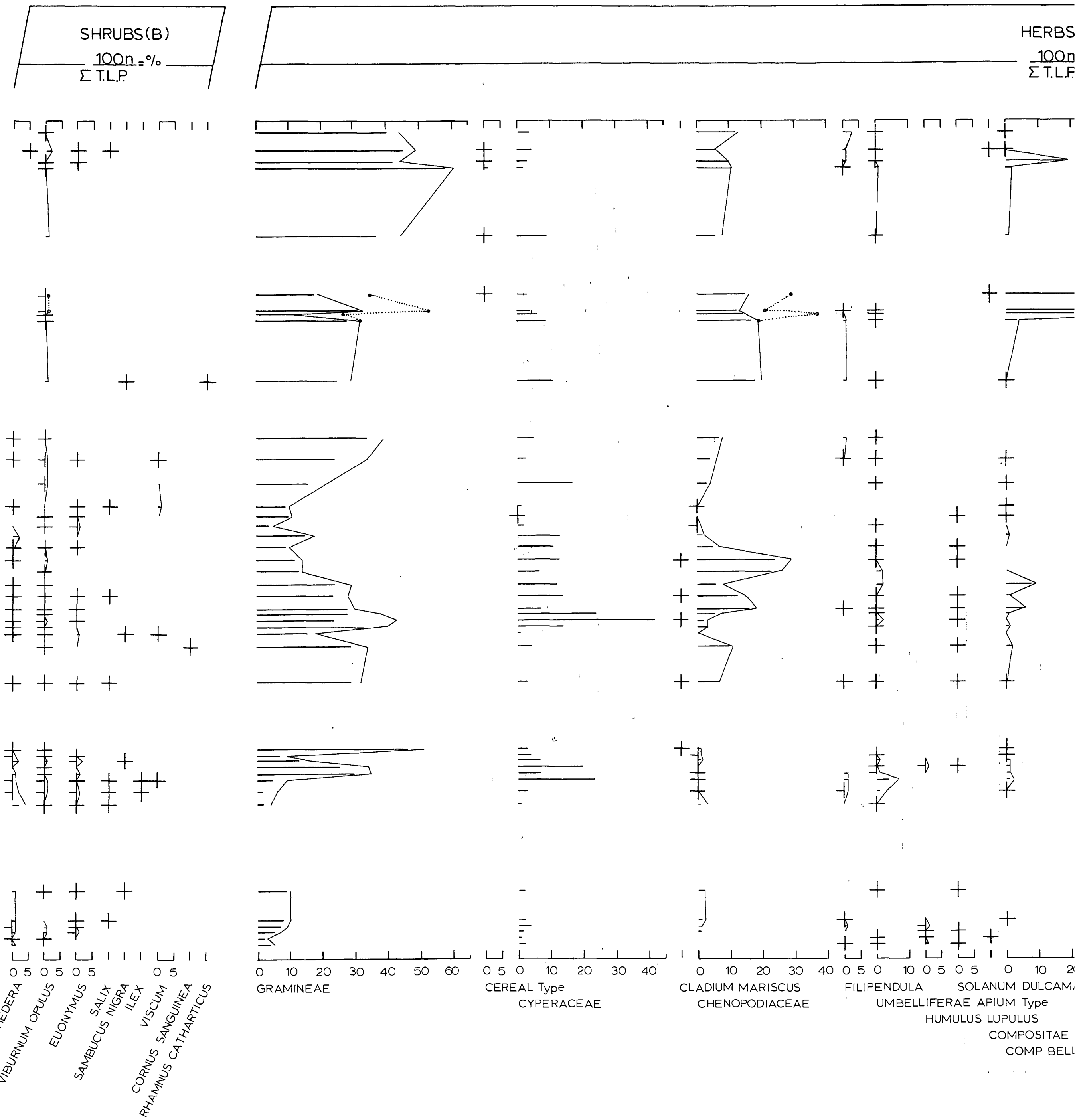
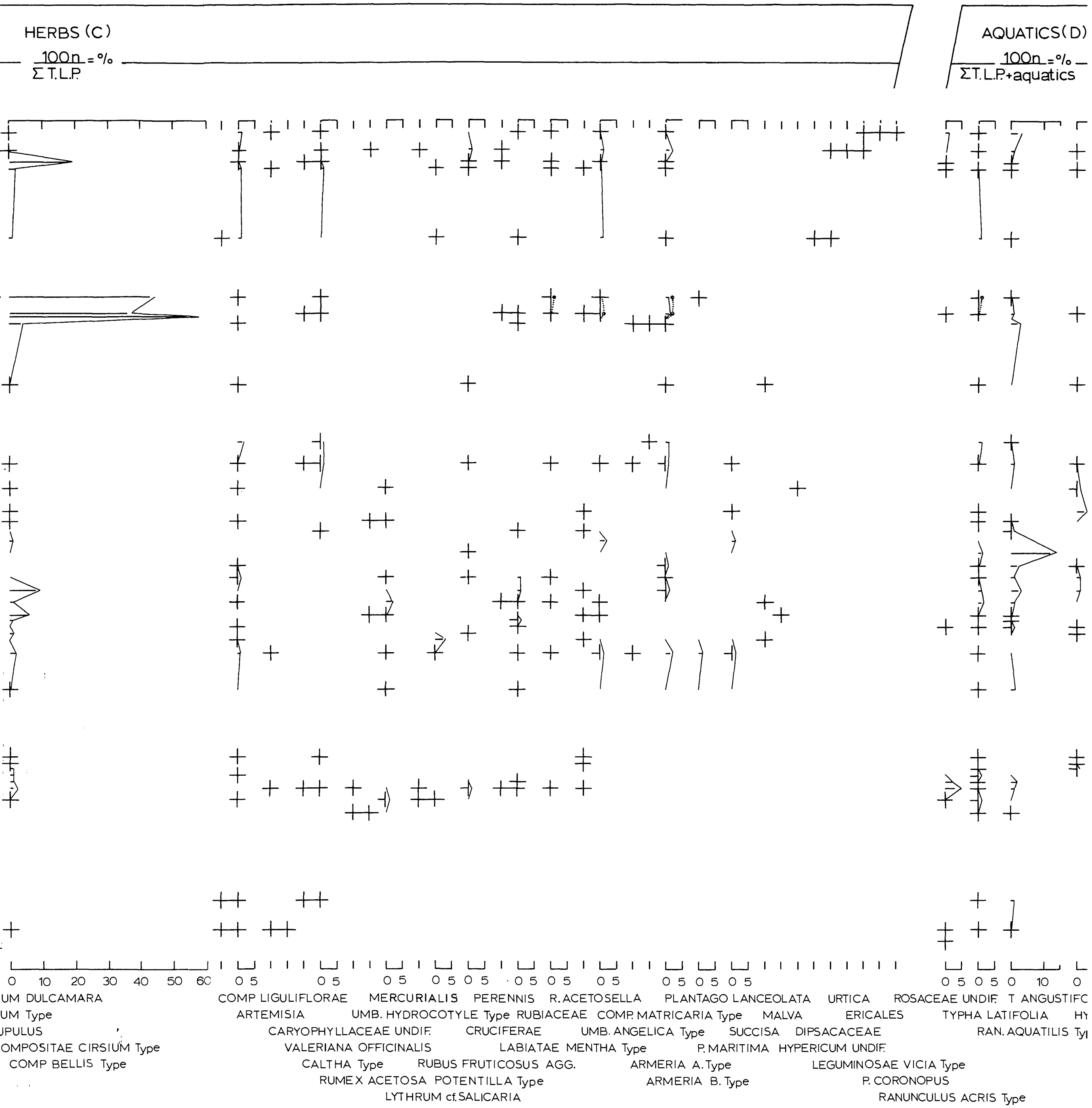
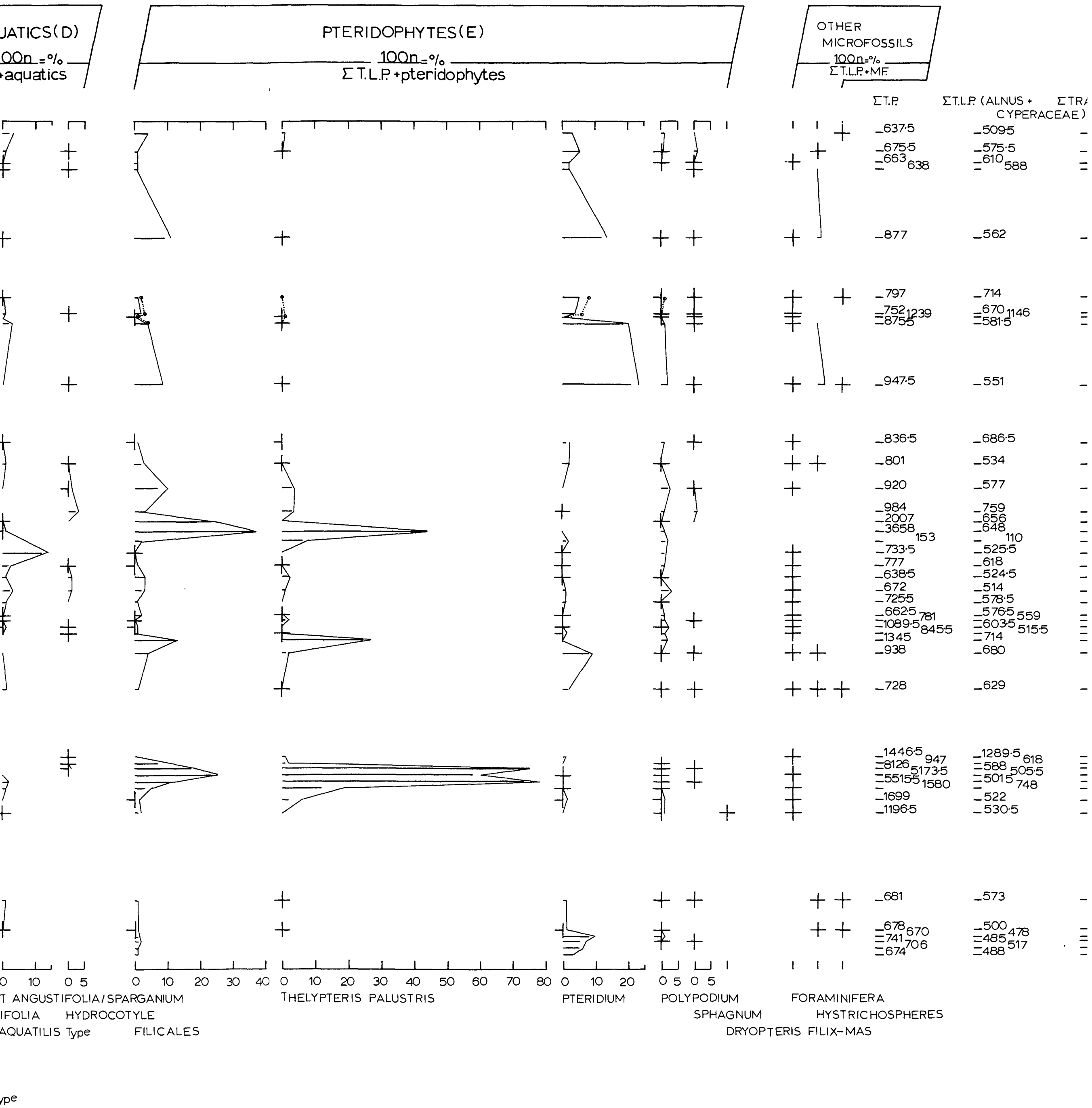
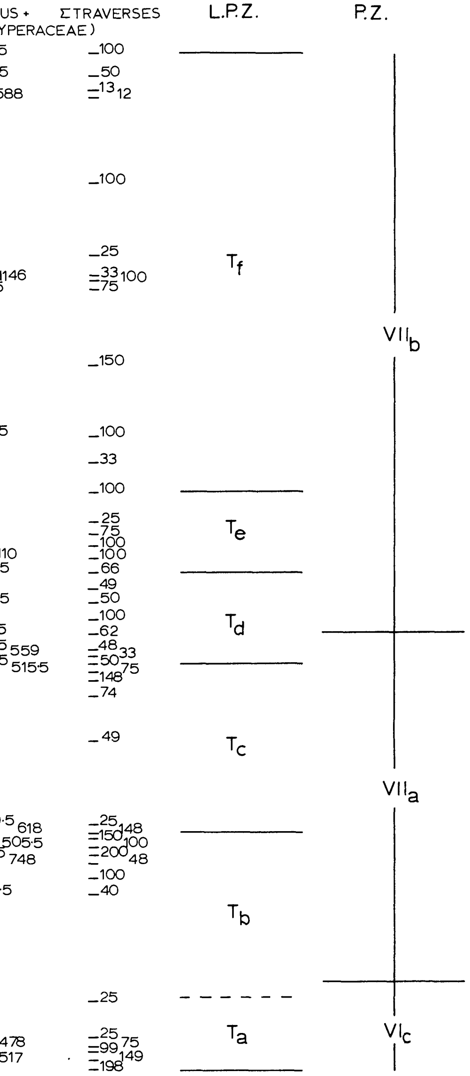


Figure 6. Pollen diagram from Tilbury (The World's End), S.B.I.


HERBS (C)
100n/ΣT.L.P. = %
AQUATICS (D)
100n/ΣT.L.P.+aquatics = %
0 10 20 30 40 50 60
UM DULCAMARA
UM Type
UPULUS
OMPOSITAE CIRSIUM Type
COMP BELLIS Type
COMP LIGULIFLORAE
ARTEMISIA
CARYOPHYLLACEAE UNDIF.
VALERIANA OFFICINALIS
CALTHA Type
RUMEX ACETOSA
LYTHRUM cf. SALICARIA
MERCURIALIS PERENNIS
UMB. HYDROCOTYLE Type
CRUCIFERAE
LABIATAE MENTHA Type
RUBUS FRUTICOSUS AGG.
POTENTILLA Type
R. ACETOSELLA
RUBIACEAE
UMB. ANGELICA Type
COMP. MATRICARIA Type
ARMERIA A. Type
ARMERIA B. Type
PLANTAGO LANCEOLATA
MALVA
SUCCISA
P. MARITIMA
URTICA
ERICALES
DIPSACACEAE
HYPERICUM UNDIF.
LEGUMINOSAE VICIA Type
P. CORONOPUS
RANUNCULUS ACRIS Type
ROSACEAE UNDIF.
TYPHA LATIFOLIA
RAN. AQUATILIS Ty
T. ANGUSTIFO
HY



UATICS(D)
00n =%
+aquatics
PTERIDOPHYTES(E)
100n =%
Σ T.L.P. +pteridophytes
OTHER MICROFOSSILS
100n=%
Σ T.L.P.+MF.
ΣT.P.
ΣT.L.P. (ALNUS + CYPERACEAE)
ΣTRA
T ANGUSTIFOLIA/SPARGANIUM
IFOLIA
HYDROCOTYLE
AQUATILIS Type
FILICALES
THELYPTERIS PALUSTRIS
PTERIDIUM
POLYPODIUM
SPHAGNUM
DRYOPTERIS FILIX-MAS
FORAMINIFERA
HYSTRICHOSPHERES
ype


US + ΣTRAVERSES
YPERACEAE)
L.P.Z.
P.Z.
Tf
Te
Td
Tc
Tb
Ta
VIIb
VIIa
VIc

negligible or absent. Herbs poor in taxa – Gramineae rises to 9 % Σ t.l.p. at top of zone with small rise of Chenopodiaceae pollen. Shrubs poor, continuous *Hedera* curve, appearance of *Viburnum opulus*.

(i) *Local pollen assemblage zone Ta* (Quercus, Corylus *type*, Alnus, Ulmus *and* Pinus)

The basal deposit shows the dominance of woodland at this time, the high values of *Quercus*, *Corylus* type and *Alnus* pollen indicating the local presence of wet alder fen wood.

(ii) *Local pollen assemblage zone Tb* (Quercus, Corylus *type*, Alnus, *Cyperaceae*, *Gramineae and Pteridophytes*)

An initial alder carr developed, possibly together with areas of mixed fen, to be replaced by freshwater mixed fen–sedge fen communities. This interpretation is supported by the rise of aquatic pollen, particularly of *Typha latifolia* and *Ranunculus aquatilis* type pollen.

(iii) *Local pollen assemblage zone Tc* (*Gramineae*, Quercus *and* Corylus *type*)

The taxa indicate the presence of a saltmarsh community in association with *Phragmites* dominated freshwater fen.

(iv) *Local pollen assemblage zone Td* (*Gramineae*, *Cyperaceae and Chenopodiaceae*)

A small expansion in tree pollen with the beginning of peat accumulation, indicates the local growth of wet alder-oak fen woods. This phase is quickly replaced by a return to sedge/mixed fen vegetation with more local saltmarsh communities nearby. The continued growth and expansion of the latter is supported by the high but sporadic frequencies of Chenopodiaceae pollen at 24 % Σ t.l.p., with high erratic values of Compositae *Bellis* type, *Artemisia* and Labiatae *Mentha* type pollen. However, inwashing from nearby sources is a more likely explanation for the abundance of Chenopodiaceae pollen, rather than a proposal of *in situ* growth. The persistent presence of brackish water foraminifera indicates a continued river influence here.

(v) *Local pollen assemblage zone Te* (Quercus, Corylus *type*, Alnus, *Gramineae and pteridophytes*)

The communities of l.p.z., Td are replaced at 795 cm by the development of oak-alder fen woodland, with later revertence to sedge fen/reedswamp conditions. Gramineae pollen, probably from *Phragmites australis*, remains dominant throughout.

(vi) *Local pollen assemblage zone Tf* (*Gramineae*, *Cyperaceae and Chenopodiaceae*)

This type of environment with permanent water influence appears to continue until the end of deposition. During the short phases of silty peat growth saltmarsh taxa expand to form the dominant local vegetation. As at the other sites upstream, the upper part of the sequence from 146–757 cm shows the increasing anthropogenic influence upon the pollen assemblage.

(*c*) *Dating*

From the radiocarbon dates shown in table 1, some points may be noted.

Q-1426 provides the oldest dating of a biogenic deposit in the inner estuary, showing that a further biogenic layer not recorded at sites upstream enters the sequence in this area. The initiation of biogenic deposition begins at 8170 ± 110 B.P.; a pollen assemblage markedly different from the assemblages found in the basal deposits at Stone and Broadness occurs indicating a late p.z. VIc date. However, *Alnus* forms an important element in the pollen assemblage reaching 20 % Σ t.l.p. Its early appearance here before 8000 B.P., in proportions similar to those found in p.z. VII, clashes with radiocarbon datings of similar high alder frequencies at other sites in the country (Oldfield 1965; Smith & Pilcher 1973; Godwin 1975). Explanation probably lies in the local nature of the deposit, with waterlogging of the valley site and its southerly position favouring the early expansion of alder.

The deposit between 1220–1250 cm is conformable in pollen assemblage and radiocarbon age, growth beginning at 7050 ± 100 B.P., with a date indicative of p.z. VII. Recognition of the p.z. VII*a*/VII*b* boundary is not clear, due to local pollen influences. However, the *Ulmus* curve shows an elm decline at 830 cm, with values falling from 3–1 % Σ t.l.p. and thereafter remaining low and sporadic in nature.

Table 1. Radiocarbon dates from Tilbury SB21/1

code	date/a B.P.	depth from surface/cm
Q-1426 SB21/1/C1	8170 ± 110	1547–1550
Q-1427 SB21/1/C2	7830 ± 110	1533–1536
Q-1428 SB21/1/C3	7050 ± 100	1248–1252
Q-1429 SB21/1/C4	6575 ± 95	1220–1224
Q-1430 SB21/1/C5	6200 ± 90	852–854
Q-1431 SB21/1/C6	3850 ± 80	731–735
Q-1432 SB21/1/C7	3240 ± 75	410–415
Q-1433 SB21/1/C8	3020 ± 65	392–397

(*d*) *Diatom analysis*

The changes in salinity encountered, as evidenced by the diatom assemblages, are described for each of the five phases of clay/silt deposition (figure 7).

(i) *Stratum T*1: 1267–1525 cm

At the base an early dominance of brackish water Mesohalobion taxa occurs, mainly benthonic in habitat. This reaches a maximum of 60 % Σ total diatom count (t.d.) with *Cyclotella striata*, *Nitzschia navicularis*, *Nitzschia punctata*, *Campylodiscus echineis*, *Synedra tabulata* var. *fasciculata* and *Navicula rostellata* forming the main Mesohalobion taxa. The Oligohalobion freshwater to saltwater tolerant species form a small influence at uniform levels of < 20 % Σ t.d. *Cocconeis pediculus*, *Fragilaria construens* var. *venter* and *Navicula cincta* form the main species. A rapid expansion of marine, Polyhalobion taxa has replaced the brackish species by 1405–1425 cm, reaching 66 % Σ t.d. The curve continues to rise toward the top of this layer with only a slight fall as the peat contact is approached. Planktonic and epiphytic species dominate the Polyhalobion curve, with *Nitzschia granulata*, *Melosira sulcata*, *Cymatosira belgica*, *Raphoneis minor*, *Raphoneis surirella*, *Cocconeis scutellum*, *Coscinodiscus excentricus* and *Raphoneis amphiceros* forming the main taxa.

(ii) *Stratum T*2: 875–1215 cm

The Polyhalobion influence is strong from the outset, maintaining high values and expanding toward the top of T2, where it reaches a maximum of 75 % Σ t.d., before declining to 20 % Σ t.d. over the regression contact. Those species found in stratum T1 again dominate the taxa, which now become species rich. Brackish water species mainly epiphytic in habitat are important, with *Campylodiscus echeneis*, *Cyclotella striata*, *Achnanthes hauckiana* and *Nitzschia punctata* as the main taxa. Oligohalobion frequencies are low, declining from relatively high basal values to form an erratic curve, the taxa remaining much the same as in stratum T1. The expansion of Mesohalobion species between 875–900 cm, with a preponderance of broken valves at 80% Σ t.d., reflects a decrease in the marine tidal influence consequent upon a sea level regression.

(iii) *Stratum T*3: 467–727 cm

Polyhalobion species remain dominant, generally 50% Σ t.d. The assemblage is unchanged except for the increased importance of *Campylosira cymbelliformis* and *Melosira sulcata*. At the base Oligohalobion indifferent species' values reach 40% Σ t.d., falling sharply to < 10% Σ t.d. at the 690 cm level. Taxa of importance here are *Rhoicosphenia curvata*, *Navicula mutica*, *Navicula cincta*, *Fragilaria construens* var. *venter*, *Fragilaria brevistriata* and *Nitzschia tryblionella*. Brackish water species expand at the top to dominance, with *Melosira moniliformis*, *Navicula peregrina* and *Gyrosigma spencerii* the important taxa.

(iv) *Stratum T*4: 232–395 cm

This level has a dominance of both Oligohalobion halophile and indifferent diatom species at the base, each of which reach 20% Σ t.d. These groups become more taxa rich with *Fragilaria construens* var. *venter*, *Fragilaria brevistriata*, *Fragilaria pinnata*, *Navicula cryptocephala* and *Navicula cincta* of particular importance. By the 300 cm level, Mesohalobion diatoms have risen to dominance, reaching 90% Σ t.d. at the top. *Diploneis interrupta*, *Diploneis didyma*, *Navicula pygmea* and *Nitzschia sigma* form the main taxa.

(v) *Stratum T*5: 146–170 cm

Brackish water species, particularly *Diploneis didyma*, *Diploneis suborbicularis*, *Navicula peregrina*, *Nitzschia punctata* and *Scolopleura brunksii* are dominant following high basal Oligohalobion values.

The diatom assemblages found at Tilbury strongly resemble those from littoral and estuarine/saltmarsh environments (Körber-Grohne 1967; Alhonen 1971; Berglund 1971; Eronen 1974). The pattern of change in the strata shows an early and strong marine diatom influence in the sediments; this remains dominant until the top of the sequence. Over the transgression and regression contacts the frequencies of the marine species tends to decline, with a concomitant increase in broken valves. This suggests a decrease in the tidal influence consequent upon sea level regression, with shallow water, allowing reworking and erosion of the deposits. Mesohalobion species maintain sporadic, but high, values throughout, expanding at the base and upper contacts, with Oligohalobion species increasing in importance upward. These trends become clear above the 395 cm level. The apparent freshening of the diatom assemblage and the progressive decline of marine taxa, shows that the river and upper estuarine conditions have become dominant by now. Further, it indicates that the rate of sea level rise has fallen.

4. Crossness (Thamesmead)

Site: TQ48158051: 51° 30′ 11″ N; 0° 8′ 5″ E

Plumstead and Erith Marshes, Thamesmead form an expanse of flat, drained land lying upon average between 0.5 to 1 m O.D. and is about 12.5 km^2 in area (figure 8). To the north, east and west this area is encompassed by the Thames and in the south is bounded by an east–west aligned Chalk ridge which reaches 61 m in places. The sampling site lies to the northwest of the marsh close to Crossness Point and is located 160 m at 180° from the entrance gate to Crossness sewage works.

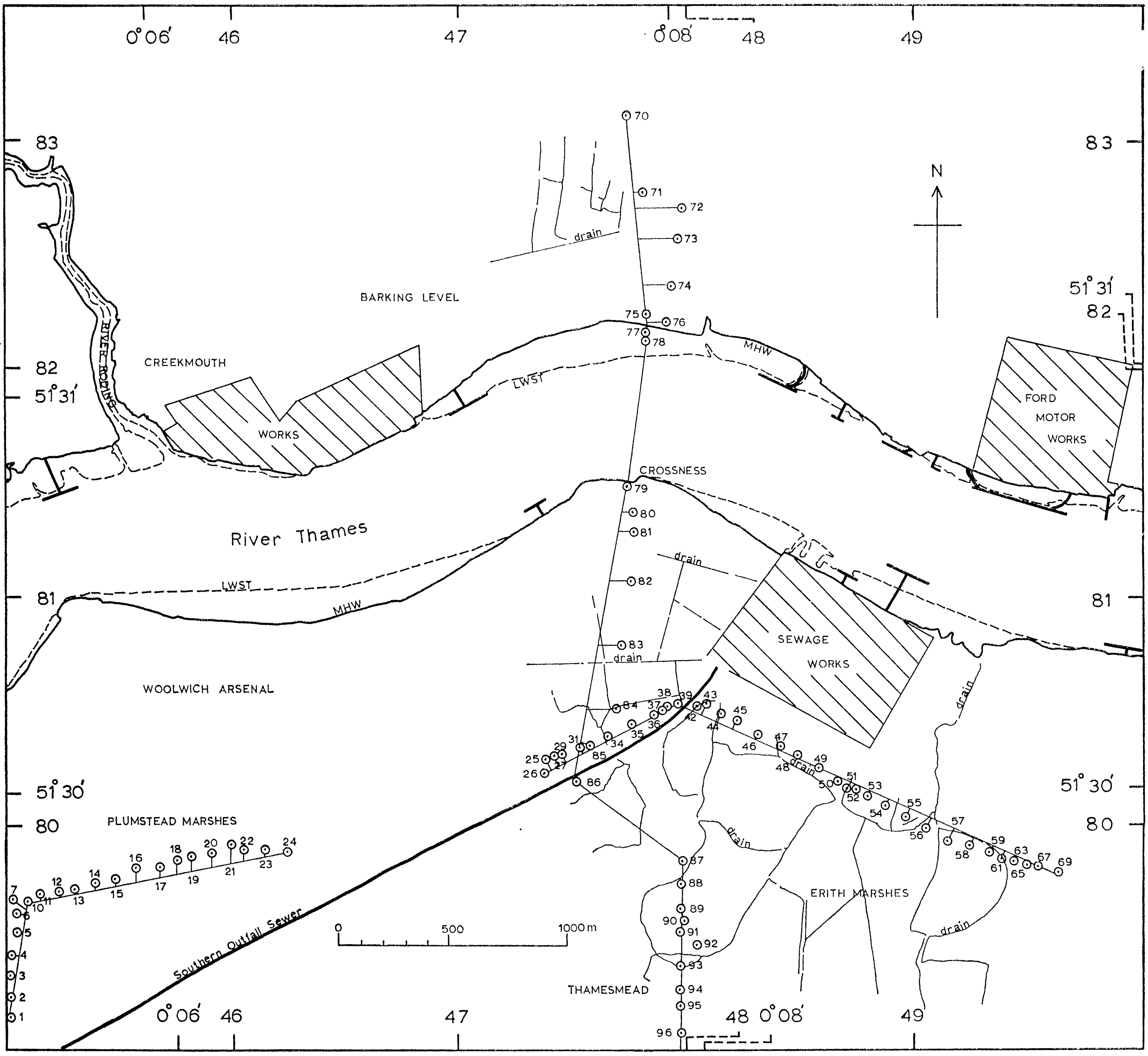
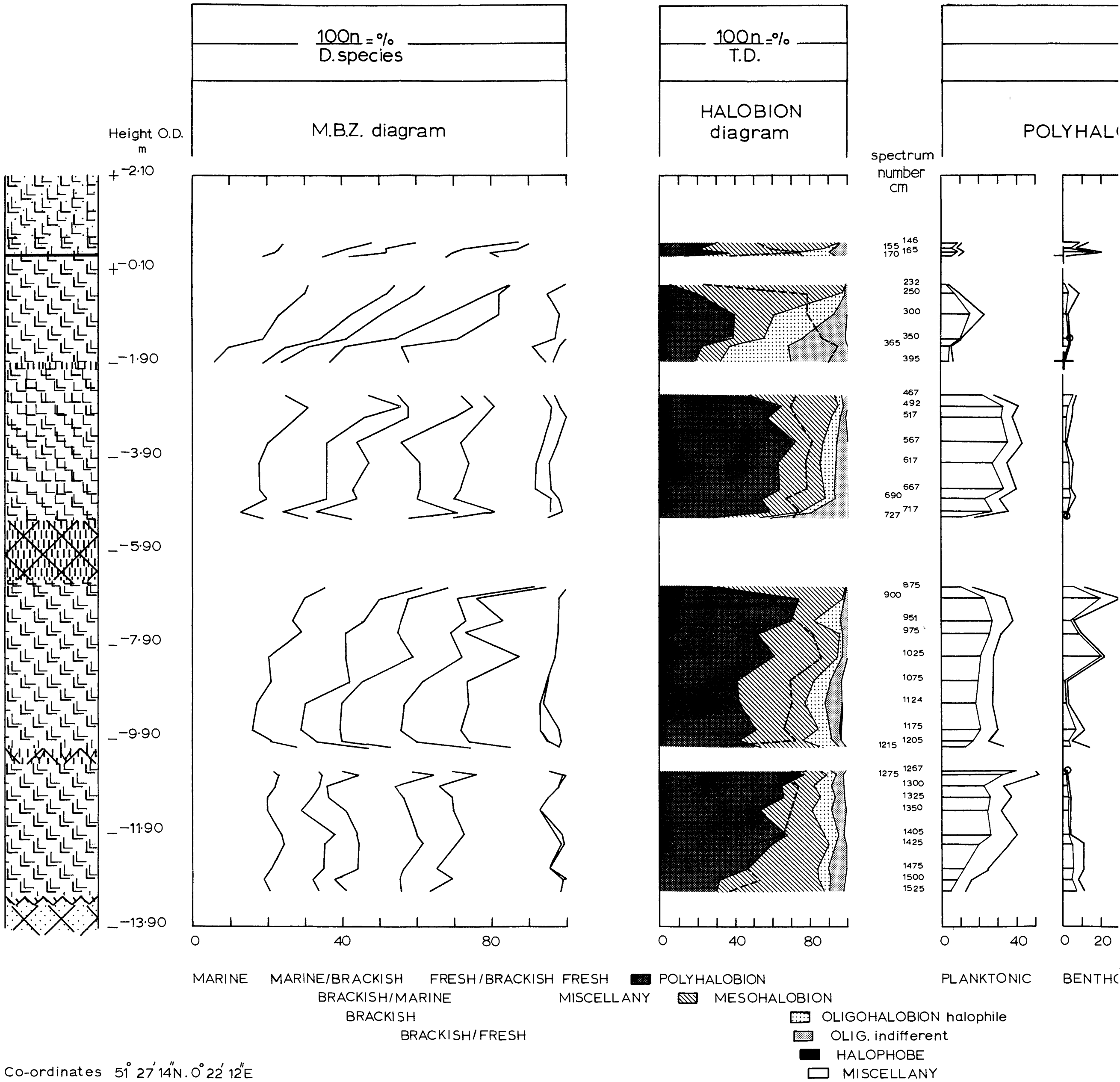
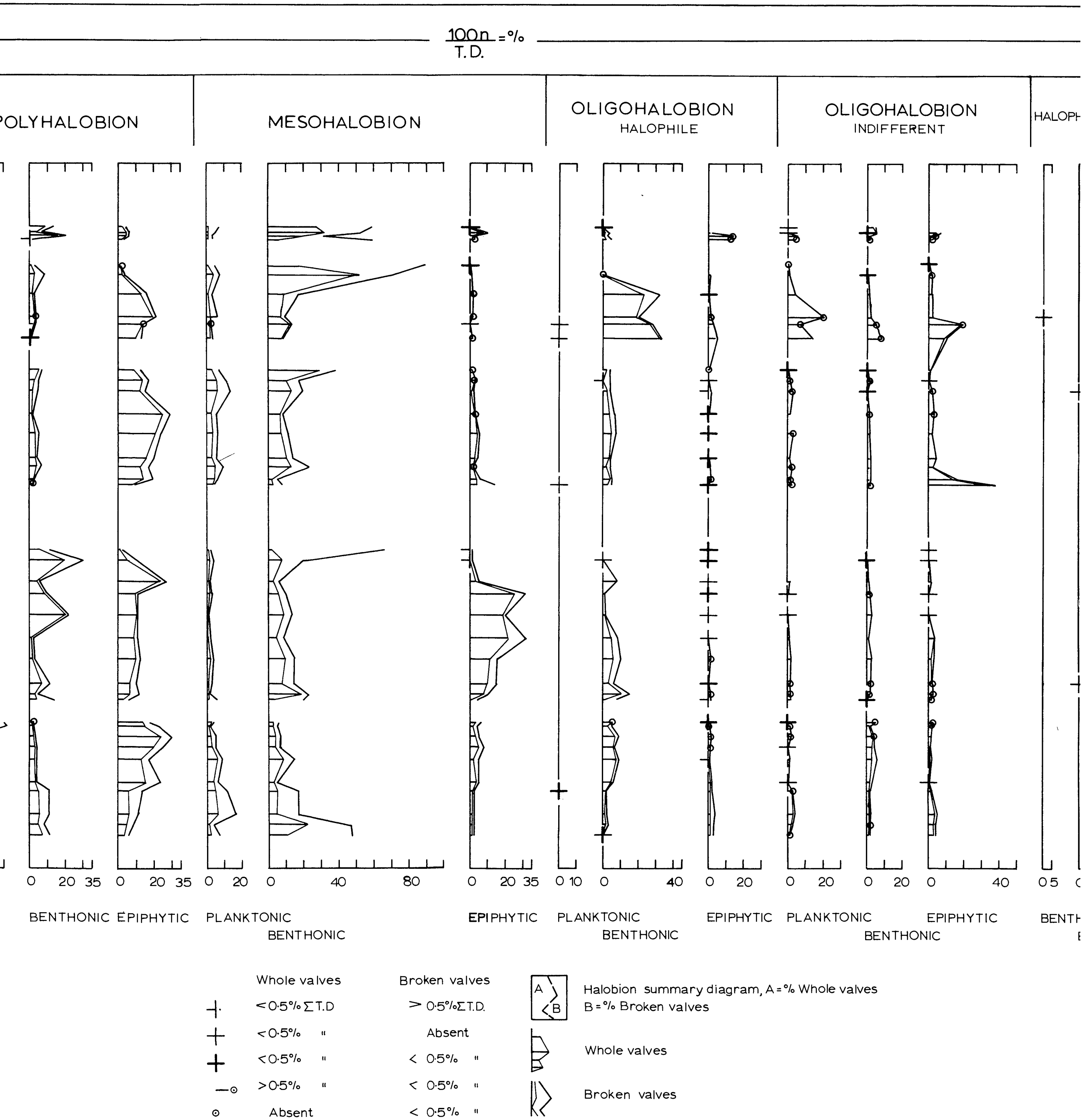


Figure 8. Site map of Plumstead and Erith Marshes with Barking Level, showing borehole locations (⊙).

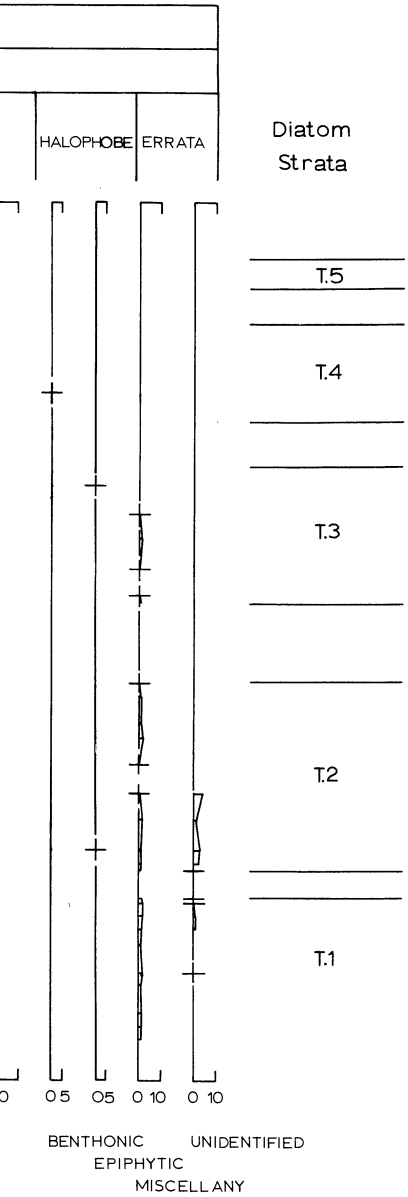


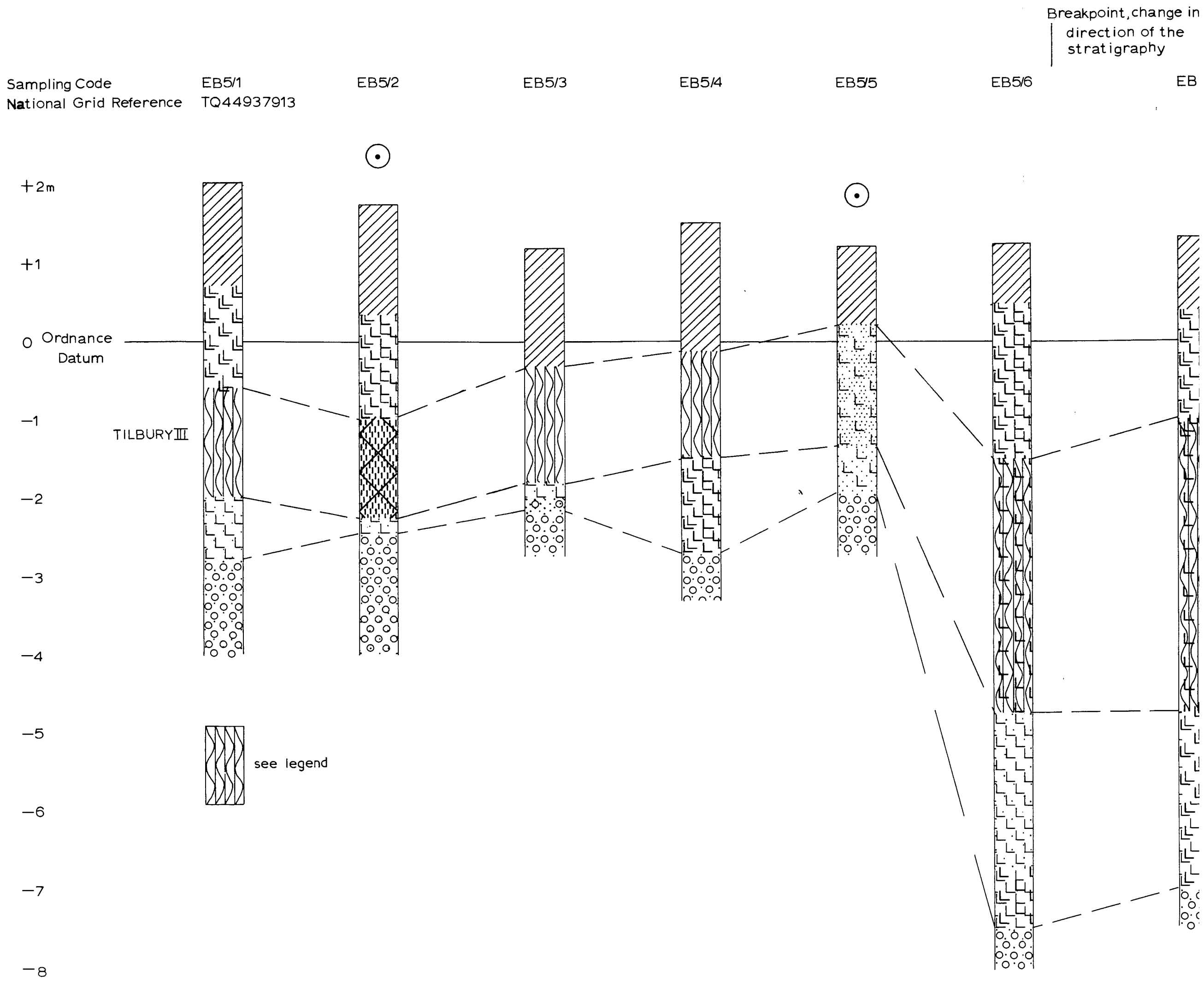
Co-ordinates 51° 27′ 14″N. 0° 22′ 12″E
National Grid Reference TQ 6466 7540
Fieldwork B.W.C./R.J.D. 741121
Analysed 750514–751209 R.J.D.

FIGURE 7. Diatom di



Diatom diagram from Tilbury (The World's End), S.B.I.


HALOPHOBE
ERRATA
Diatom
Strata
T.5
T.4
T.3
T.2
T.1
0
0 5
0 5
0 10
0 10
BENTHONIC
UNIDENTIFIED
EPIPHYTIC
MISCELLANY


Breakpoint, change in direction of the stratigraphy
Sampling Code
National Grid Reference
EB5/1
TQ44937913
EB5/2
EB5/3
EB5/4
EB5/5
EB5/6
EB
+2m
+1
0 Ordnance Datum
−1
TILBURY III
−2
−3
−4
−5
see legend
−6
−7
−8

nt, change in
ion of the
igraphy

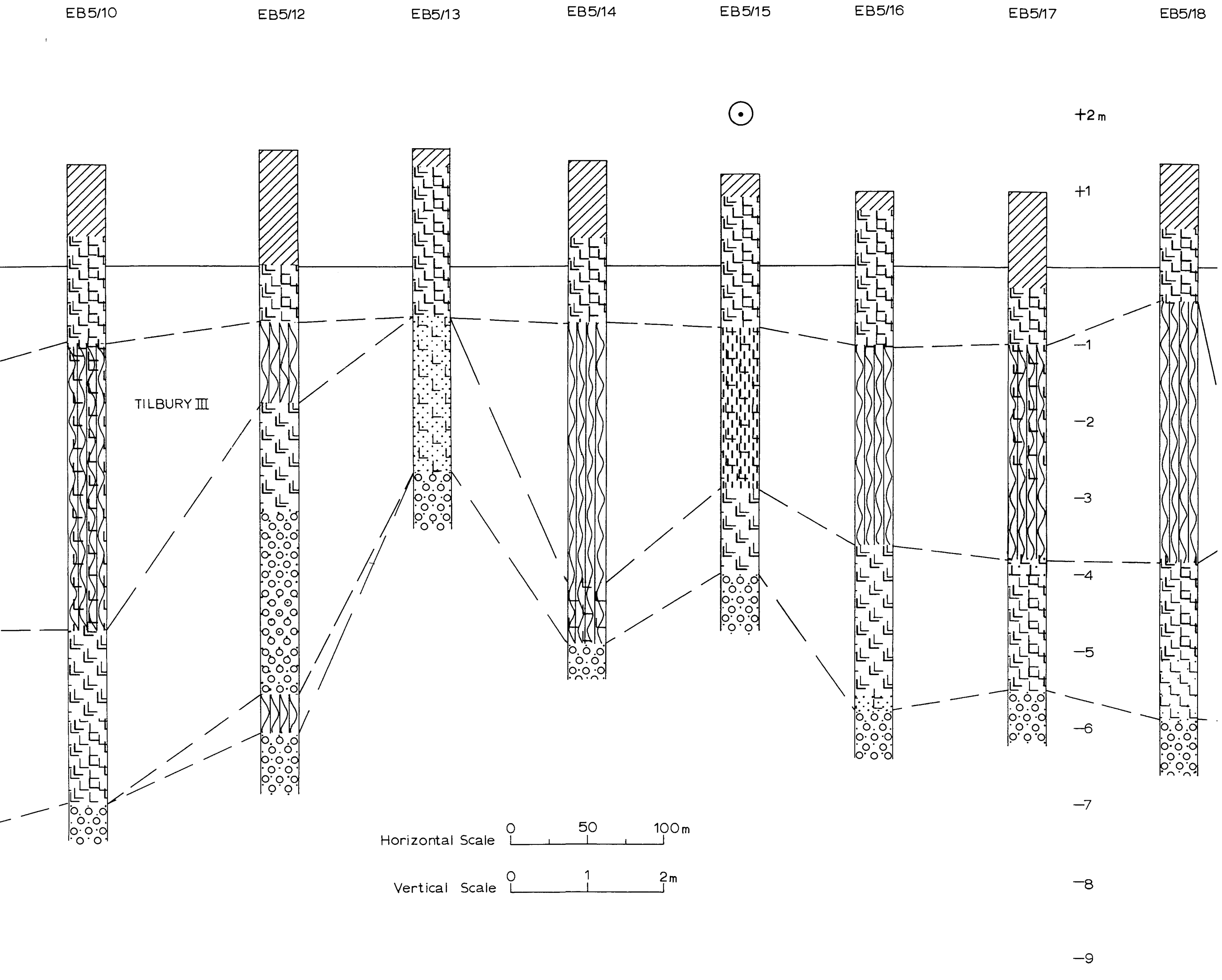
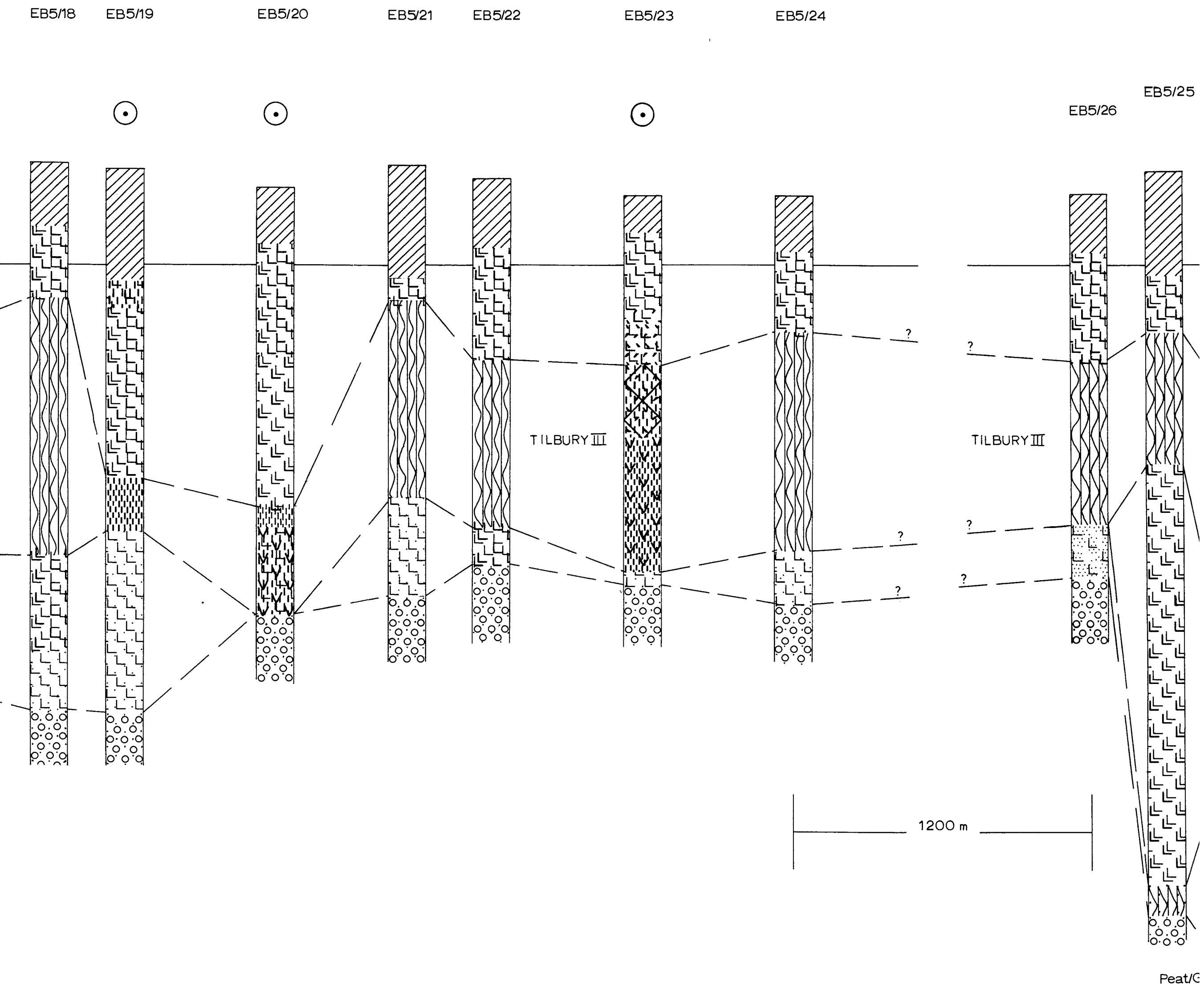
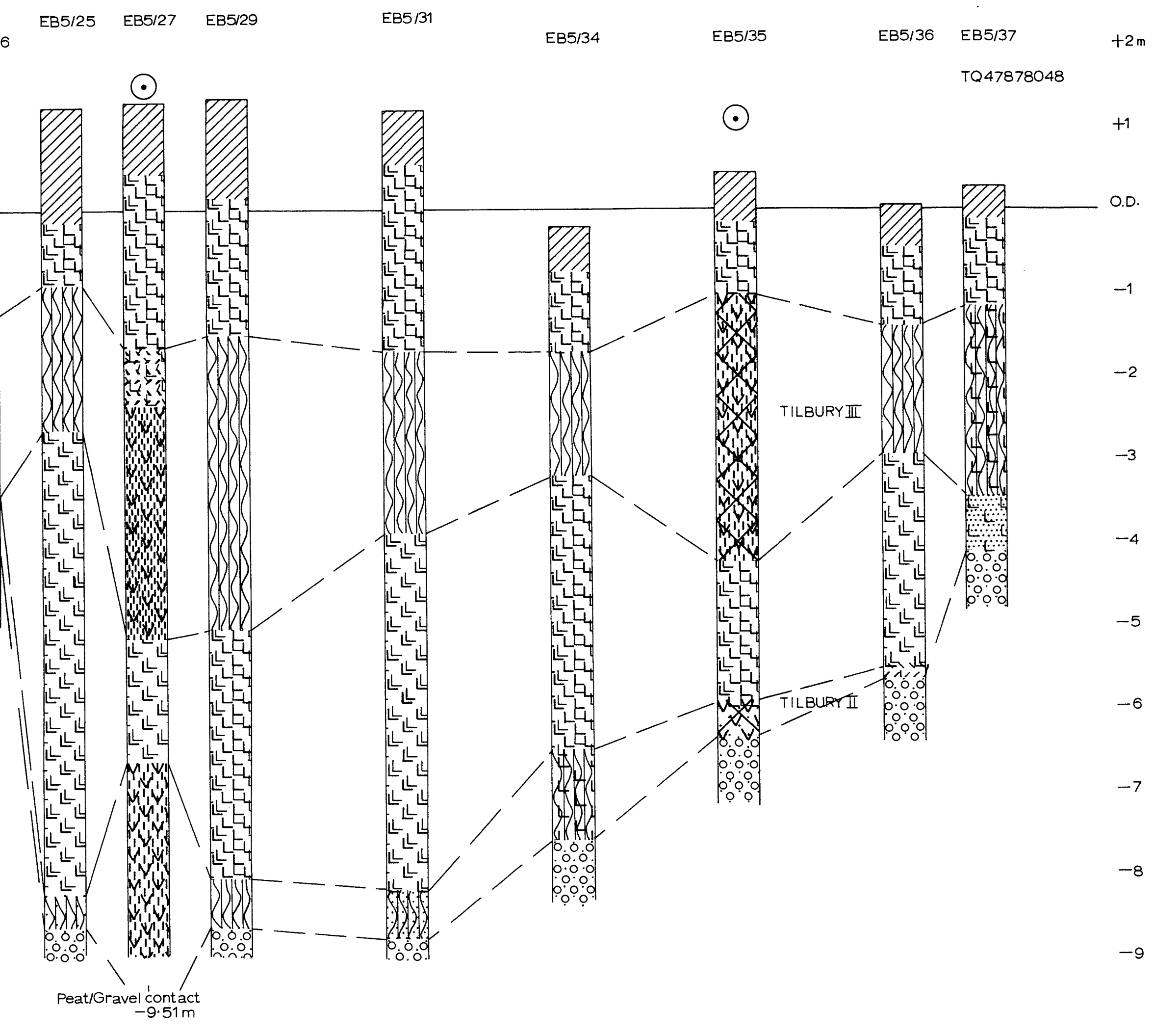


FIGURE 9. Stratigraphic diagram from Plumstead Marshes, based upon borehol
ment symbol represents a medium brown fen peat, well humified with a si
graphic lines (---) above the basal gravel are tentative, used only as a visu



n borehole data supplied by Foundation Eng. Ltd and the author. The sedi-
with a significant gyttja component, branches and twigs are common. Strati-
as a visual guide. ⊙, Sample borehole.


6
EB5/25
EB5/27
EB5/29
EB5/31
EB5/34
EB5/35
EB5/36
EB5/37
TQ47878048
+2 m
+1
O.D.
−1
−2
−3
−4
−5
−6
−7
−8
−9
TILBURY III
TILBURY II
Peat/Gravel contact
−9·51 m

(*a*) *Stratigraphy*

Two principal sections have been drawn (figures 9 and 10) along a west to east line through Plumstead and Erith Marshes. A further section, running north–south, (figure 11) was taken from Barking Level (TQ47738312) to Crossness Point and from there to Thamesmead (TQ47997911). Ground heights of the boreholes studied lie between 1 and 2 m O.D.

Woolwich and Reading Beds underlie the Quaternary deposits here which show an irregular profile with ridge and channel features. Depths for the channel bases occur at −14 to −16 m O.D. in EB5/81, 85 and 86 (figure 11).

The Devensian gravel forms an irregular profile, characterized by ridges and undulating sub-horizontal areas. The surface levels occur commonly at −5 to −6 m O.D., cut by channels reaching to −8 to −9 m O.D. In Barking Level the gravel surface is higher, with a maximum depth of −5 m O.D. Channels can be identified in all the sections, for example between EB5/44–46, 48–53 and 82–86. In the latter, the channel corresponds with a longer feature identified in borings EB5/26–37. This channel passes partially along the line of the Southern Outfall Sewer, before swinging northward. The channel edge is marked in figure 9 by boring EB5/34. The gravel is composed of fine-coarse orange/light brown rounded flint, with sandstone and quartzite pebbles. Orange sand commonly forms an important element in the gravel. A fine silt/sand was frequently recorded on the gravel ridges, shown in EB5/5, 13, 26 and 37.

The Flandrian deposits are composed of three principal strata which occur throughout this area. A single peat bed, Tilbury III, interleaves medium blue-grey silt/clay, producing two separate inorganic layers, Th III/IV and Th II. Variable in height, Tilbury III lies between −1 to −5 m O.D., forming on average a deposit 2.5 m thick. Toward Thamesmead the peat thickens and becomes more uniform in height (as shown in boreholes EB5/87–96, figure 11). The peat bed is correlated with Tilbury III deposits downstream on the basis of height, pollen content and ^{14}C assays. The irregular profile may best be explained by erosion of the deposit during inundation, with channels cut in the peat to allow tidal runoff. These features are exemplified between boreholes EB5/18–21, 45–47, 63–69, 82–84 and 92–94. Within the silt/clay deposits infilling such channels, fine sand and gravel lenses with shells were occasionally found, characteristic of sediments found in such intertidal channels today (Ginsberg 1975; Klein 1967; Reineck 1967). A present day analogy exists in the formation of creeks and the larger ebb and flow channels in the intertidal mudflat and saltmarsh areas of the outer estuary.

The biogenic deposits consist of medium red-brown homogeneous monocot peat, dominated by the stems and leaves of *Phragmites* and Cyperaceae. Varying proportions of gyttja and woody elements are present. Branches, twigs and leaves of *Betula*, *Corylus*, *Alnus* and *Quercus* were found in the basal layers of the peat in many boreholes. This wood layer is characteristic of Tilbury III throughout the area. Wood remains and fruits, comprising *Corylus*, *Betula*, *Salix*, *Alnus* and *Quercus* were also found, however, in small quantities throughout the peat profile. This suggests strong local variations within the fen vegetation at the time of peat formation. Lenses of grey silt/clay, more commonly forming a grey-brown silt/clay matrix, were noted in many boreholes (for example EB5/6, 10, 17 and 37). This inorganic fraction occurred in conjunction with the basal wood peat layer before growth of the monocot peat, indicating deposition in a wood fen environment.

The silt/clay termed Thames III and Thames IV forms a compact mottled brown deposit in the upper 0.5–1 m of the stratum. This level is interpreted as forming the most recent remnant of intertidal mudflat and saltmarsh development, with iron staining apparent along cracks and old root lines. *In situ* remains of *Phragmites* and Cyperaceae were common. Below this level the deposit becomes a medium blue-grey silt/clay. Thames II underlies the main peat and is similar in colour and composition to Thames III. Autocompacted branches and twigs of *Alnus*, *Quercus* and *Corylus* become common.

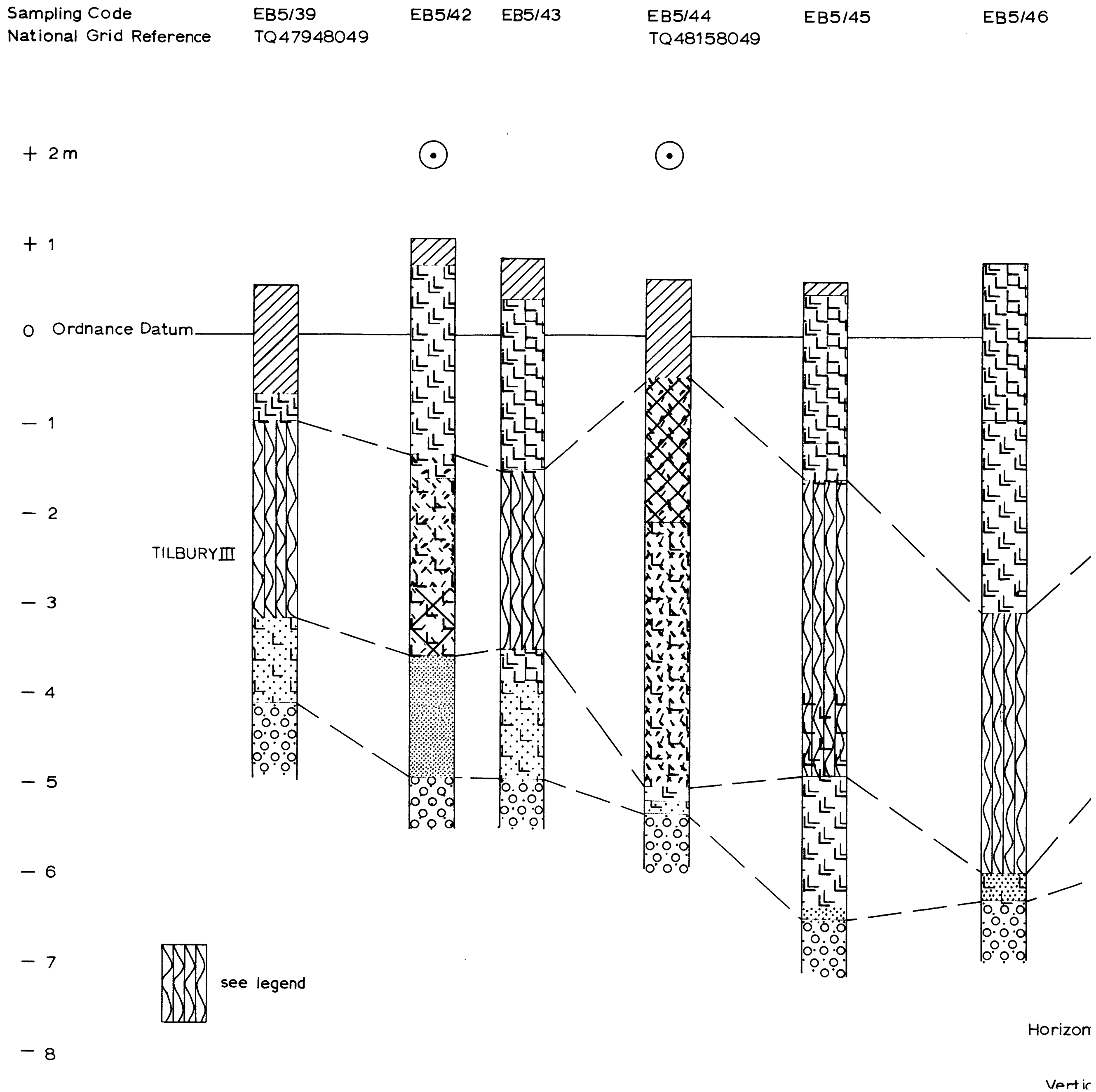
The channels formed in the gravel surface are infilled by clay/silt of Thames II with a further distinct wood peat 0.5–1 m thick, termed Tilbury II, identified here. This lies between −5.5 to −6.5 m O.D., with a maximum depth of −8 m O.D. in boreholes EB5/29–34. Roots, branches and twigs of *Alnus* and *Quercus* are common, with a small gyttja element and some silt and sand present. In the light of these sections the previous work of Spurrell (1889) showing two continuous peat beds covering the area, is incorrect. Over the marsh area Tilbury III is persistent, but Tilbury II is confined to the channels in the gravel.

(*b*) *Pollen analysis*

The stratigraphy of the upper peat, Tilbury III, as represented by the sample borehole SB5/1, is consistent with that of the area as a whole (see § 2*c*) (figure 12). *In situ* alder wood peat develops here upon a sandy silt, consequent upon a rising freshwater table. A high inorganic fraction in the peat shows the importance of river inwashing at this time. Its replacement upward by detrital wood and increasing monocot element, suggests the formation of a freshwater fen peat.

Samples for pollen analysis were taken at 20 cm and where possible at 10 cm intervals. Irregularities in this sampling pattern are due to the occurrence of branches in the core or the paucity of pollen. The assemblages throughout are dominated by arboreal pollen and spores and rarely do a.p. values fall below 50% Σ t.l.p. Three l.p.z. have been recognized (figure 12).

l.p.z. height from surface (cm)	description
Cc 140–205	Rise to dominance of a.p., with decline of Filicales. *Alnus* is high but erratic in value, > 65% Σ t.l.p. at maximum. *Quercus* and *Corylus* type remain prominent, the latter declining toward the top accompanied by *Betula*. *Ulmus* values remain low and sporadic. Appearance of *Fagus* and *Acer* pollen. Shrub values continue their expansion, *Salix* being important but erratic in value, accompanied by the appearance of *Cornus sanguinea*, *Sambucus nigra*, *Sorbus* and *Ilex*. Herbs become more species rich with Gramineae remaining important > 10% Σ t.l.p. Cereal type pollen appears. *Pteridium aquilinum* rises to a maximum of 15% Σ t.l.p. + pteridophytes).
Cb 205–320	Aboreal pollen becomes less common with a rise of n.a.p. to > 50% Σ t.p. at a maximum, accompanied by a sharp rise of Filicales to > 60% Σ t.l.p. + pteridophytes). Gramineae and Cyperaceae expand together, the former generally > 25% Σ t.l.p. Herbs remain poor in taxa. Aquatics, particularly *Typha latifolia* accompany expansion of n.a.p. to 290 cm. Within the trees, *Alnus* falls to < 15% Σ t.l.p. with the expansion of *Quercus* and *Corylus* type


Sampling Code
National Grid Reference
EB5/39
TQ47948049
EB5/42
EB5/43
EB5/44
TQ48158049
EB5/45
EB5/46
+ 2m
+ 1
0 Ordnance Datum
− 1
− 2
TILBURY III
− 3
− 4
− 5
− 6
− 7
− 8
see legend
Horizon
Vertic

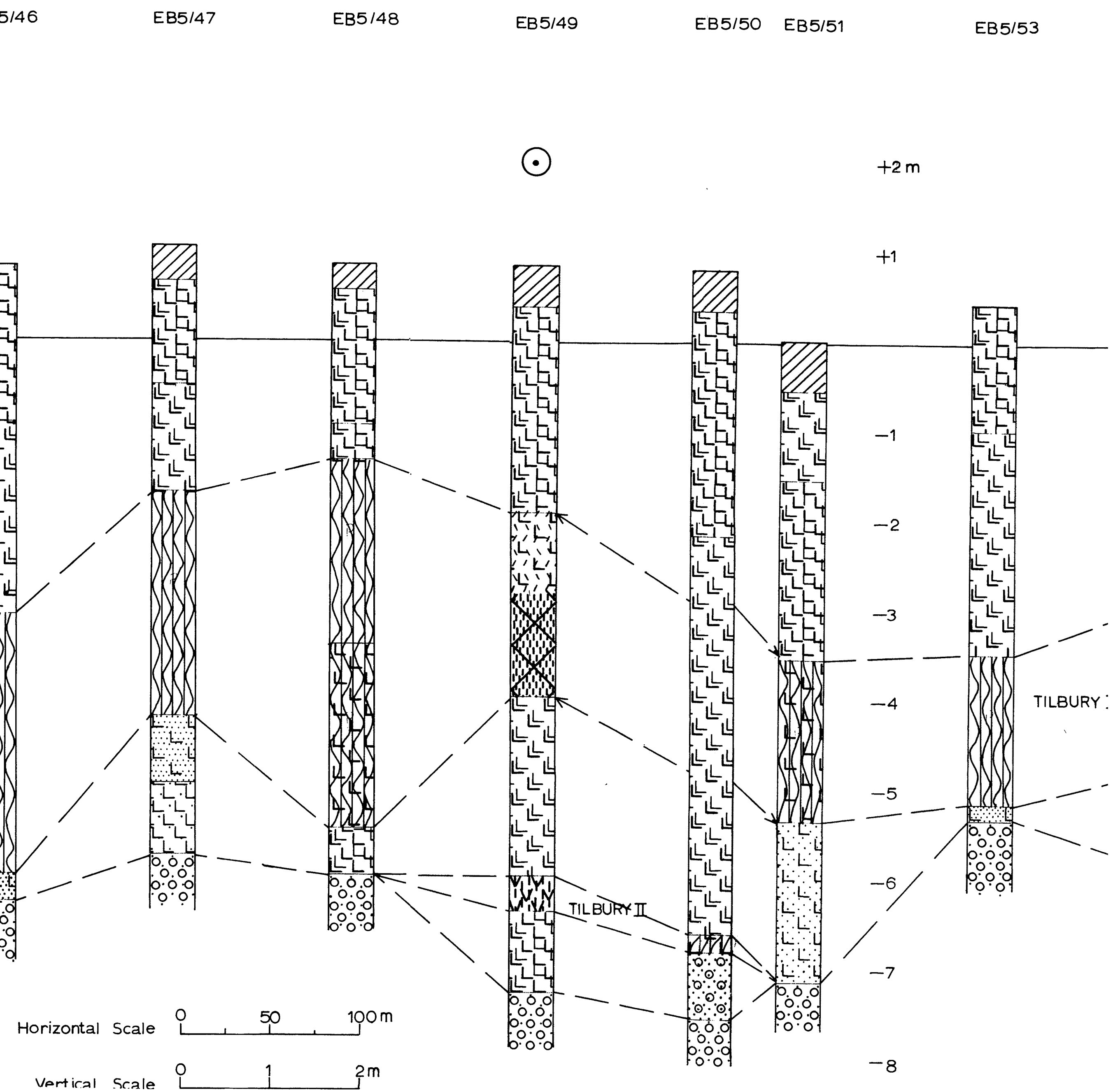
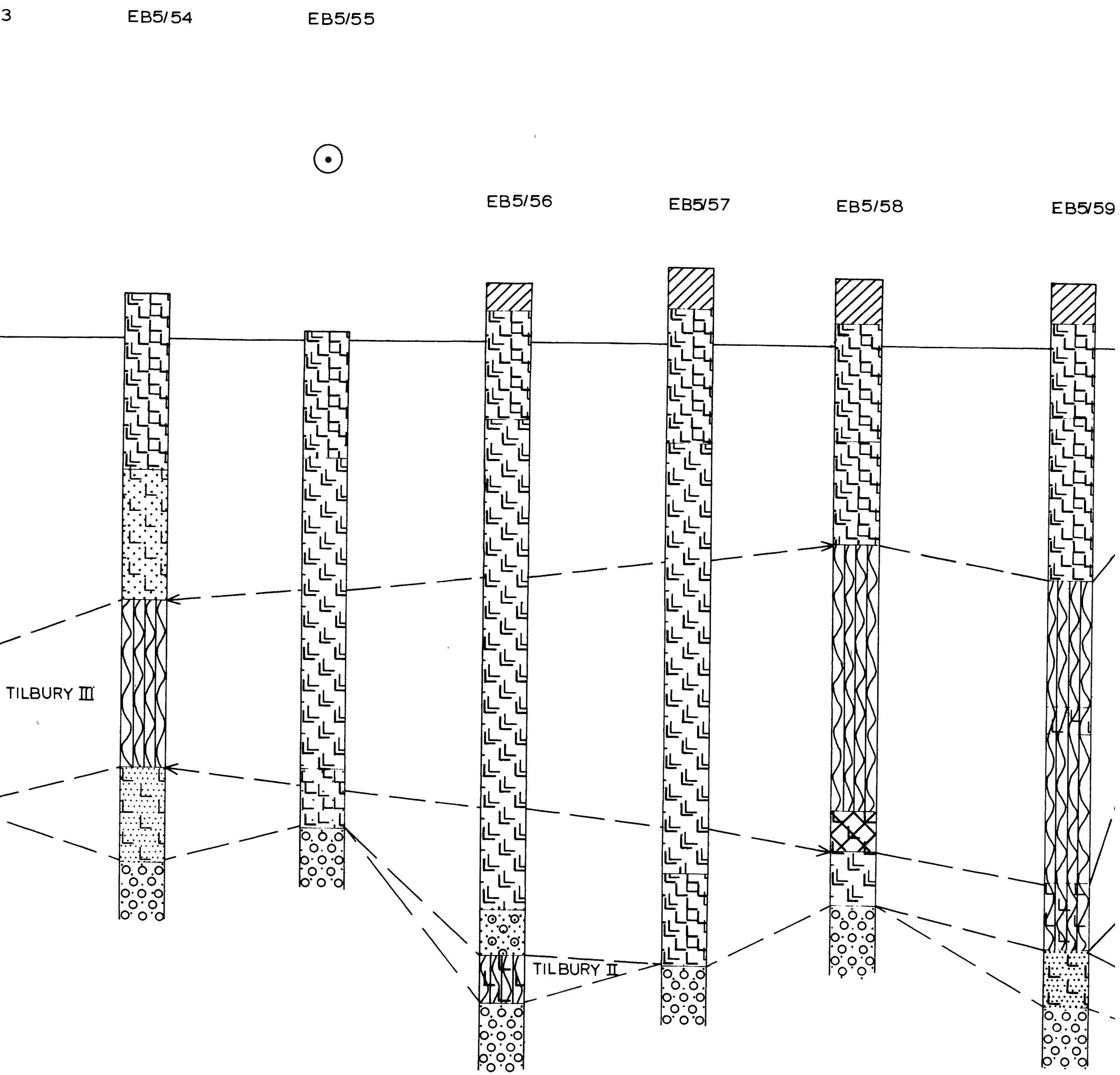
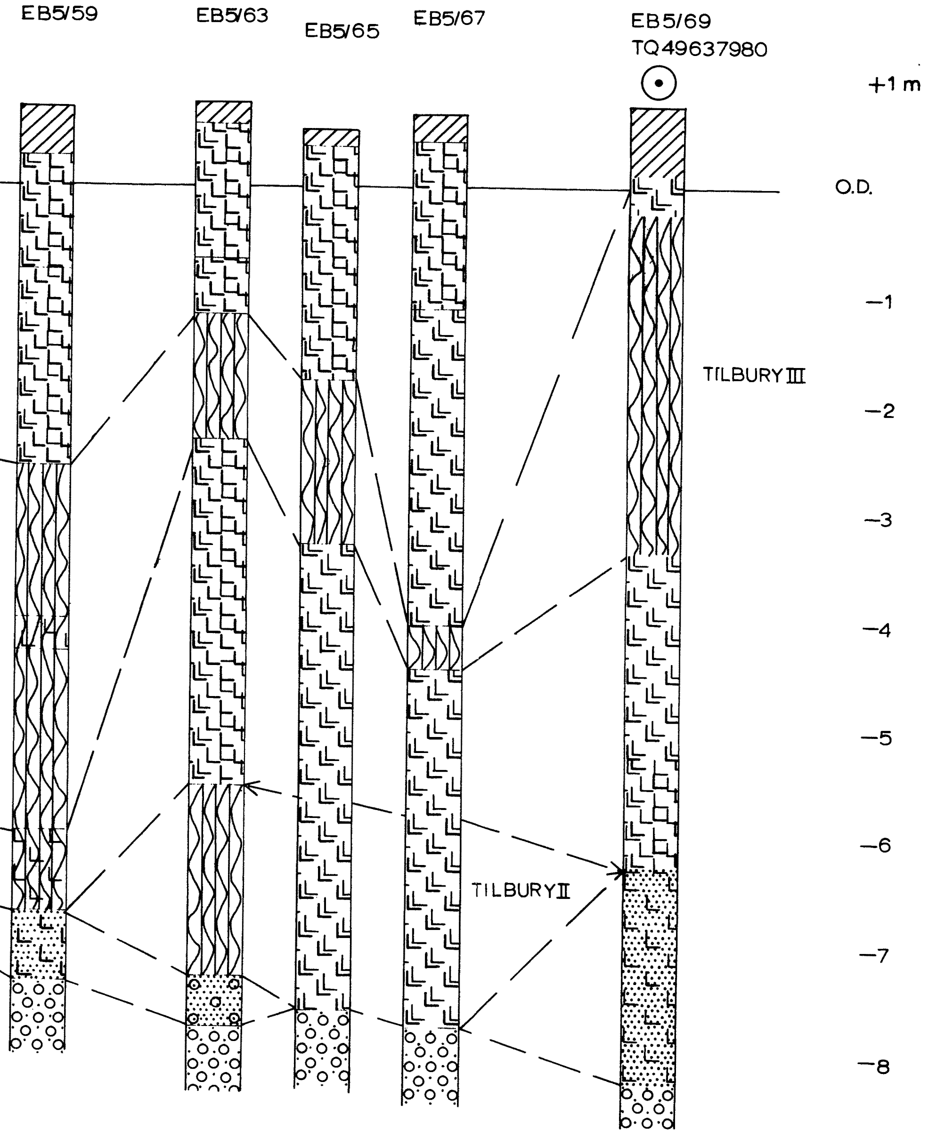


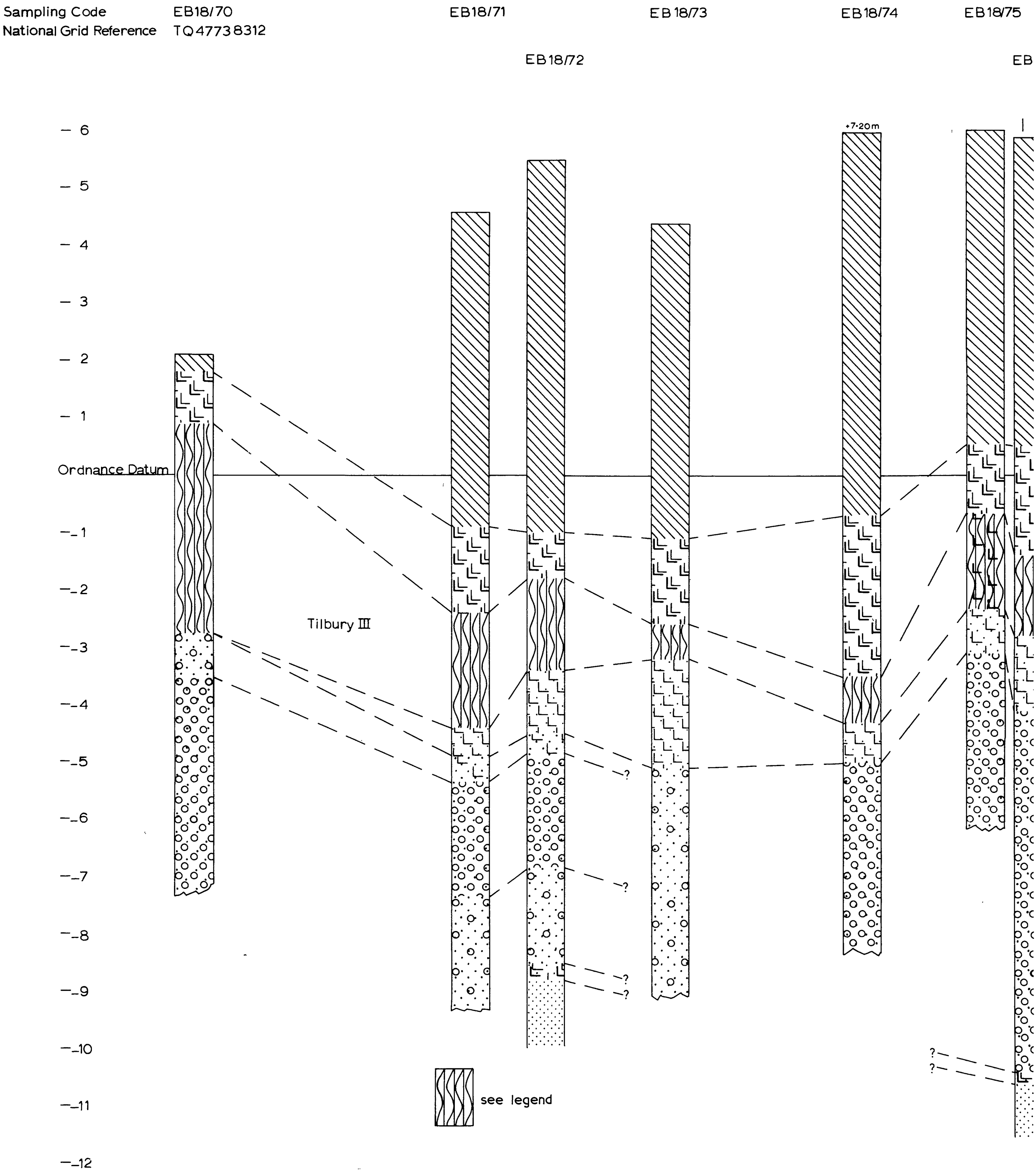
FIGURE 10. Stratigraphic diagram from Erith Marshes, based upon borehole data supplied by Found
(---) above the basal gravel are tentative, used only as a visual guide. The sediment symbol r
with a significant gyttja component; branches and twigs are common. ⊙, Sampled borehole.



by Foundation Eng. Ltd and the author. Stratigraphic lines
symbol represents a medium brown fen peat, well humified
borehole.


EB5/59
EB5/63
EB5/65
EB5/67
EB5/69
TQ49637980
+1 m
O.D.
−1
TILBURY III
−2
−3
−4
−5
−6
TILBURY II
−7
−8

(*Facing p.* 372)


Sampling Code
National Grid Reference
EB18/70
TQ 4773 8312
EB18/71
EB 18/72
EB 18/73
EB18/74
EB18/75
EB
+7·20m
6
5
4
3
2
1
Ordnance Datum
–1
–2
–3
–4
–5
–6
–7
–8
–9
–10
–11
–12
Tilbury III
?
see legend

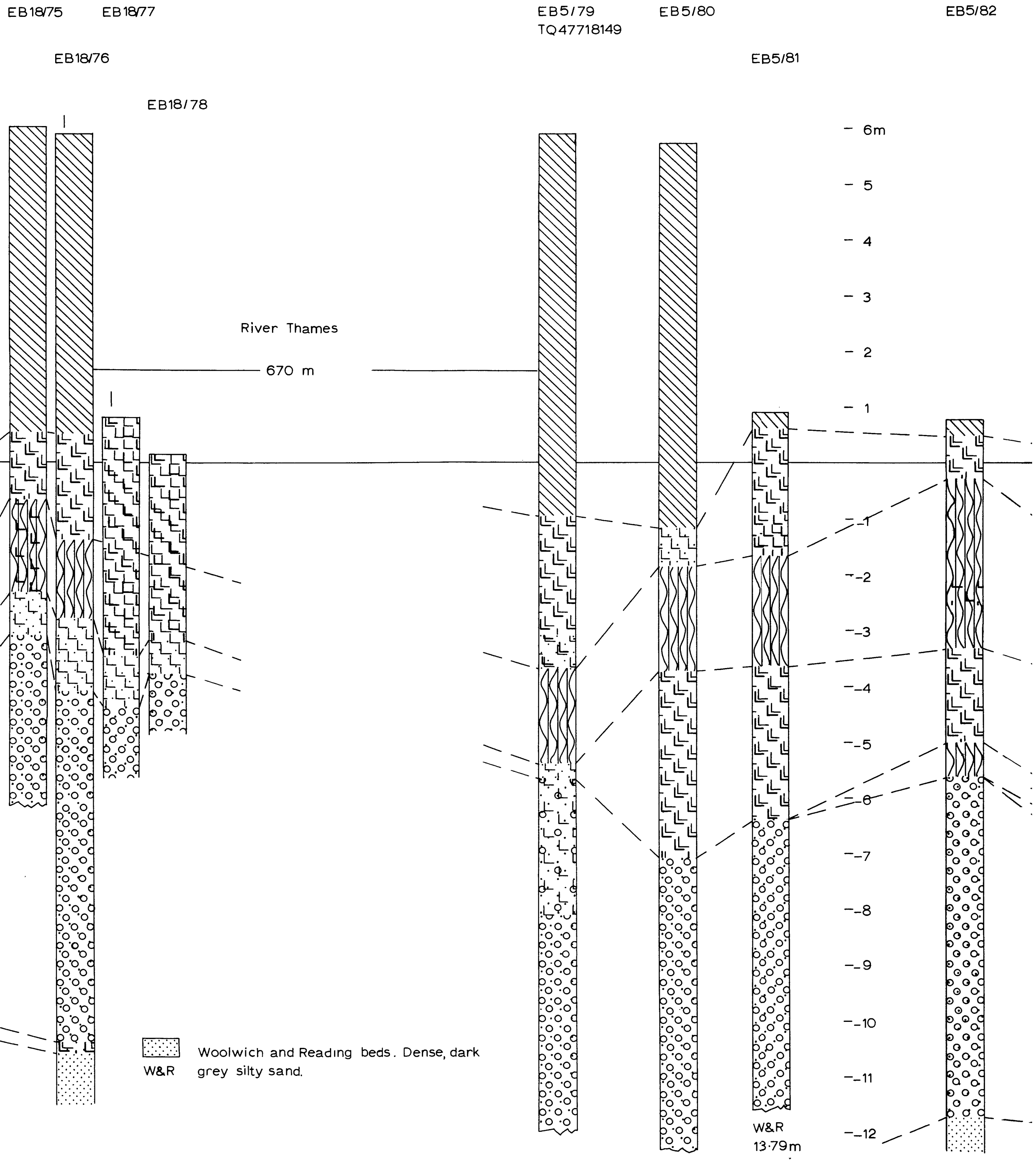
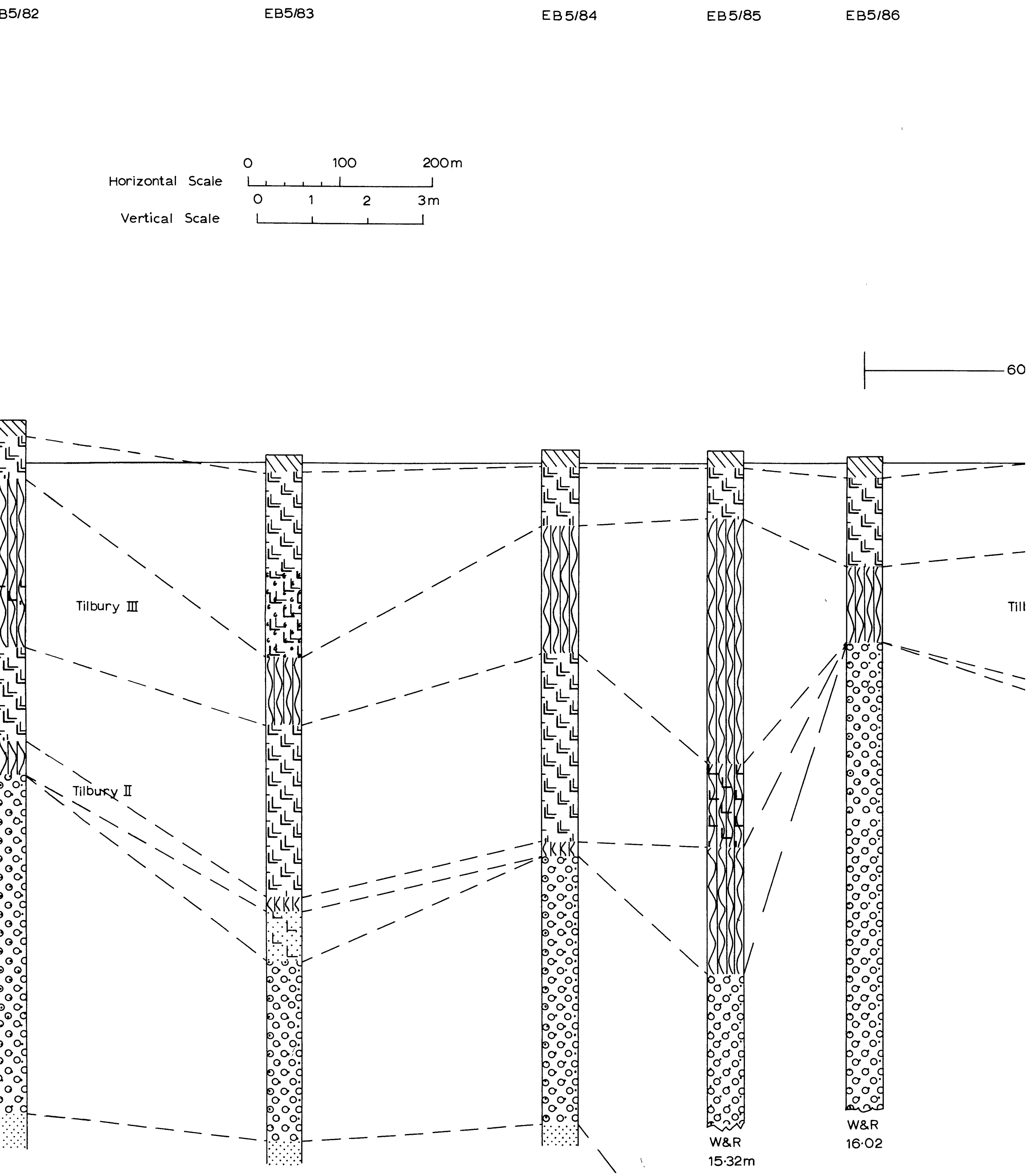
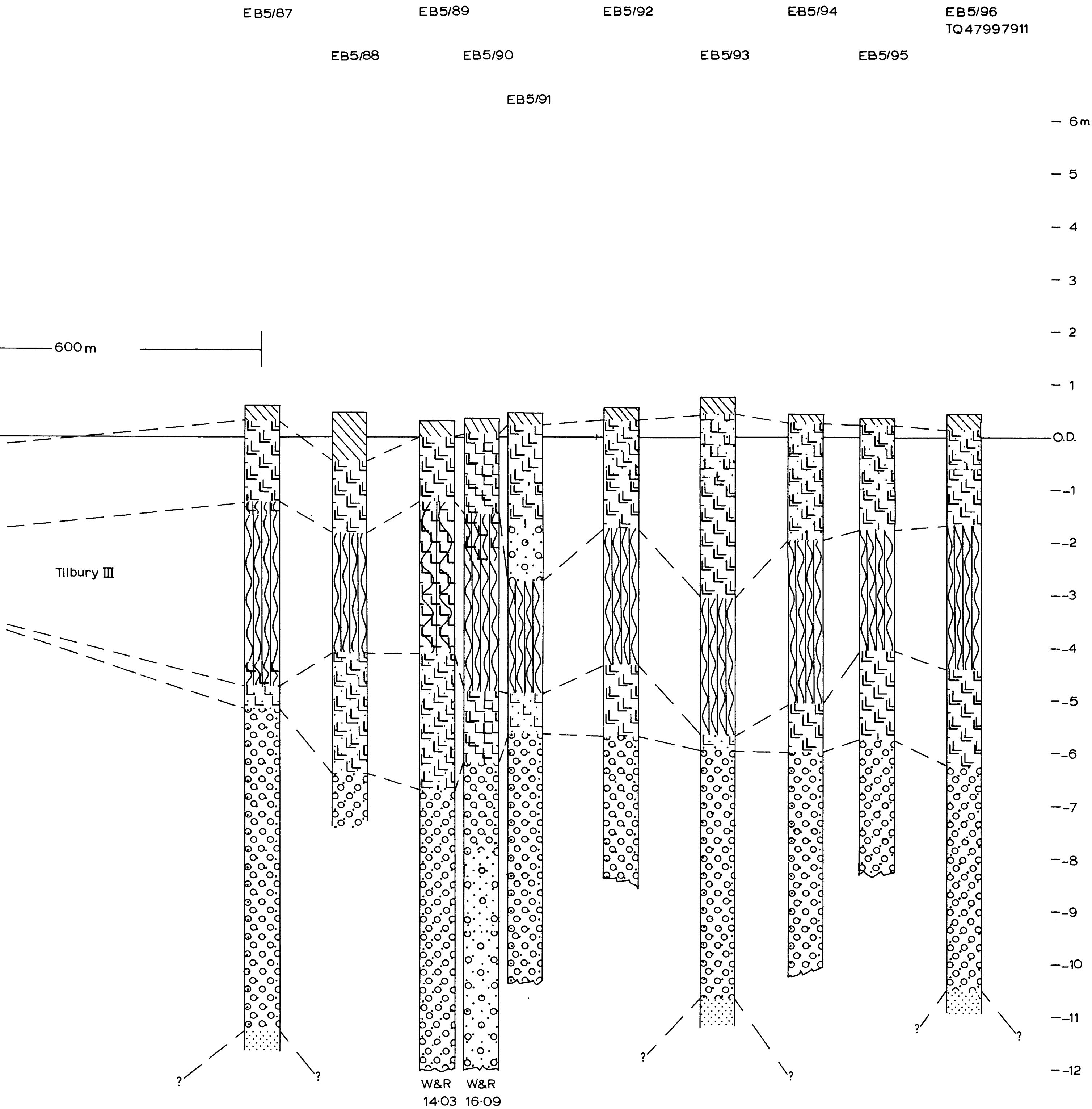


FIGURE 11. Stratigraphic diagram from Barking Level and Erith
and the author. The sediment symbol represents a medium r
bark and fruits of *Alnus*, *Quercus* and *Corylus* are common, par
tions are used where the inorganic element in the biogenic dep



nd Erith Marshes, based upon borehole data from Binnie & Partners Ltd, C.E.G.B., G.L.C. medium red-brown fen peat, well humified with a significant component; branches, twigs, mon, particularly at the base of Tilbury III. Appropriate Troels-Smith symbols and propor-genic deposit exceeds 25% of the total.


EB5/87
EB5/88
EB5/89
EB5/90
EB5/91
EB5/92
EB5/93
EB5/94
EB5/95
EB5/96
TQ47997911
600 m
Tilbury III
W&R
14·03
W&R
16·09
6 m
5
4
3
2
1
O.D.
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
-11
-12

pollen values. *Betula* and *Tilia* frequencies also rise markedly. *Fraxinus* forms a continuous curve.

Ca 320–375 *Quercus* and *Corylus* type pollen dominate the pollen assemblage. *Alnus* values are high (> 60 % Σ t.l.p.) with low but persistent frequencies of *Ulmus* and *Tilia*, the latter erratic, but increasing towards the top of the zone. *Hedera* forms a continuous curve, accompanied by sporadic occurrences of *Rhamnus catharticus* and *Viburnum opulus*. Herb frequencies are low and erratic.

Alnus, *Salix* and Cyperaceae pollen with Filicales spores are over-represented in the pollen assemblage and are of local origin. This may be gauged by the divergence of the graphs for Σ t.l.p. and Σ (t.l.p. – *Alnus* + Cyperaceae) and is clear in l.p.z. Ca 320–375 cm, where the high values of *Alnus* pollen accounts for the difference in values, particularly of *Quercus* and *Corylus* type pollen. The local nature of the pollen spectra may be closely linked to the stratigraphic and related hydrological changes at the site.

(i) *Local pollen assemblage zone Ca* (Quercus, Corylus *type and* Alnus)

High *Alnus* pollen values suggest the formation of alder carr at the outset. *Quercus* and *Corylus* were also present in drier areas probably, although *Quercus* can live under wet conditions – even seasonal flooding (Johnson & York 1915; Walker 1966). Finds of branches and twigs of both *Alnus* and *Quercus* with fruits of *Alnus glutinosa* confirm this interpretation as does the abundance of Filicales and *Thelypteris palustris* spores, plants which favour the shady, wet conditions of an alder carr. A high clay/silt fraction occurs below 363 cm and with the presence of pre-Quaternary spores and Hystrichospheres shows river inwashing. *Pinus* pollen reaches high values here, declining only with the onset of peat growth. Such behaviour by *Pinus* within riverine areas, is indicative of water influence upon the deposits (Hartman 1968).

(ii) *Local pollen assemblage zone Cb* (*Gramineae*, *Cyperaceae*, Quercus *and* Corylus *type*)

The apparent decline of *Betula*, *Corylus* type and *Quercus* pollen may show a fall in the water table. The area probably remained wet and marshy with the formation of open pools. This would allow development of less shaded communities, a development indicated by the expansion of grasses, sedges and aquatic taxa, particularly the pollen of *Typha angustifolia*/*Sparganium* and *Typha latifolia*. However, the vegetation complex would still provide habitats for more shade tolerant taxa, as shown by *Caltha* type, *Mercurialis perennis* pollen and *Thelypteris palustris* spores.

(iii) *Local pollen assemblage zone Cc* (Alnus, Quercus *and* Corylus *type*)

The last phase of vegetation development shows the return to alder fen woods, *Alnus* expanding to 70 % Σ t.l.p. Herb taxa favouring wet, shady conditions also expand in value, particularly *Caltha* type, *Humulus lupulus*, *Filipendula* and *Mercurialis perennis* pollen. The herb taxa overall become more numerous, with the ratio of herb pollen remaining high at 20 % Σ t.l.p. Persistent frequencies of *Plantago laceolata* pollen appear, together with other taxa liking dry, open conditions found today in waste places and with arable farming, for example the pollen of *Rumex acetosa*, *R. acetosella*, *Artemisia*, *Plantago media*, Caryophyllaceae *Dianthus* type and Scrophulariaceae cf. *Odontites*. Cereal type pollen appears in the pollen assemblage. These taxa with *Pteridium aquilinum* are often associated with man and disturbance and the changes in n.a.p. assemblage may represent the increasing influence of man upon the extra-local vegetational composition.

The behaviour of *Tilia* pollen frequencies remain high throughout the pollen diagram, occasionally exceeding 5% Σ t.l.p. These relatively large values support the conclusions of Godwin (1975) and Birks, Deacon & Peglar (1975), regarding the importance of *Tilia* in the forest composition of southeastern and eastern England during Flandrian times. *Tilia* probably formed an important forest component with *Quercus* and *Corylus*, growing upon the nearby well drained chalk upland. From 162 cm *Tilia* maintains low values of 1% Σ t.l.p. or less and this corresponds with the expansion of cereal pollen and ruderal taxa associated with man.

(*c*) *Dating – the elm decline*

Dating is based upon the pollen evidence and two radiocarbon dates. From these assays, Q-1282 and Q-1333, the deposit is shown to have formed between 5640 ± 75 and 4195 ± 100 B.P. The pollen assemblage is characteristic of p.z. VII. Division into subzones VII*a*/VII*b* depends upon the recognition of the elm decline. *Ulmus* values are low throughout, rarely rising above 3% Σ t.l.p. Between 300 and 310 cm a continuous decline in *Ulmus* values begins, particularly marked in the curve for Σ (t.l.p. – *Alnus* + Cyperaceae). A sharp decline to frequencies below 1% Σ t.l.p. does not occur, however, until 278–285 cm and it is this point which is taken to mark the elm decline.

5. Stone Marsh and the Dartford Tunnel

Site: TQ565759: 51° 27′ 30″ N; 0° 14′ 30″ E

Stone Marsh (figure 13) together with Dartford and Crayford saltmarshes form a uniform, low area, at about 0.0–0.5 m O.D. and is 9 km² in extent, occurring at the confluence of the rivers Thames and Darent. Borehole SB1/1 lies 405 m at 80° from the ventilation building (TQ56587586) of the old Dartford Tunnel and has the following coordinates: TQ57027594; 51° 27′ 40″ N; 0° 15′ 36″ E.

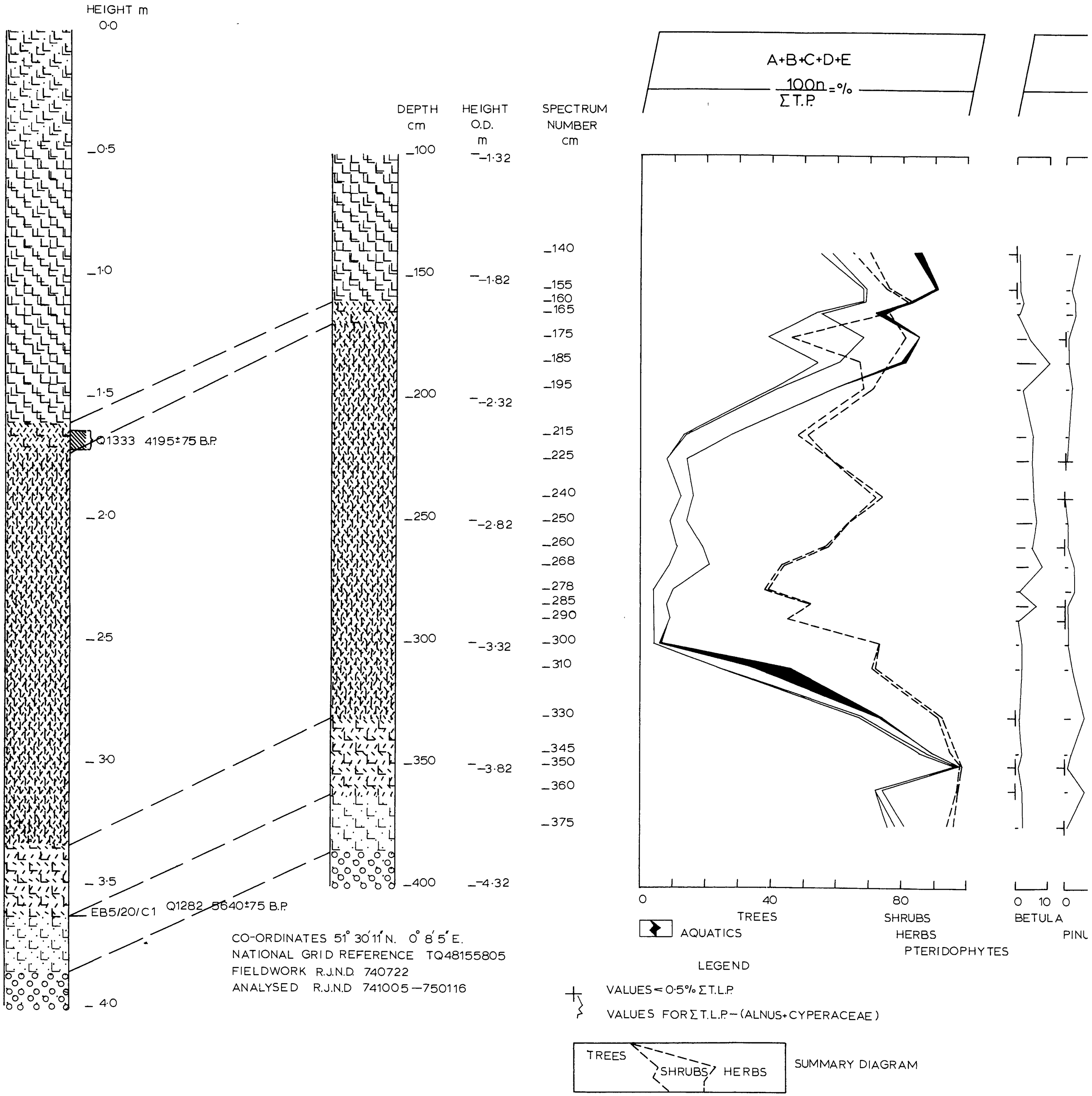
(*a*) *Stratigraphy*

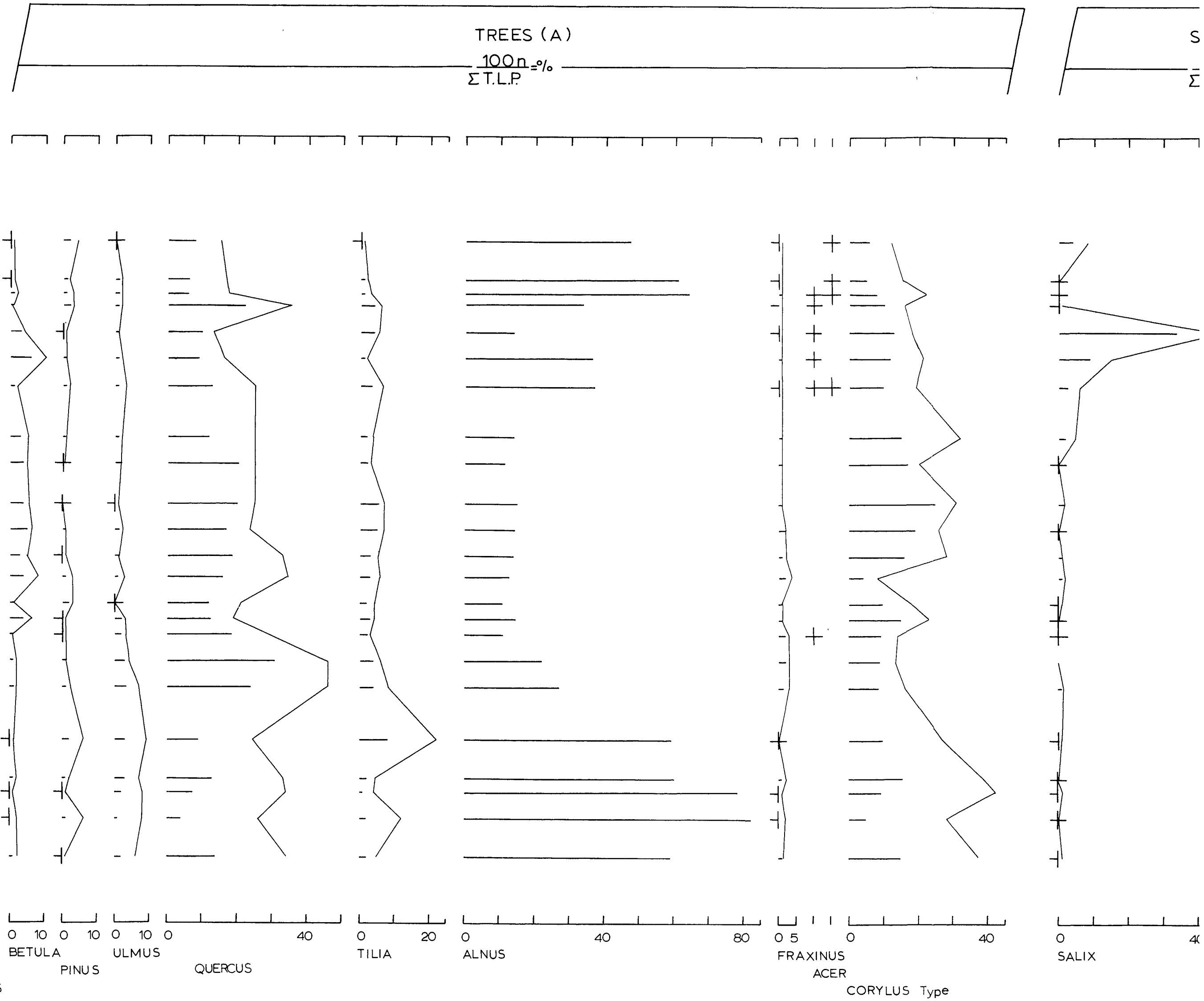
Figure 14 is a three dimensional cross section demonstrating the stratigraphic relationship of the Flandrian sequences north and south of the river.

Chalk underlies the area at depths between – 14.5 and – 17 m O.D. Southward, the chalk rises to – 6.1 m O.D. in borehold 25 and – 5.2 m O.D. in borehole 12. The surface is characterized by weathered chalk and flint fragments, contained within a soft white 'putty' like chalk matrix. Solution hollows have developed within the solid chalk, although these are not shown in the section.

Sands and gravel lie above the chalk. From an average depth of – 10 to – 11 m O.D. in West Thurrock and Stone Marshes, the gravel surface rises to 1 m in borehole 12. In many boreholes a 0.7 to 1 m thick dense, fine to medium brown-yellow sand lies above the gravel. The gravel is composed of fine to coarse yellow-orange rounded flints with a high sand fraction. Channel features are common, infilled by the clay/silt of Thames I.

Three biogenic levels are recognized, reaching their fullest development in the Dartford Tunnel and Stone Marsh area. These interleave a blue-grey clay/silt, the silt fraction normally predominant here. The upper biogenic level is termed Tilbury IV on the basis of its strati-


HEIGHT m
0·0
–0·5
–1·0
–1·5
Q1333 4195±75 B.P.
–2·0
–2·5
–3·0
–3·5
EB5/20/C1 Q1282 5640±75 B.P.
–4·0
DEPTH cm
HEIGHT O.D. m
SPECTRUM NUMBER cm
–100 –1·32
–150 –1·82
–200 –2·32
–250 –2·82
–300 –3·32
–350 –3·82
–400 –4·32
–140 –155 –160 –165 –175 –185 –195 –215 –225 –240 –250 –260 –268 –278 –285 –290 –300 –310 –330 –345 –350 –360 –375
CO-ORDINATES 51° 30′ 11″ N. 0° 8′ 5″ E.
NATIONAL GRID REFERENCE TQ48155805
FIELDWORK R.J.N.D. 740722
ANALYSED R.J.N.D 741005–750116
A+B+C+D+E
100n/ΣT.P. = %
0 40 80
TREES
SHRUBS
HERBS
PTERIDOPHYTES
AQUATICS
0 10 0
BETULA
PINU
LEGEND
VALUES < 0·5% ΣT.L.P.
VALUES FOR ΣT.L.P. – (ALNUS+CYPERACEAE)
TREES
SHRUBS
HERBS
SUMMARY DIAGRAM



TREES (A)
100n / ΣT.L.P. =%
0 10 0 10 0 10 0 40 0 20 0 40 80 0 5 0 40 0
BETULA
PINUS
ULMUS
QUERCUS
TILIA
ALNUS
FRAXINUS
ACER
CORYLUS Type
SALIX

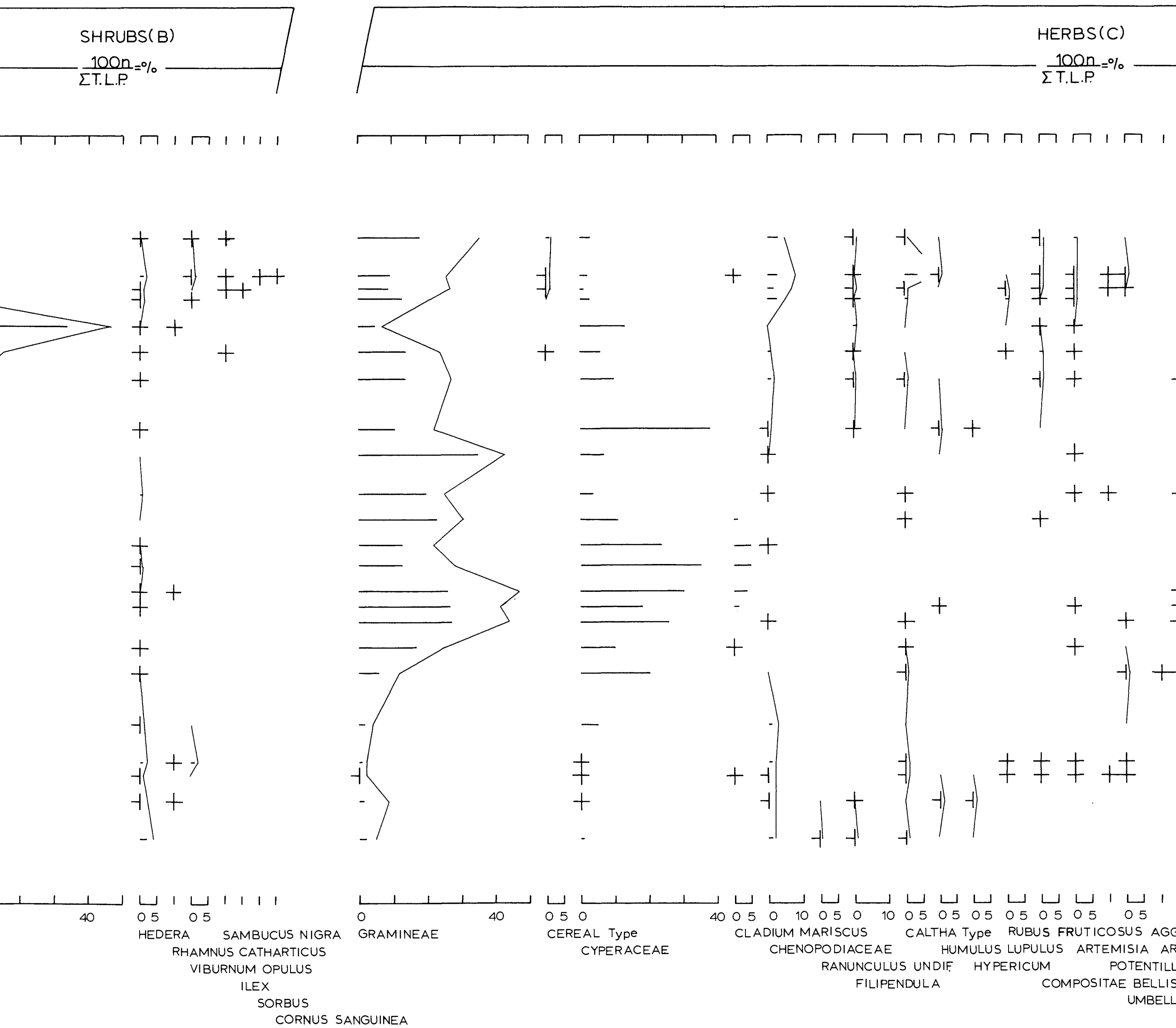
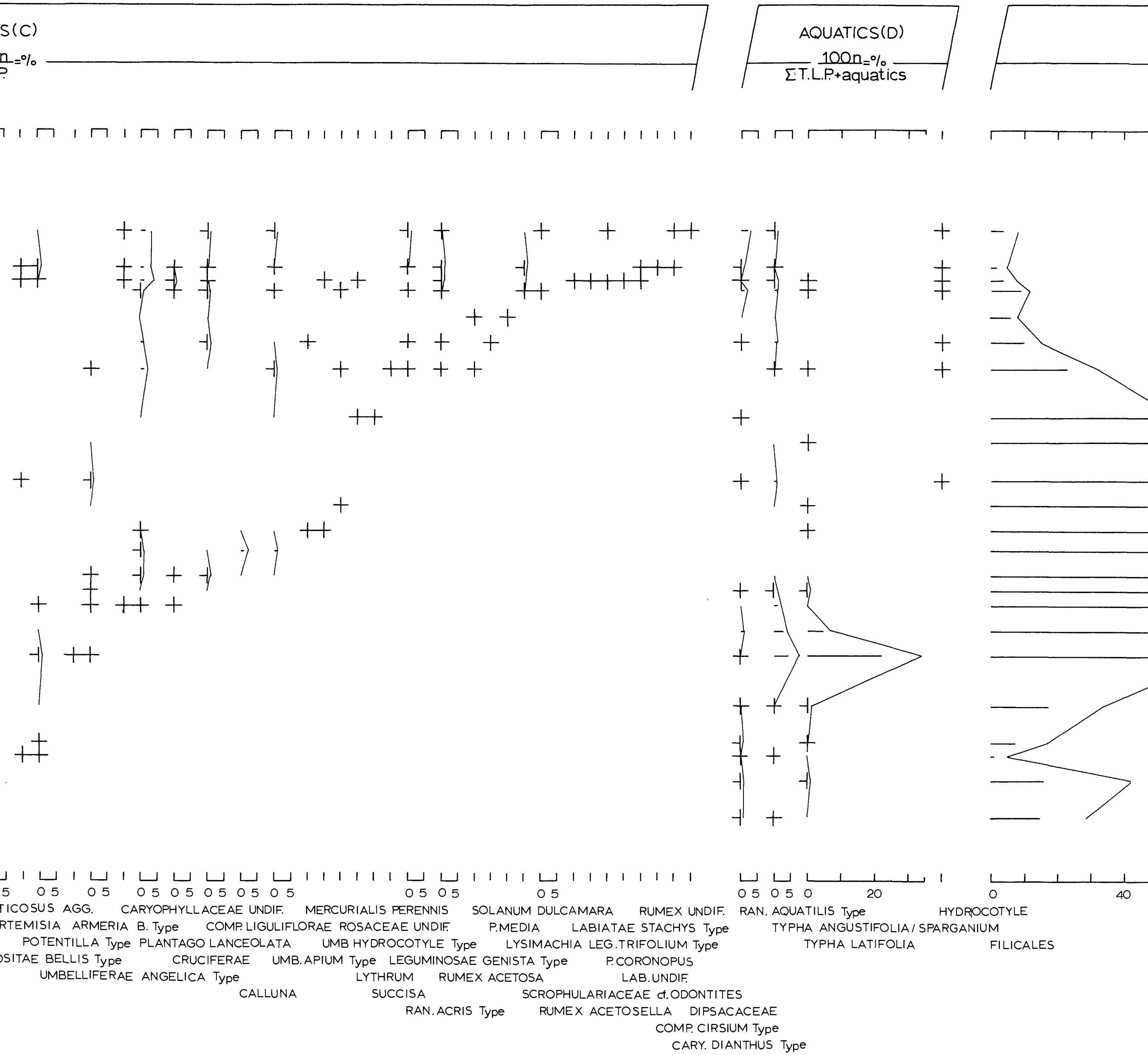
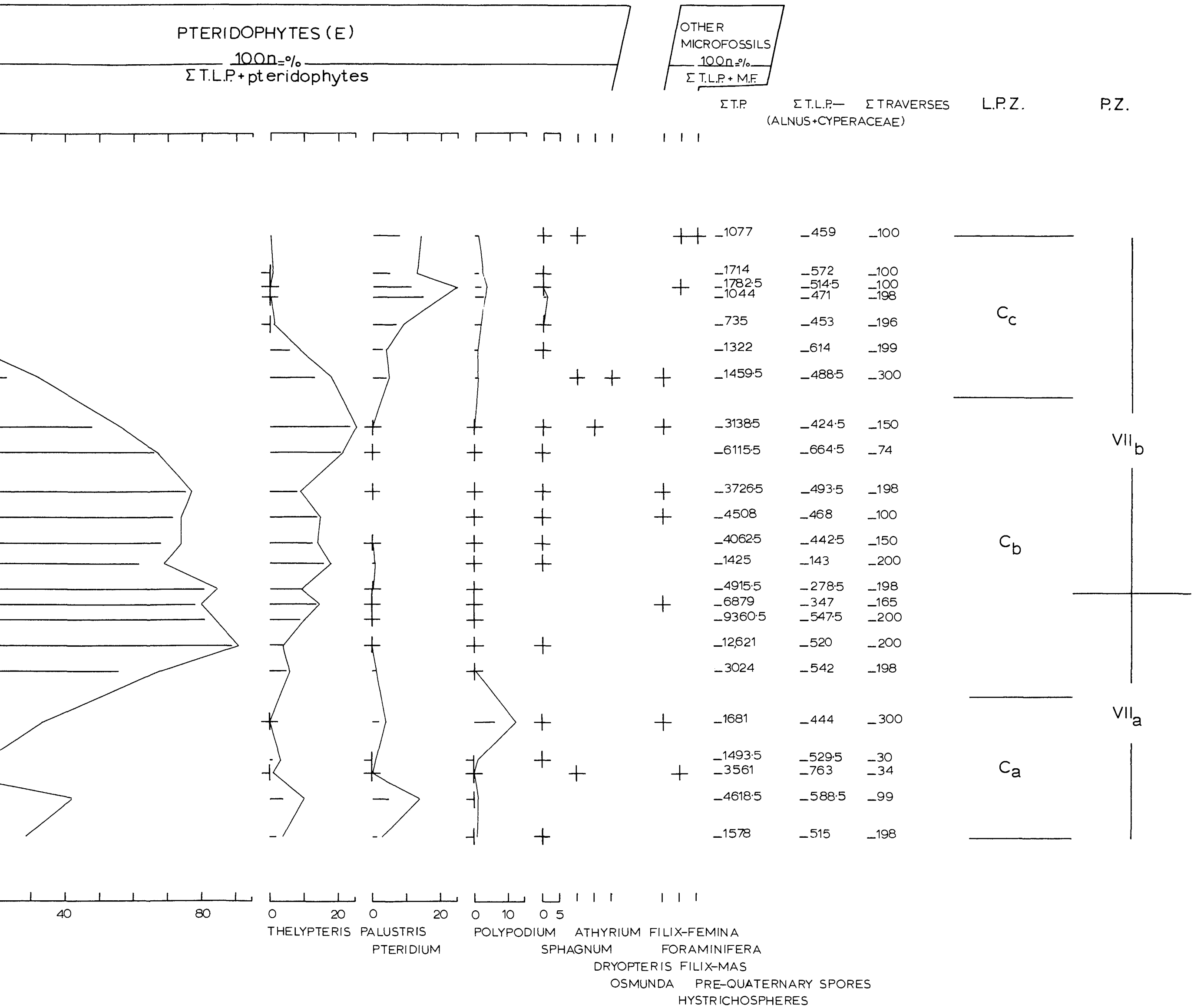


FIGURE 12. Pollen diagram from Crossness, S.B.I.

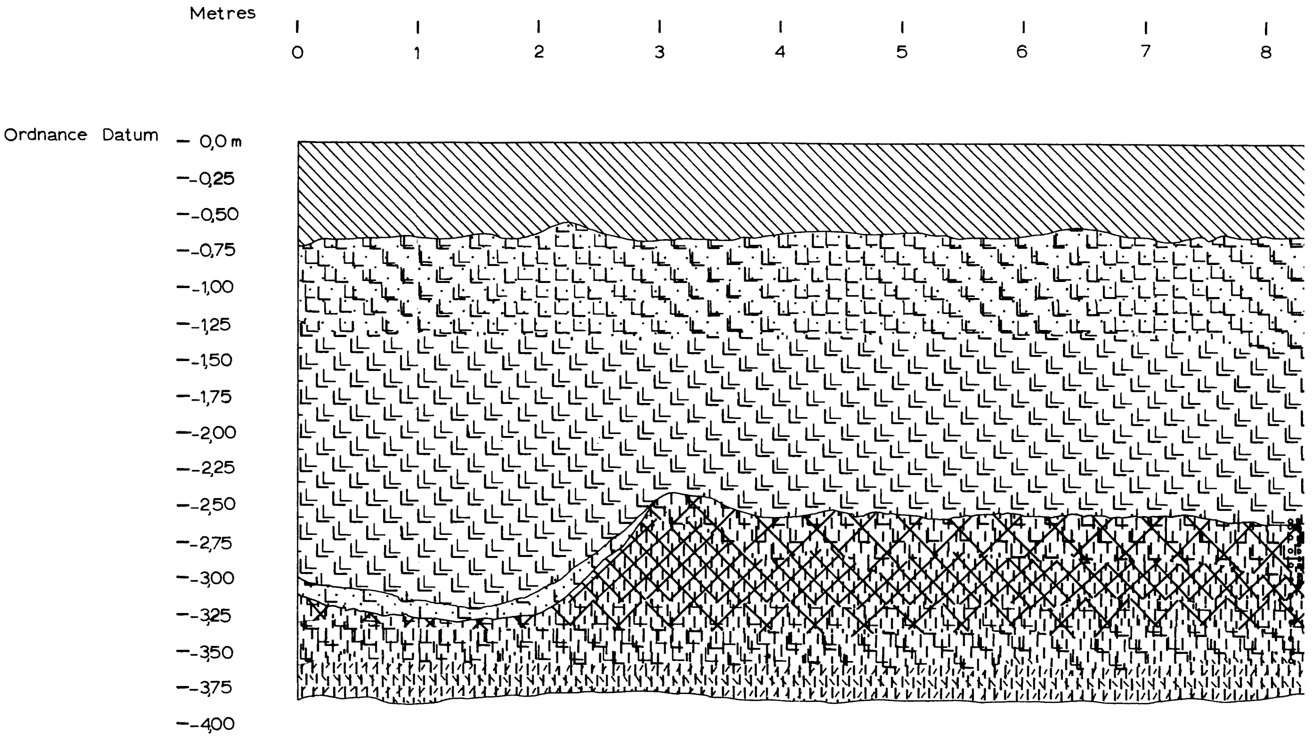


S(C)
AQUATICS(D)
100n =%
ΣT.L.P.+aquatics
0 5 0 5 0 5 0 5 0 5 0 5 0 5 0 5 0 5 0 5 0 5
0 5 0 5 0 20 0 40
TICOSUS AGG. CARYOPHYLLACEAE UNDIF. MERCURIALIS PERENNIS SOLANUM DULCAMARA RUMEX UNDIF.
RTEMISIA ARMERIA B. Type COMP. LIGULIFLORAE ROSACEAE UNDIF. P. MEDIA LABIATAE STACHYS Type
POTENTILLA Type PLANTAGO LANCEOLATA UMB HYDROCOTYLE Type LYSIMACHIA LEG. TRIFOLIUM Type
OSITAE BELLIS Type CRUCIFERAE UMB. APIUM Type LEGUMINOSAE GENISTA Type P. CORONOPUS
UMBELLIFERAE ANGELICA Type LYTHRUM RUMEX ACETOSA LAB. UNDIF.
CALLUNA SUCCISA SCROPHULARIACEAE cf. ODONTITES
RAN. ACRIS Type RUMEX ACETOSELLA DIPSACACEAE
COMP. CIRSIUM Type
CARY. DIANTHUS Type
RAN. AQUATILIS Type HYDROCOTYLE
TYPHA ANGUSTIFOLIA / SPARGANIUM
TYPHA LATIFOLIA FILICALES

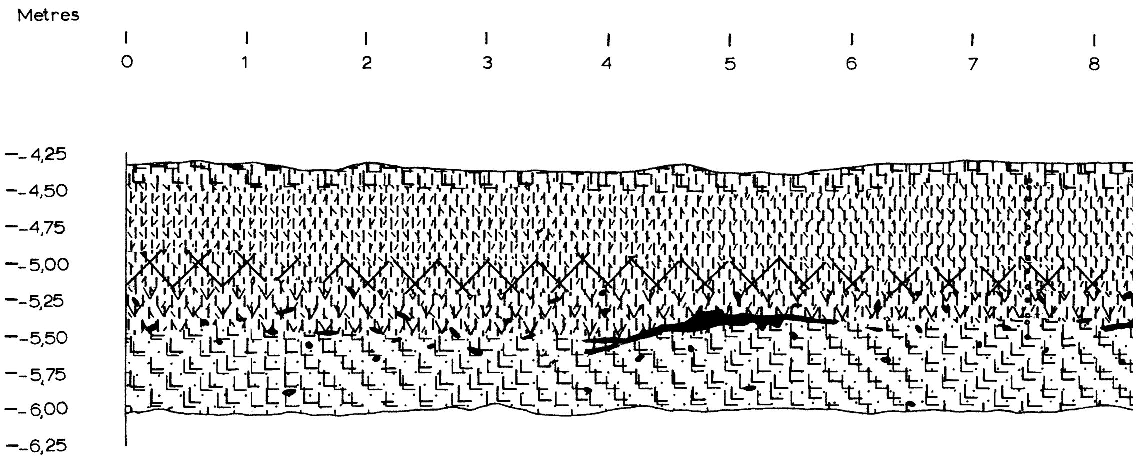

PTERIDOPHYTES (E)
100n=%
Σ T.L.P.+pteridophytes
OTHER MICROFOSSILS
100n=%
Σ T.L.P.+M.F.
Σ T.P.
Σ T.L.P.— (ALNUS+CYPERACEAE)
Σ TRAVERSES
L.P.Z.
P.Z.
1077 459 100
1714 572 100
1782·5 514·5 100
1044 471 198
735 453 196
1322 614 199
1459·5 488·5 300
3138·5 424·5 150
6115·5 664·5 74
3726·5 493·5 198
4508 468 100
4062·5 442·5 150
1425 143 200
4915·5 278·5 198
6879 347 165
9360·5 547·5 200
12,621 520 200
3024 542 198
1681 444 300
1493·5 529·5 30
3561 763 34
4618·5 588·5 99
1578 515 198
C_c
C_b
C_a
VII_b
VII_a
40
80
0 20
0 20
0 10
0 5
THELYPTERIS PALUSTRIS
PTERIDIUM
POLYPODIUM
SPHAGNUM
ATHYRIUM FILIX-FEMINA
FORAMINIFERA
DRYOPTERIS FILIX-MAS
OSMUNDA
PRE-QUATERNARY SPORES
HYSTRICHOSPHERES

(*Facing p.* 374)

FACE 1



FACE 2



Fieldwork 740521–740530

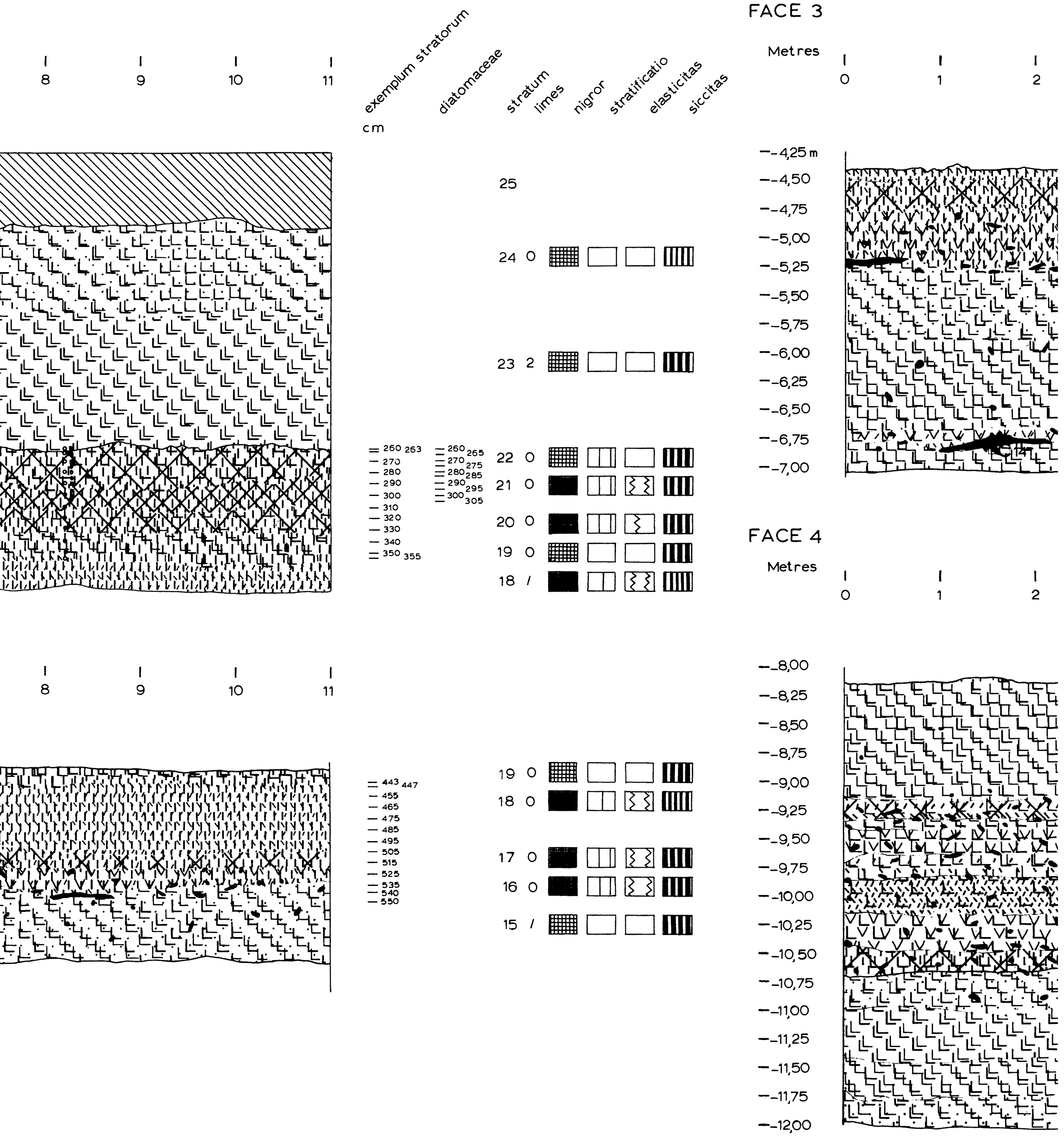
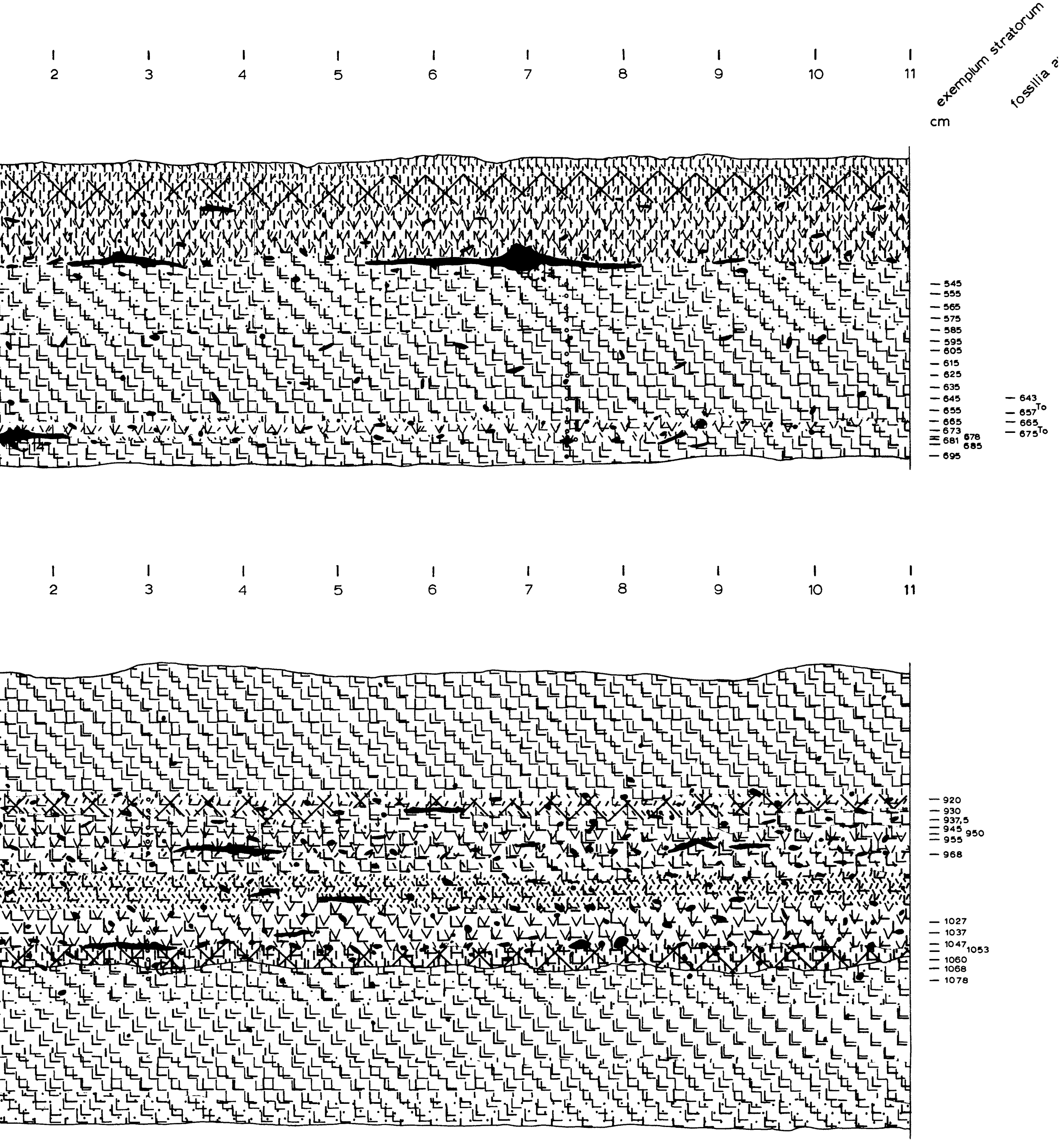
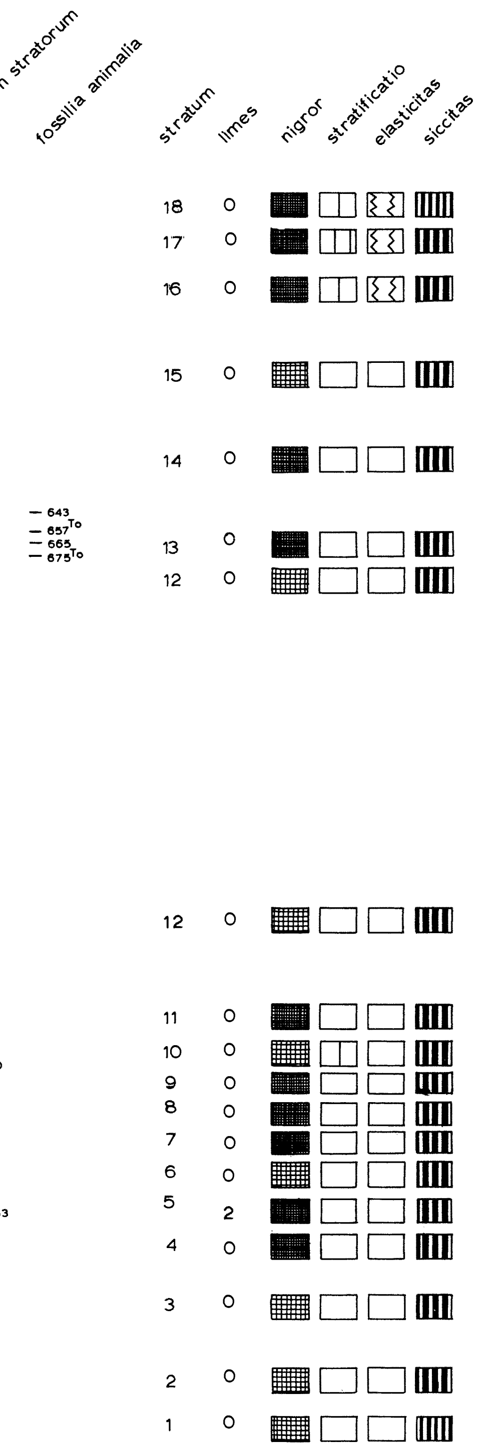


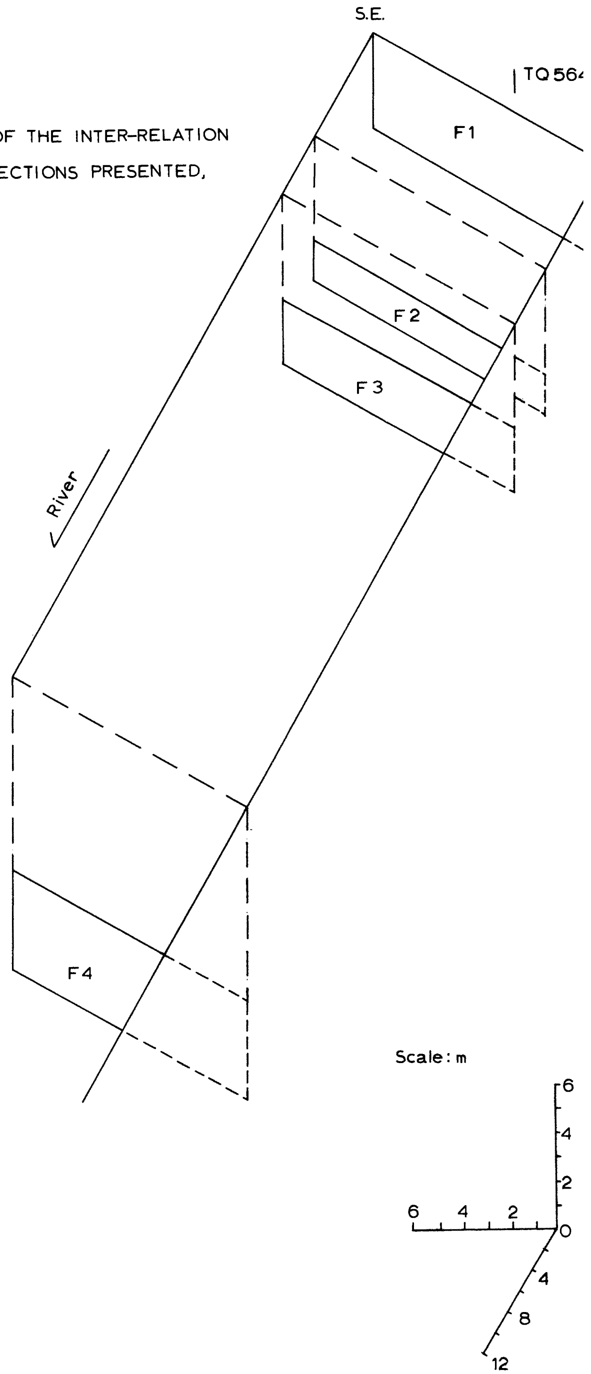
FIGURE 15. Sections from the New Dartford Tunnel, constructed fro[m]
of component elements and terminology have be[en]



ucted from exposures observed during 1974. Sediment symbols, the proportion
y have been used in accordance with Troels-Smith (1955).



SCALE DRAWING OF THE INTER-RELATION OF THE TUNNEL SECTIONS PRESENTED, FACES 1–4




TQ 56407572
N.W.
6
4
2
0
2
4
8
12

graphic position and radiometric age. The layer lies on average at −0.5 m O.D., reaching a maximum surface depth of −2.6 m O.D. (figure 14). In composition it forms a grey-brown silty monocot peat, with *Phragmites* and Cyperaceae stems and leaves occurring *in situ*. (fig. 15, face 1). Inland the inorganic fraction decreases, with a strong muddy gyttja element apparent. Examination of the Dartford Tunnel sections showed a channel cut through this layer (figure 15). This demonstrates the occurrence in the biogenic deposits of characteristic intertidal mudflat or saltmarsh creeks (see § 4).

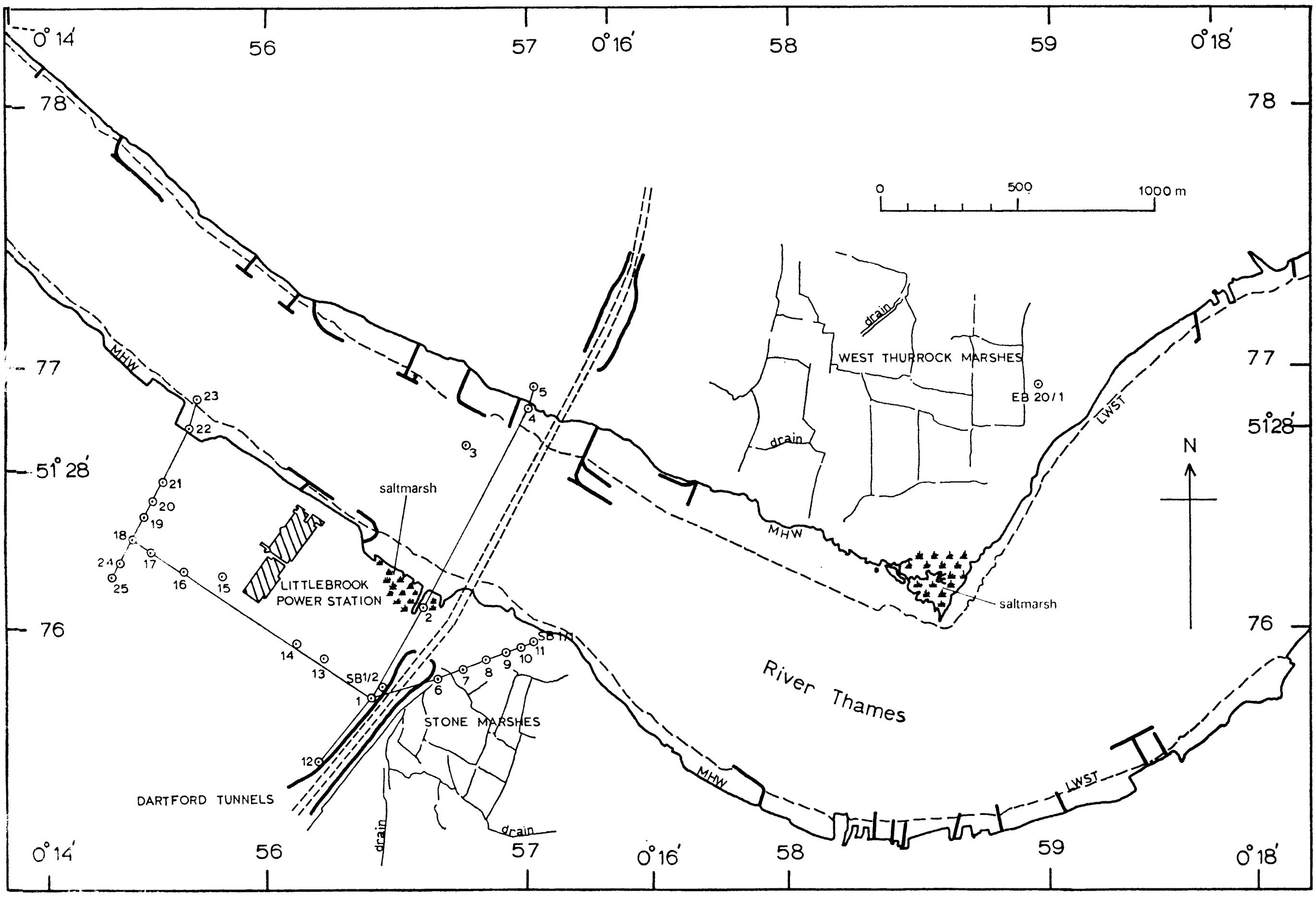


FIGURE 13. Site map of West Thurrock and Stone Marshes, showing borehole locations (⊙).

The main and most persistent peat bed, Tilbury III, forms a deposit 2–2.5 m thick upon average, occurring between the limits of −1 to −6 m O.D. Between boreholes 14–16 the two peats, Tilbury III and IV appear to merge. In West Thurrock Marshes the deposit is conformable in height and was found between −1.14 to −5.14 m O.D. in borehole 5. In composition the stratum forms a medium to dark red-brown crumbly monocot peat and wood material was common. At the base, wood peat was found and branches, twigs, bark and fruits of *Alnus*, *Quercus*, *Corylus* and *Pinus* were identified. In the upper levels the wood element was replaced by gyttja and monocot fractions. Bedded leaves and stems of *Phragmites* and Cyperaceae were common. In the tunnel excavations (figure 15, face 3) a separate and *in situ* alder wood peat occurred between −6.65 to −6.8 m O.D. This could not be conclusively traced in the surrounding boreholes. A radiocarbon assay at -6.85 m O.D. showed that the deposit was 5693 ± 80 B.P. old and occurred before the growth of Tilbury III here. A third widespread biogenic layer, Tilbury II, formed by a 20–50 cm thick alder wood peat, occurs at *ca.* -8.5 m O.D. and develops generally upon a sandy clay/silt. In the tunnel (figure 15, face 4) a series of thin *in situ* alder and oak wood peats form between -9.2 to -10.64 m O.D. These are interleaved by clay/silts full of *Quercus*, *Alnus* and *Corylus* wood.

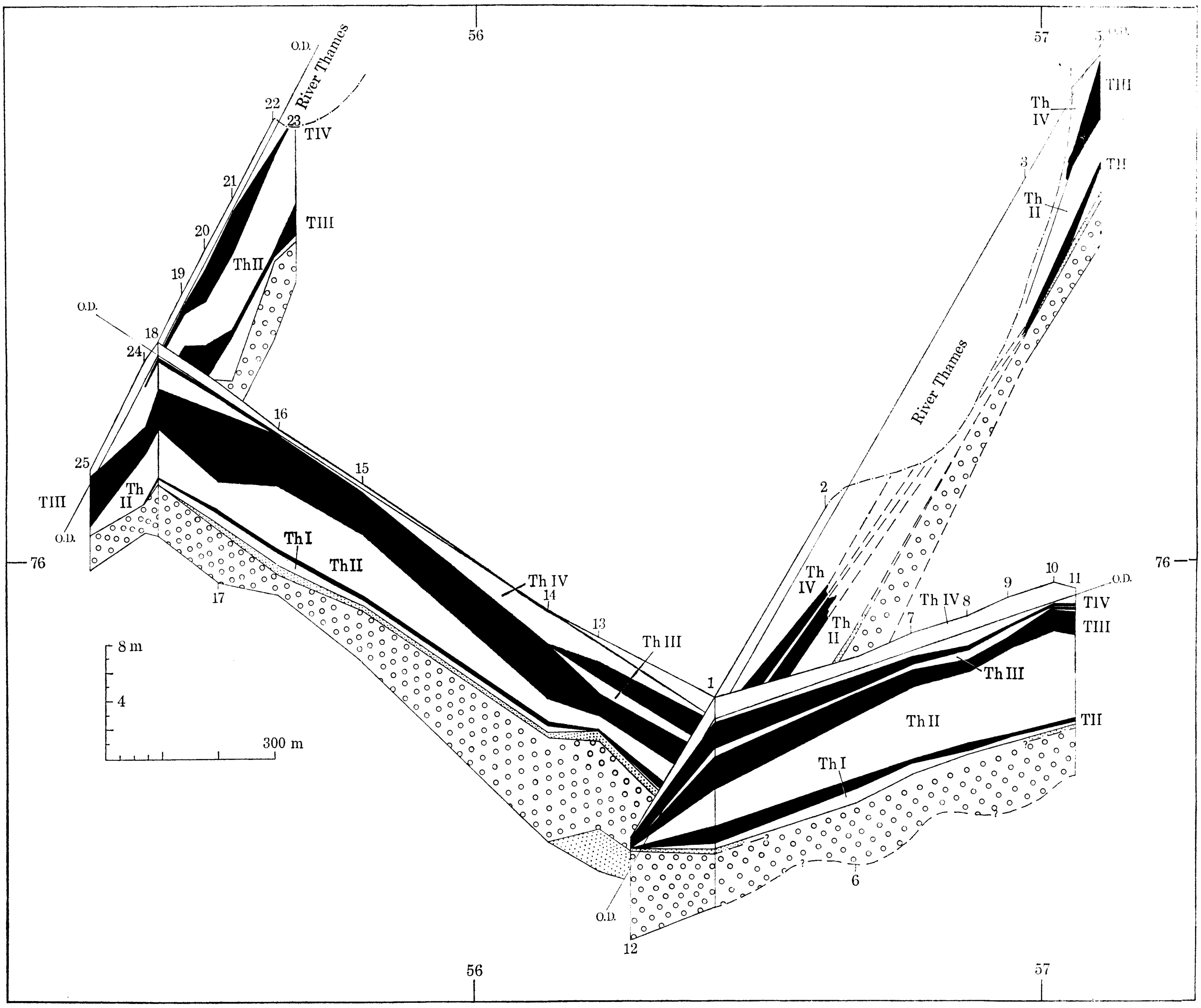


FIGURE 14. Three dimensional section from the Littlebrook/Stone Marsh area, constructed from open sections and borehole data, supplied by the C.E.G.B. and the author.

Th IV above Tilbury IV is composed in its upper levels of an iron stained, medium grey-brown, mottled, silt/clay. Below -0.5 m O.D. the layer became a blue-grey, clay/silt. Thames III is composed of a similar homogeneous and cohesive clay/silt and contains *in situ* *Phragmites* and Cyperaceae stems and leaves. Thames II is more extensive, with bands of silt 10–12 cm thick, often found alternating with a blue-grey, silt/clay. Thames I lies beneath the basal peat here, Tilbury II, and is represented by a dark grey sandy clay/silt. approximately 50 cm thick.

(*b*) *Pollen analysis*

The stratigraphy of the sample borehole SB1/1 conforms with the area's general sedimentary sequence and the deposits show a changing hydrological balance, with inwashing of material by the river (figure 16) (see § 2*c*). Pollen samples were taken at intervals generally not exceeding 10 cm. Between 241 and 350 cm the frequency of corroded and degraded grains increased, necessitating the abandonment of some levels. Five local pollen assemblage zones have been recognized (figure 16).

l.p.z. height from surface (cm)	description
SMe 121–240	Non-arboreal pollen expands sharply with herbs $> 50\,\%\ \Sigma$ t.p. at all levels and becoming rich in taxa. *Plantago lanceolata* forms a continuous curve with Chenopodiaceae, *Artemisia*, Umbelliferae *Apium* type and Compositae *Bellis* type. There is an appearance of cereal type pollen. *Alnus* and *Tilia* values fall with *Quercus* and *Corylus* type pollen forming the main tree taxa. *Betula* and *Pinus* expand. *Acer* and *Fagus* appear sporadically, *Pteridium aquilinum* values expand sharply to $> 20\,\%\ \Sigma$ (t.l.p. + pteridophytes).
SMd 240–275	Non aboreal pollen and spore frequencies fall, particularly Cyperaceae, with a sharp fall of Filicales, though they remain important. Expansion of arboreal pollen, mainly *Quercus*, *Corylus* type, *Alnus* and *Tilia*. Gramineae values remain between 15–20 % Σ t.l.p. before declining at the top of the zone. *Alnus* values rise here. Herb species poor.
SMc 275–355	*Alnus* and Cyperaceae sporadic but rise to high values, 95 and 65 % Σ t.l.p. respectively. *Alnus* declines at top of zone. Gramineae values also rise but are generally $< 20\,\%\ \Sigma$ t.l.p. Filicales spore values rise sharply to $> 50\,\%\ \Sigma$ (t.l.p. + pteridophytes). *Ulmus* and *Pinus* become low and sporadic $< 2\,\%\ \Sigma$ t.l.p.
SMb 355–515	Arboreal pollen values fall but remain dominant at 50 % Σ t.l.p. on all levels. *Alnus* declines to generally $< 15\,\%\ \Sigma$ t.l.p. *Quercus*, *Alnus*, *Corylus* type and *Pinus* with *Ulmus* are the main tree taxa. Gramineae and Cyperaceae values have risen but are $< 10\,\%\ \Sigma$ t.l.p. Herbs still poor in taxa. Chenopodiaceae pollen $> 5\,\%\ \Sigma$ t.l.p. throughout. Spores occur at consistently high values. Filicales approximately 10 % Σ (t.l.p. + pteridophytes).
SMa 870–960	*Alnus*, *Quercus*, *Corylus* type and *Ulmus* are the main taxa. Dominance of a.p. $> 75\,\%\ \Sigma$ t.l.p. Little consistent change, high values throughout, though *Quercus* does rise to $> 19\,\%\ \Sigma$ t.l.p. at 910–930 cm. Herb values are low, Chenopodiaceae and Gramineae rise at top of zone. Filicales spores expand between 910 and 930 cm to $> 10\,\%\ \Sigma$ (t.l.p. + pteridophytes).

(i) *Local pollen assemblage zone SMa* (Alnus, Quercus, Corylus *type and* Ulmus)

In situ growth of *Alnus* at 910–930 cm with remains of branches, twigs and fruits of *Alnus glutinosa*, *Quercus* and *Corylus*, show the local nature of this deposit. High values of *Alnus* pollen, often exceeding 50% Σ t.l.p., suggests the initial formation of an alder carr. Between 910–930 cm, the expansion of *Quercus*, *Tilia* and *Salix* pollen values may represent the development of drier conditions locally, forming oak-alder dominated fen woods. Filicales spores, probably *Thelypteris palustris*, are abundant together with shade tolerant herb and shrub pollen taxa, such as *Caltha* type, *Humulus lupulus*, *Filipendula*, *Hedera* and *Viburnum opulus*. Expansion of Gramineae and Chenopodiaceae pollen values (to approximately 5% Σ t.l.p.) with Compositae *Bellis* type, may show the existence of nearby saltmarsh communities.

(ii) *Local pollen assemblage zones SMb SMc and SMd* (*Gramineae, Cyperaceae,* Alnus *and Filicales*)

The clay/silt representing l.p.z. SMb shows a pollen assemblage similar to that in l.p.z. SMa. The a.p. assemblage may represent a more regional pollen rain and is in keeping with the characterization of p.z. VII as forming 'mixed oak forest'. Identification of a separate l.p.z. during this phase is based upon the rising frequencies of herbaceous pollen to 23% Σ t.l.p. Values of Gramineae and Chenopodiaceae pollen expand to a maximum at the top of this zone, accompanied by a rise of Cyperaceae pollen with continuous curves for *Artemisia* and Compositae *Bellis* type pollen. Such development suggests local saltmarsh communities giving way to freshwater fen with the Gramineae expansion.

L.p.z. SMc shows a hydroseral change to alder carr. The replacement of *Alnus* by *Quercus*, *Corylus* type and *Tilia* as the dominant tree pollen, suggests development in SMd to an oak-hazel fen wood. This is supported by the crumbly and woody composition of the peat, Filicales values reaching their maximum here of 85% Σ (t.l.p. + pteridophytes) (Godwin 1943). The corroded and degraded state of the pollen indicates periods of oxidation due to dessication under a fluctuating water table.

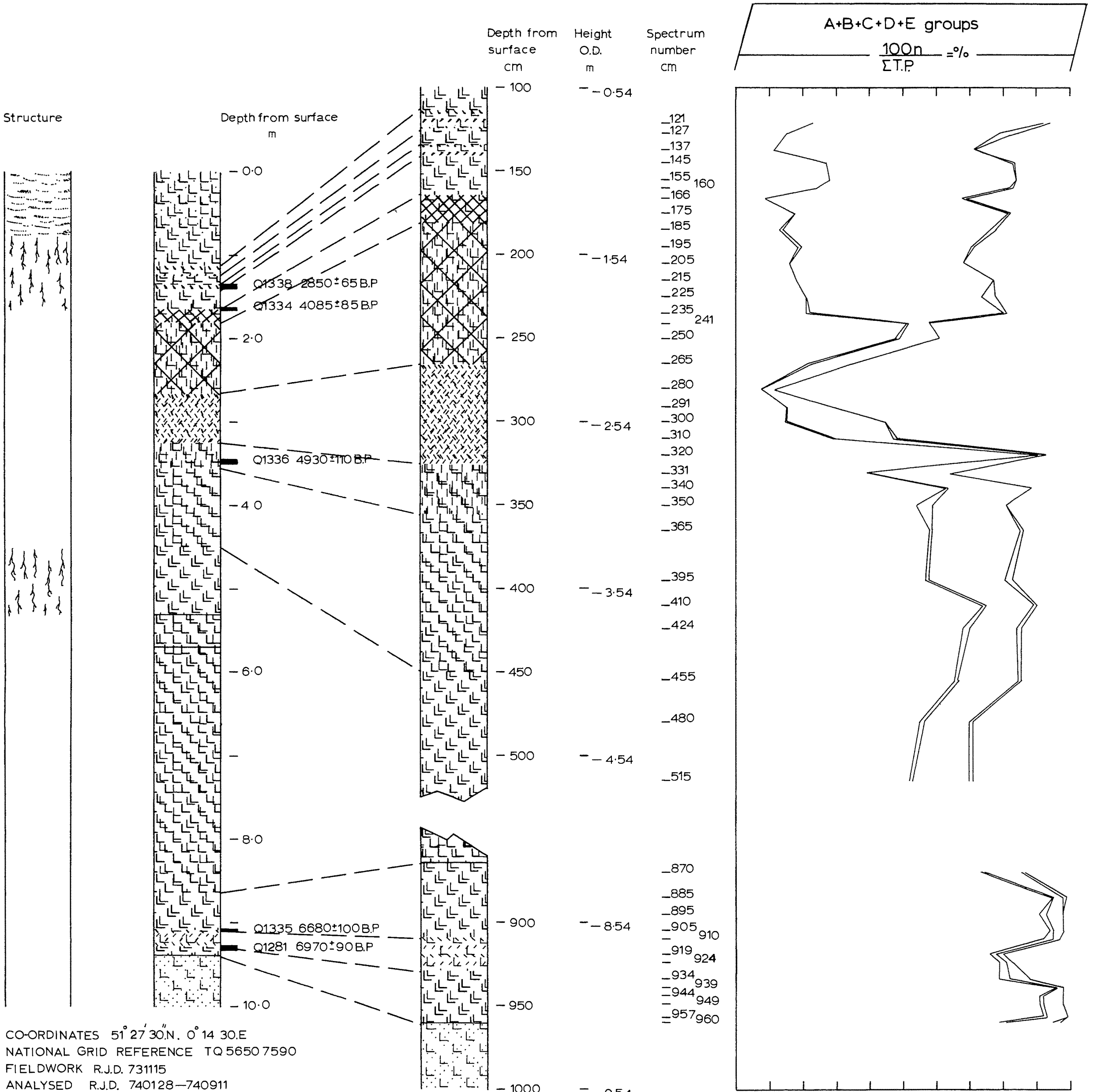
(iii) *Local pollen assemblage zone SMe-expansion of herbs* (*Gramineae, Cyperaceae and Chenopodiaceae*)

The *in situ* growth of *Phragmites* with high Gramineae reaching 40% Σ t.l.p., Cyperaceae and Chenopodiaceae pollen, indicates a change to fen/reedswamp locally. *Juncus geradii* and *Juncus maritimus* seeds were common, showing possible growth close to the mark of m.h.w.s.t. Non-arboreal pollen dominates Σ t.p. with herbs becoming taxa rich, particularly with ruderal pollen species associated with man's influence.

Tilia pollen frequencies again suggest that lime may have been an important forest component, values reaching 8% Σ t.l.p. Locally it is likely that the sedge fen remained unaffected by man. The high Gramineae pollen values may probably be accounted for by the *in situ* growth of *Phragmites australis*. Saltmarsh communities may have formed an important component of the local vegetation, especially during the formation of the silty peat at 113–124 cm. Here Chenopodiaceae values reach 15% Σ t.l.p. accompanied by Compositae *Bellis* type, *Plantago maritima*, *Artemisia* and *Armeria* type pollen.

(*c*) *Dating – the elm decline*

The pollen spectra place these deposits in p.z. VII, a dating confirmed by five radiocarbon dates for the core (see table 2). Sub-division to p.z. VII*a*/VII*b* is based upon the recognition

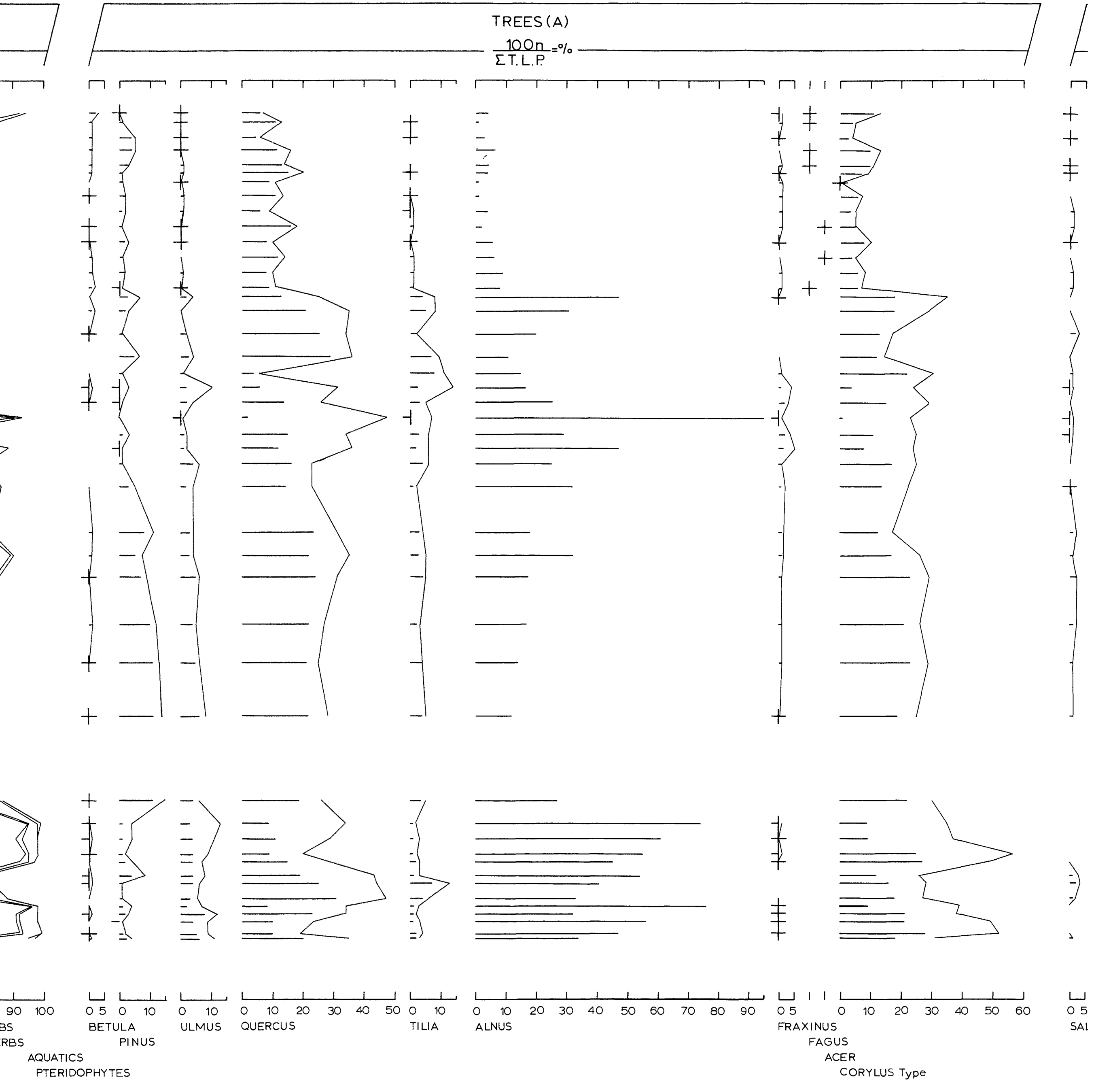


CO-ORDINATES 51° 27′ 30″N. 0° 14 30.E
NATIONAL GRID REFERENCE TQ 5650 7590
FIELDWORK R.J.D. 731115
ANALYSED R.J.D. 740128–740911

LEGEND

+ VALUES < 0·5% Σ T.L.P.

VALUES FOR Σ T.L.P. – (ALNUS + CYPERACEAE)



TREES (A)
100n / ΣT.L.P. = %
90 100
BS
RBS
AQUATICS
PTERIDOPHYTES
0 5
BETULA
0 10
PINUS
0 10
ULMUS
0 10 20 30 40 50
QUERCUS
0 10
TILIA
0 10 20 30 40 50 60 70 80 90
ALNUS
0 5
FRAXINUS
FAGUS
ACER
0 10 20 30 40 50 60
CORYLUS Type
0 5
SAL

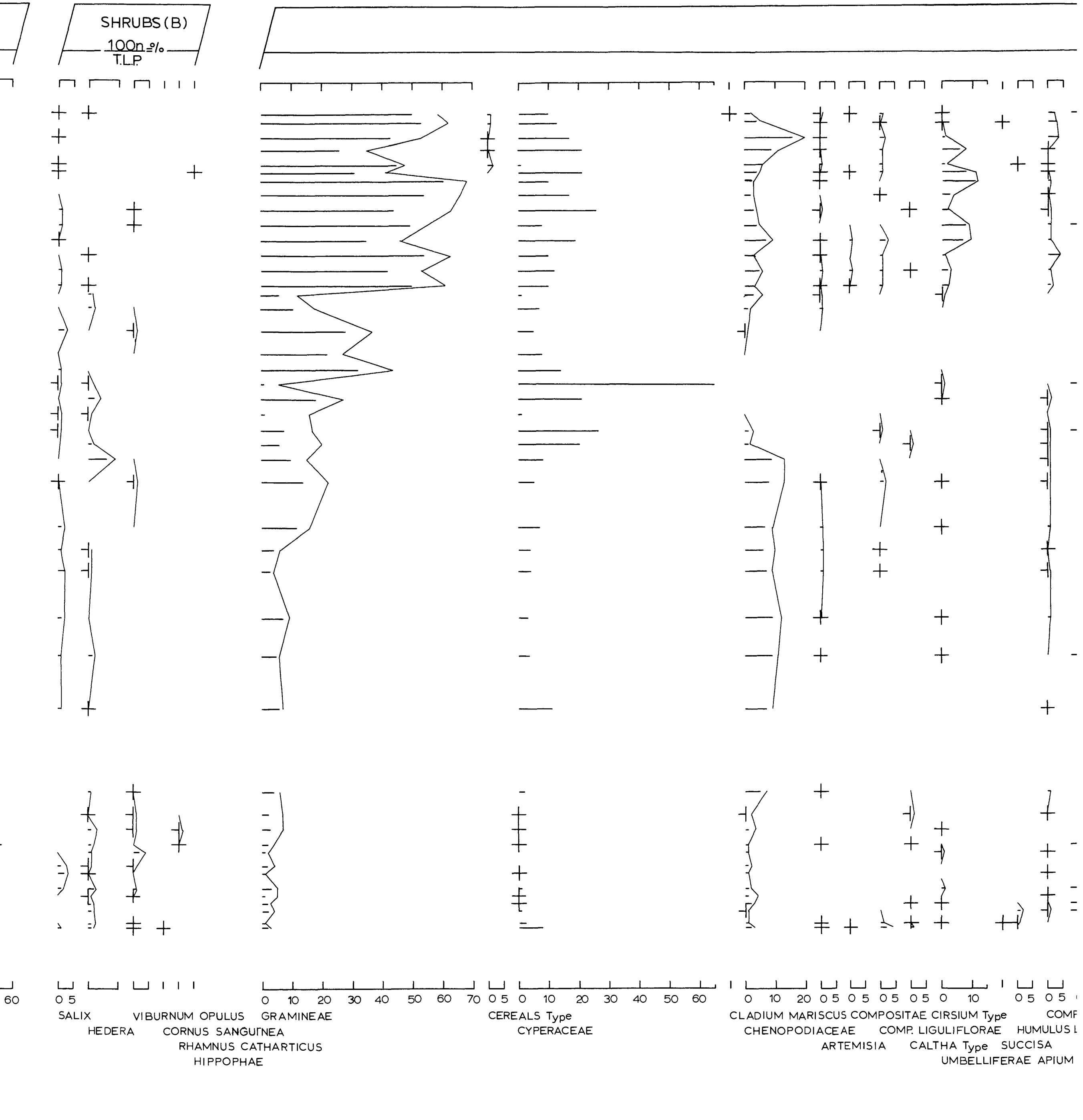
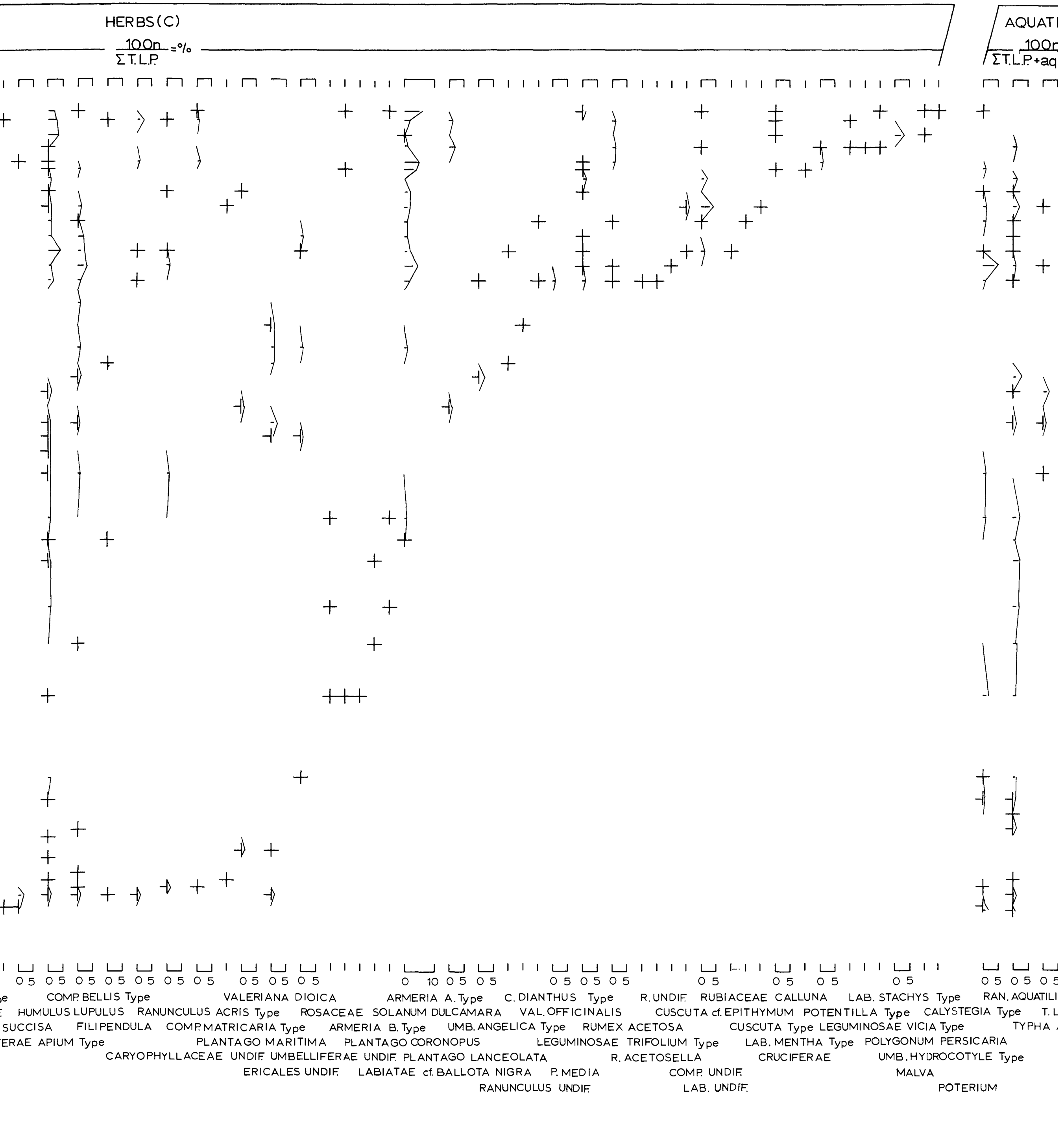
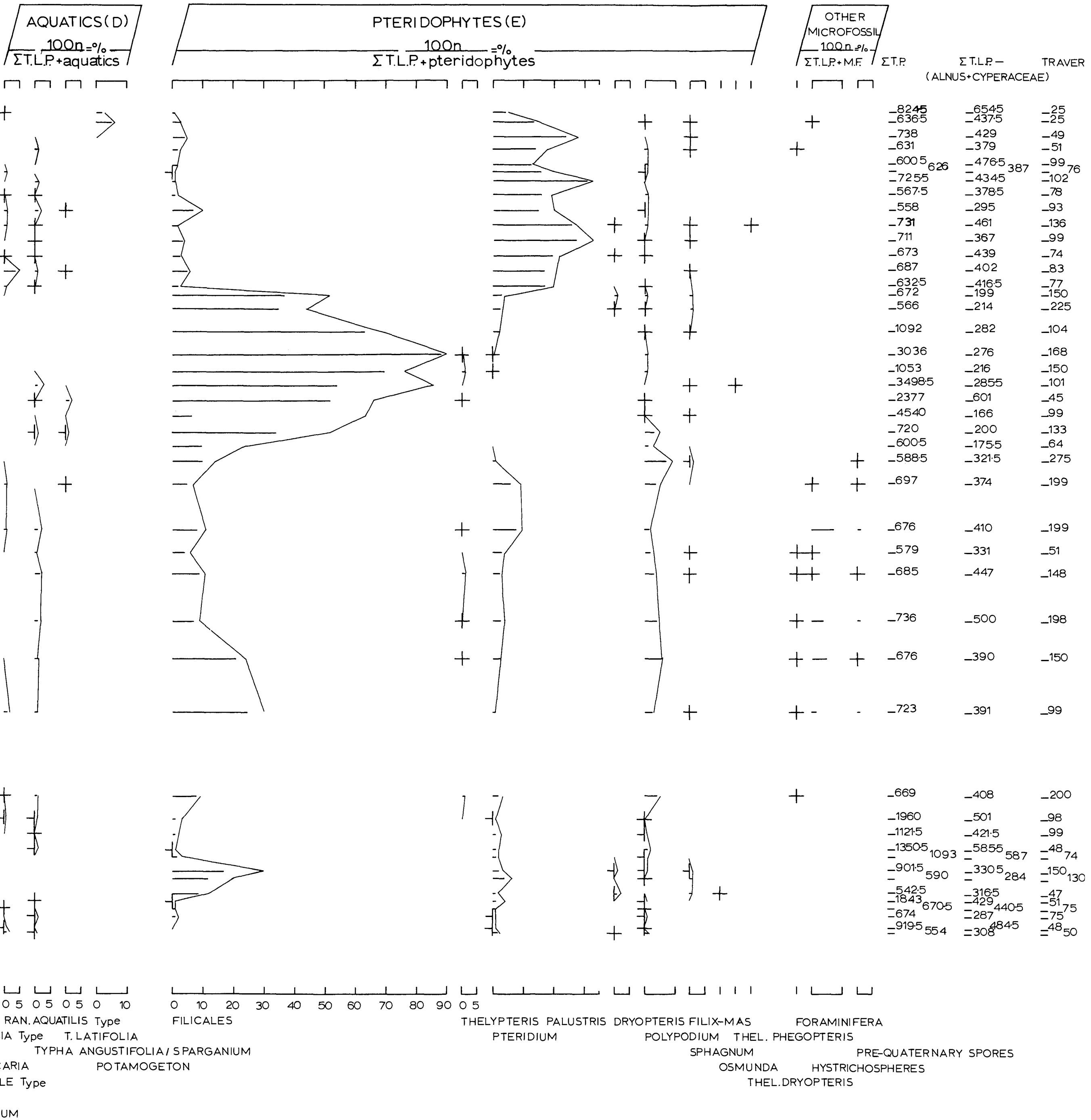
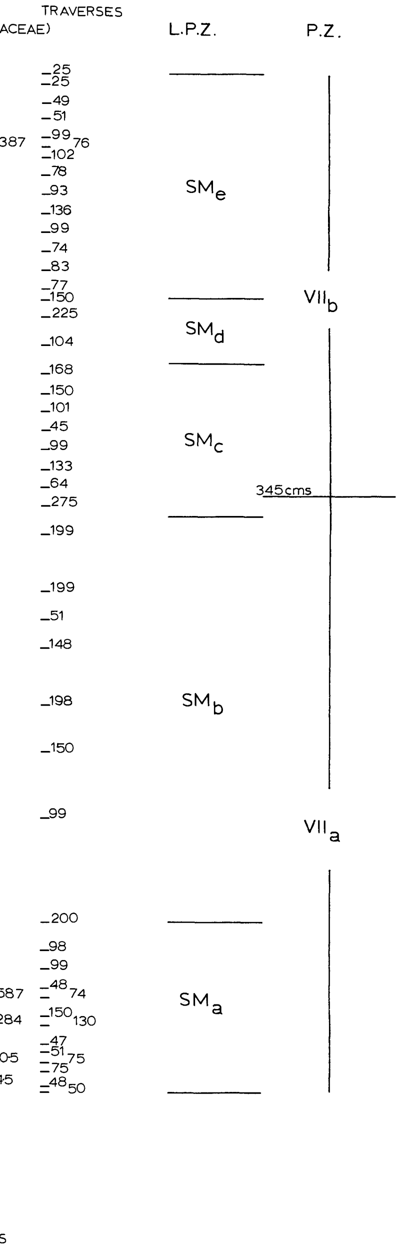


FIGURE 16. Pollen diagram from Stone Marsh, S.B.I.

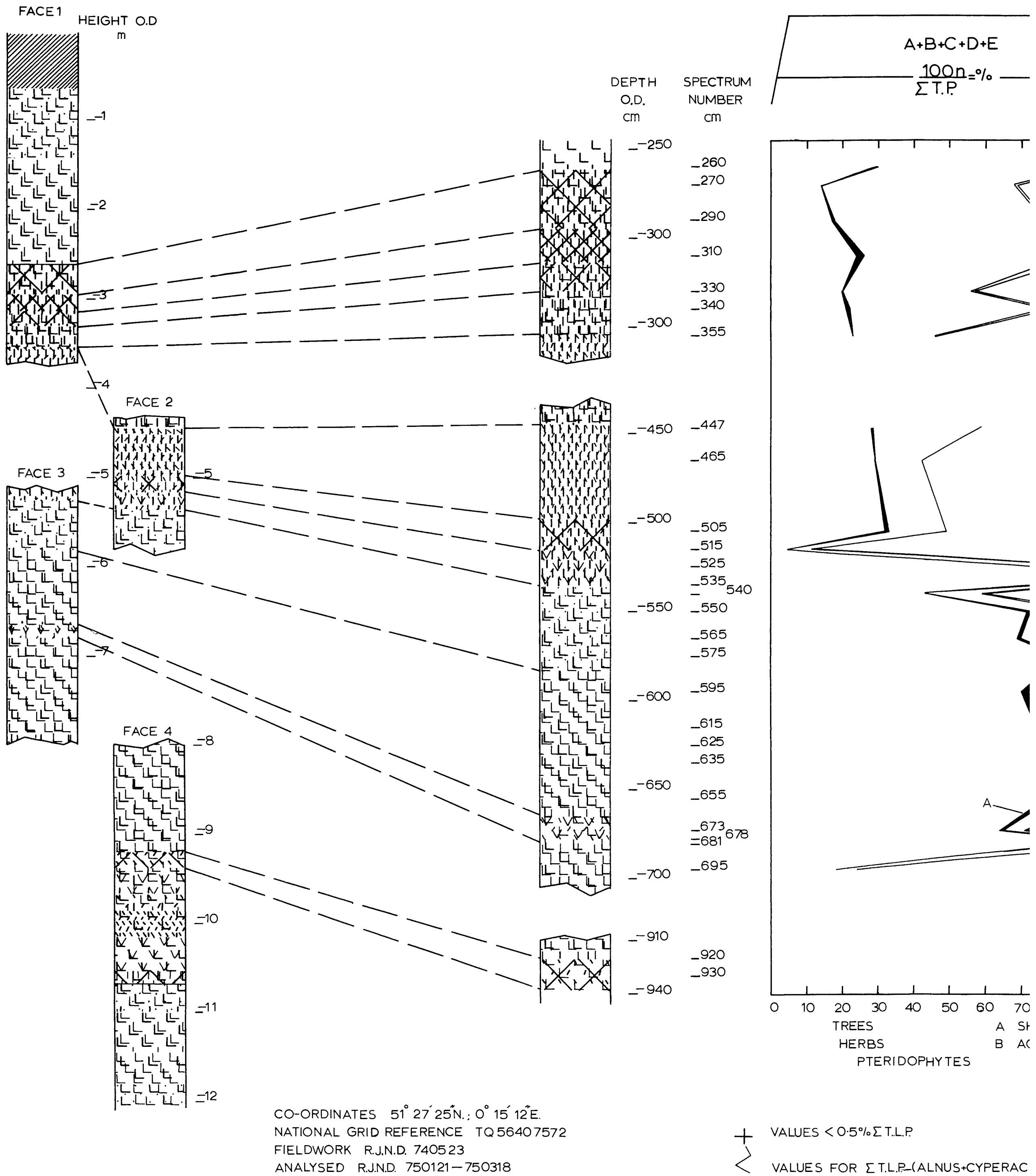


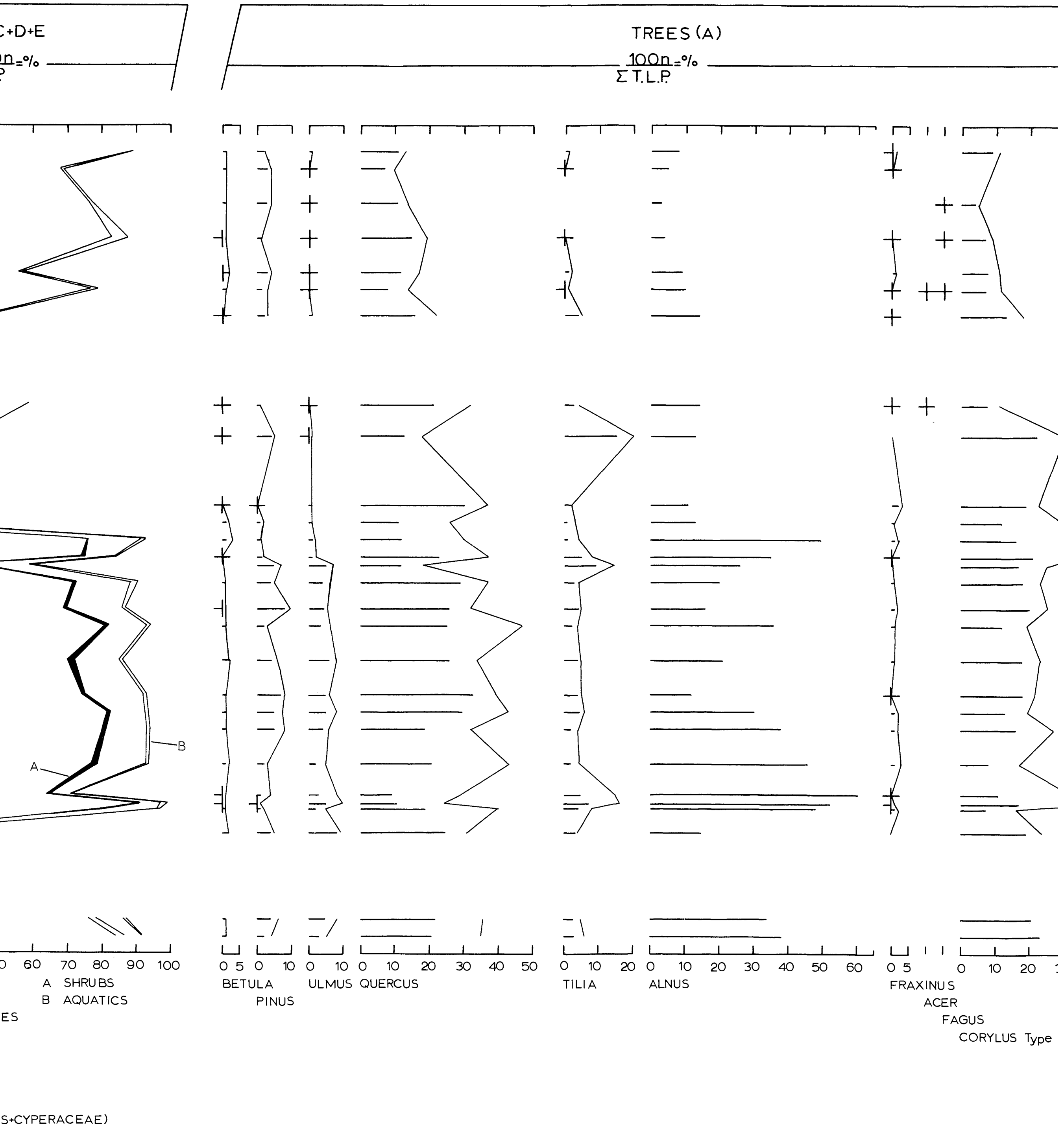
HERBS (C)
100n / ΣT.L.P. = %
AQUATI
ΣT.L.P.+aq
COMP. BELLIS Type
HUMULUS LUPULUS
SUCCISA
FILIPENDULA
APIUM Type
RANUNCULUS ACRIS Type
COMP. MATRICARIA Type
CARYOPHYLLACEAE UNDIF.
VALERIANA DIOICA
ROSACEAE
PLANTAGO MARITIMA
UMBELLIFERAE UNDIF.
ERICALES UNDIF.
ARMERIA B. Type
SOLANUM DULCAMARA
PLANTAGO CORONOPUS
LABIATAE cf. BALLOTA NIGRA
ARMERIA A. Type
UMB. ANGELICA Type
PLANTAGO LANCEOLATA
P. MEDIA
RANUNCULUS UNDIF.
C. DIANTHUS Type
VAL. OFFICINALIS
RUMEX ACETOSA
LEGUMINOSAE TRIFOLIUM Type
R. ACETOSELLA
R. UNDIF.
CUSCUTA cf. EPITHYMUM
CUSCUTA Type
COMP. UNDIF.
LAB. UNDIF.
RUBIACEAE
CALLUNA
POTENTILLA Type
LEGUMINOSAE VICIA Type
LAB. MENTHA Type
CRUCIFERAE
LAB. STACHYS Type
CALYSTEGIA Type
POLYGONUM PERSICARIA
UMB. HYDROCOTYLE Type
MALVA
POTERIUM
RAN. AQUATILI
TYPHA


AQUATICS (D)
100n / ΣT.L.P.+aquatics =%
PTERIDOPHYTES (E)
100n / ΣT.L.P.+pteridophytes =%
OTHER MICROFOSSIL
100n / ΣT.L.P.+M.F. =%
ΣT.P.
ΣT.L.P.− (ALNUS+CYPERACEAE)
TRAVER
0 5 0 5 0 5 0 10
0 10 20 30 40 50 60 70 80 90 0 5
RAN. AQUATILIS Type
IA Type
T. LATIFOLIA
TYPHA ANGUSTIFOLIA / SPARGANIUM
POTAMOGETON
ARIA
LE Type
UM
FILICALES
THELYPTERIS PALUSTRIS
PTERIDIUM
DRYOPTERIS FILIX-MAS
POLYPODIUM
SPHAGNUM
OSMUNDA
THEL. PHEGOPTERIS
THEL. DRYOPTERIS
FORAMINIFERA
HYSTRICHOSPHERES
PRE-QUATERNARY SPORES


TRAVERSES
ACEAE)
L.P.Z.
P.Z.
25
25
49
51
387
99
76
102
78
93
136
99
74
83
77
150
225
104
168
150
101
45
99
133
64
275
199
199
51
148
198
150
99
200
98
99
587
48
74
284
150
130
47
51
75
05
75
45
48
50
SMe
SMd
SMc
SMb
SMa
VIIb
VIIa
345cms
s

(*Facing p.* 378)


FACE 1
HEIGHT O.D
m
–1
–2
–3
–4
FACE 2
FACE 3
–5
–5
–6
–7
FACE 4
–8
–9
–10
–11
–12
DEPTH
O.D.
cm
SPECTRUM
NUMBER
cm
–250
–300
–300
–450
–500
–550
–600
–650
–700
–910
–940
260
270
290
310
330
340
355
447
465
505
515
525
535
540
550
565
575
595
615
625
635
655
673
678
681
695
920
930
A+B+C+D+E
100n/ΣT.P =%
A
0
10
20
30
40
50
60
70
TREES
HERBS
PTERIDOPHYTES
A SH
B AC
CO-ORDINATES 51° 27′ 25″N.; 0° 15′ 12″E.
NATIONAL GRID REFERENCE TQ 56407572
FIELDWORK R.J.N.D. 740523
ANALYSED R.J.N.D. 750121–750318
VALUES < 0·5% Σ T.L.P.
VALUES FOR Σ T.L.P.–(ALNUS+CYPERAC



C+D+E
n =%
P
TREES (A)
100n =%
Σ T.L.P.
A
B
0 60 70 80 90 100
A SHRUBS
B AQUATICS
ES
0 5 0 10 0 10 0 10 20 30 40 50
BETULA
PINUS
ULMUS QUERCUS
0 10 20
TILIA
0 10 20 30 40 50 60
ALNUS
0 5
FRAXINUS
ACER
FAGUS
0 10 20
CORYLUS Type
S+CYPERACEAE)

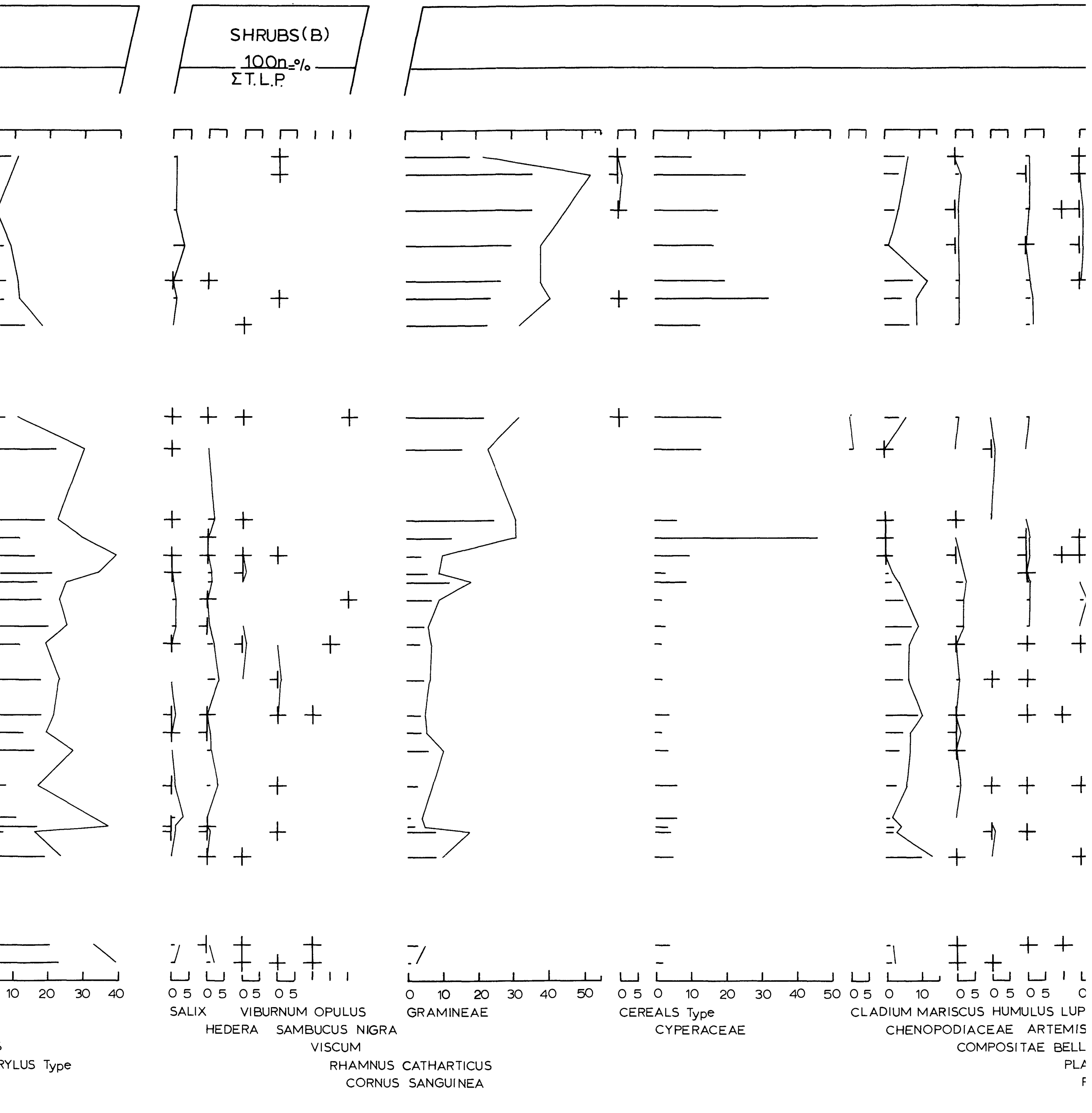
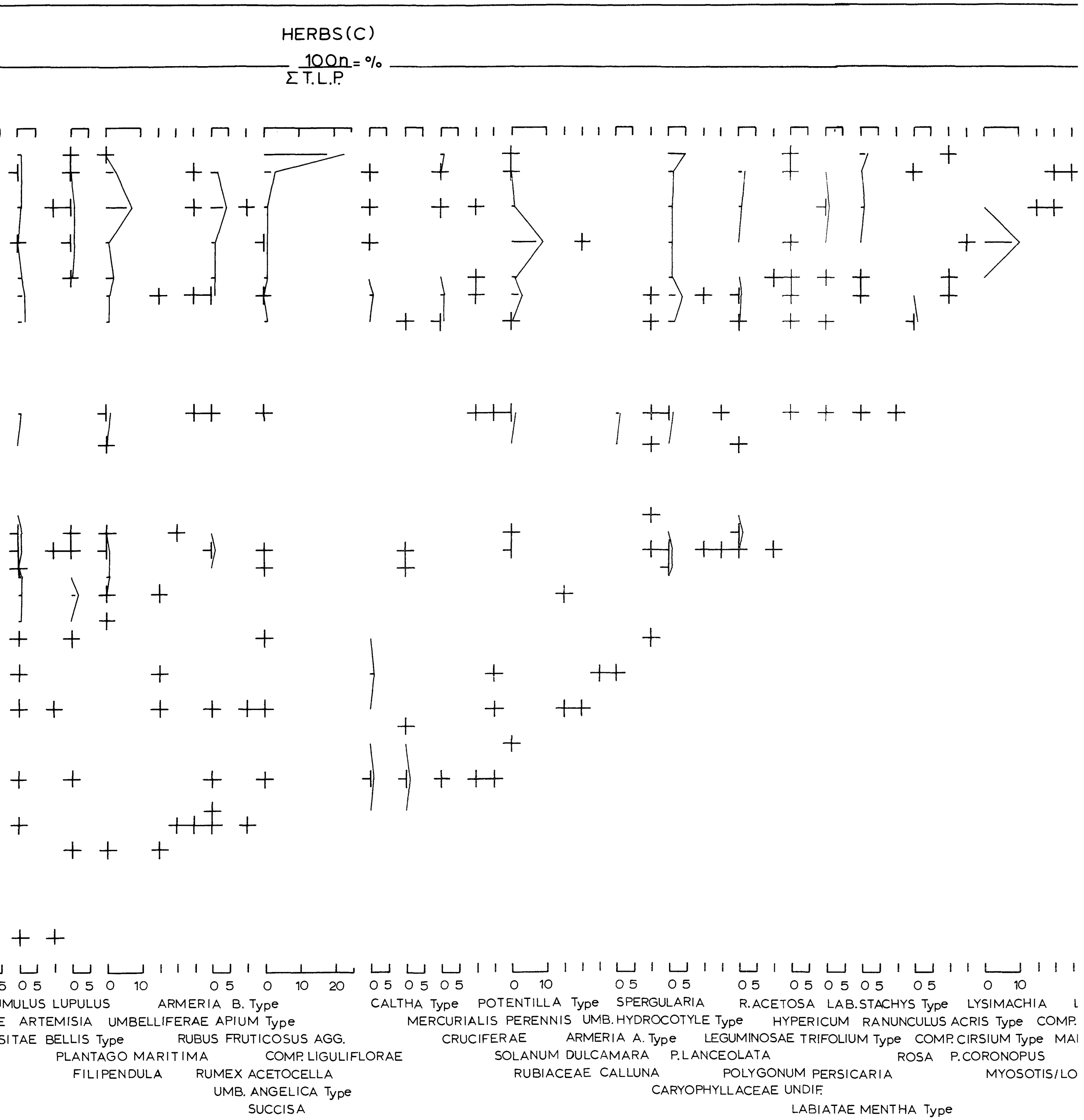
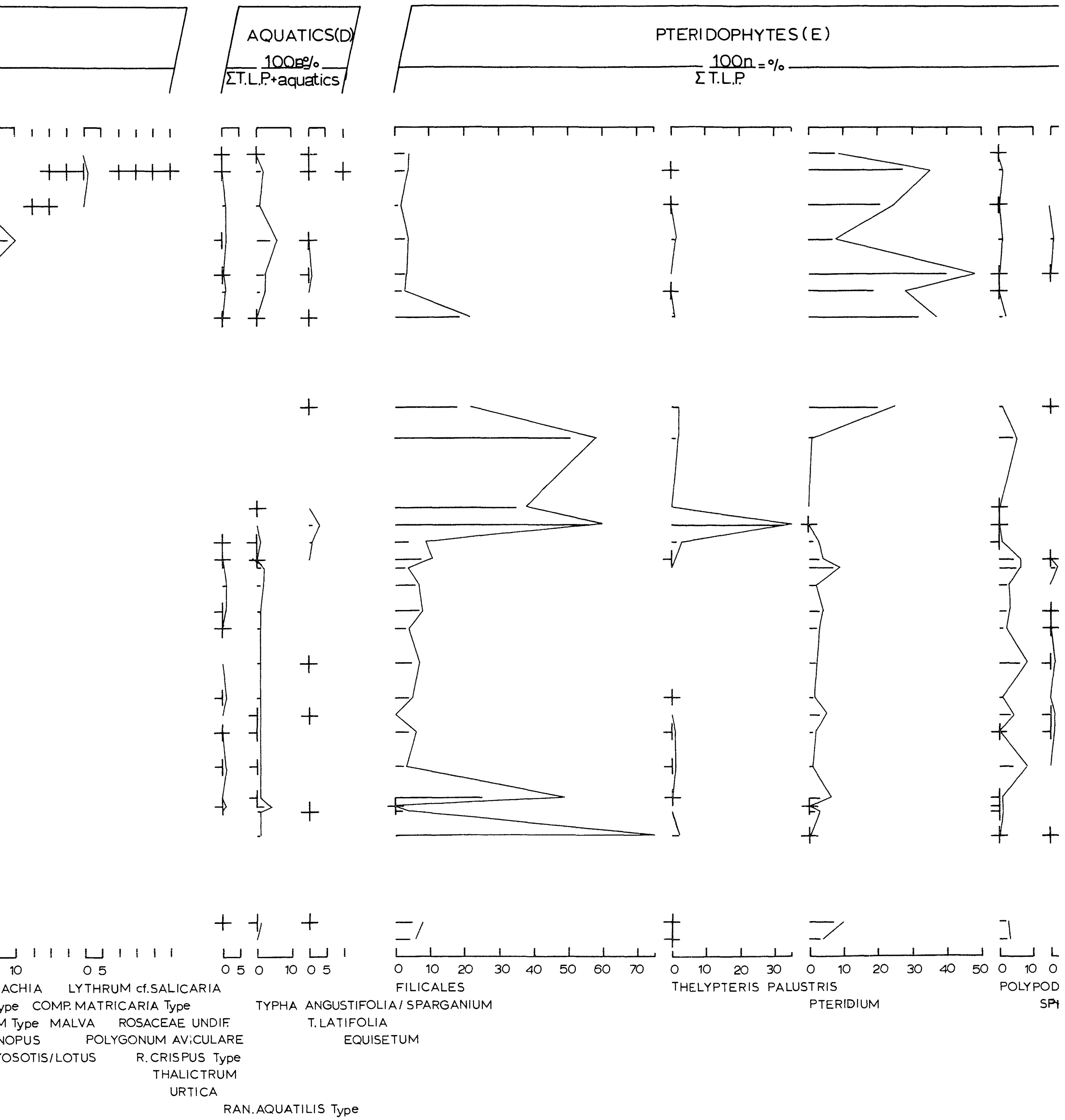


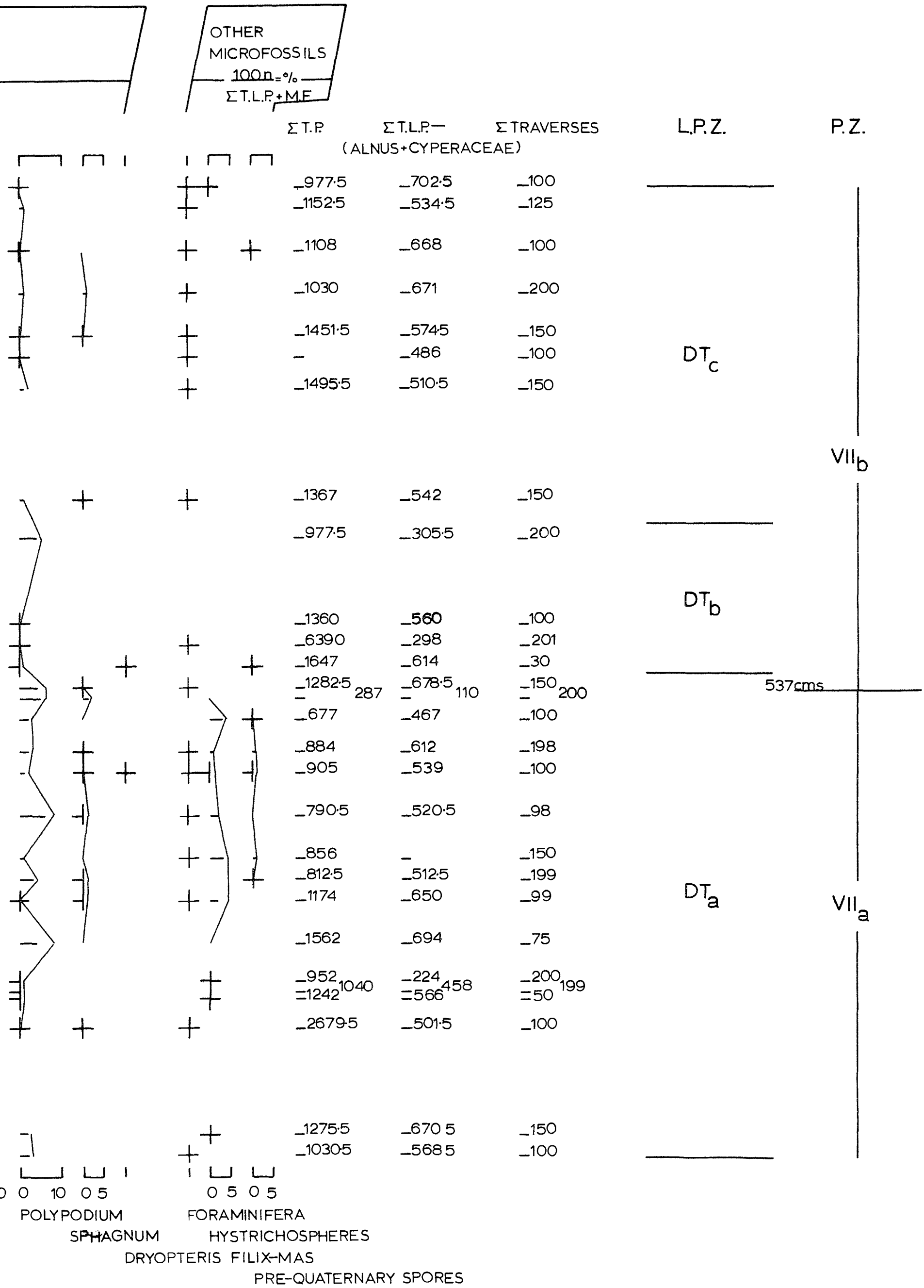
FIGURE 17. Pollen diagram from the New Dartford Tunnel


HERBS(C)
100n / ΣT.L.P. = %
ARTEMISIA
BELLIS Type
PLANTAGO MARITIMA
FILIPENDULA
ARMERIA B. Type
UMBELLIFERAE APIUM Type
RUBUS FRUTICOSUS AGG.
COMP. LIGULIFLORAE
RUMEX ACETOCELLA
UMB. ANGELICA Type
SUCCISA
CALTHA Type
MERCURIALIS PERENNIS
CRUCIFERAE
POTENTILLA Type
UMB. HYDROCOTYLE Type
ARMERIA A. Type
SOLANUM DULCAMARA
RUBIACEAE
CALLUNA
SPERGULARIA
LEGUMINOSAE TRIFOLIUM Type
P. LANCEOLATA
CARYOPHYLLACEAE UNDIF.
R. ACETOSA
HYPERICUM
POLYGONUM PERSICARIA
LABIATAE MENTHA Type
LAB. STACHYS Type
RANUNCULUS ACRIS Type
COMP. CIRSIUM Type
ROSA
P. CORONOPUS
LYSIMACHIA

rd Tunnel.



AQUATICS(D)
100n% / ΣT.L.P+aquatics
PTERIDOPHYTES (E)
100n / ΣT.L.P = %
10
0 5
0 5 0 10 0 5
0 10 20 30 40 50 60 70
0 10 20 30
0 10 20 30 40 50
0 10 0
ACHIA
LYTHRUM cf.SALICARIA
ype
COMP. MATRICARIA Type
M Type
MALVA
ROSACEAE UNDIF.
NOPUS
POLYGONUM AVICULARE
OSOTIS/LOTUS
R. CRISPUS Type
THALICTRUM
URTICA
RAN. AQUATILIS Type
TYPHA ANGUSTIFOLIA/SPARGANIUM
T. LATIFOLIA
EQUISETUM
FILICALES
THELYPTERIS PALUSTRIS
PTERIDIUM
POLYPOD



OTHER MICROFOSSILS
100n = %
ΣT.L.P.+M.F.
ΣT.P.
ΣT.L.P.— (ALNUS+CYPERACEAE)
ΣTRAVERSES
L.P.Z.
P.Z.
977·5 702·5 100
1152·5 534·5 125
1108 668 100
1030 671 200
1451·5 574·5 150
486 100
1495·5 510·5 150
1367 542 150
977·5 305·5 200
1360 560 100
6390 298 201
1647 614 30
1282·5 287 678·5 110 150 200
677 467 100
884 612 198
905 539 100
790·5 520·5 98
856 150
812·5 512·5 199
1174 650 99
1562 694 75
952 1040 224 458 200 199
1242 566 50
2679·5 501·5 100
1275·5 670 5 150
1030·5 568 5 100
DTc
DTb
DTa
VIIb
VIIa
537cms
0 0 10 0 5 0 5 0 5
POLYPODIUM
SPHAGNUM
DRYOPTERIS FILIX-MAS
FORAMINIFERA
HYSTRICHOSPHERES
PRE-QUATERNARY SPORES

of the elm decline. *Ulmus* values show a fall from 5–3 % Σ t.l.p. at 410 cm, which is accompanied by an expansion of Gramineae and *Pteridium aquilinum*, with a fall of a.p. values and the first appearance of *Plantago lanceolata* pollen. This fall is however slight and is not supported by a general increase in ruderal pollen taxa. A clear decline does occur between 340–350 cm from 4–1 % Σ t.l.p. followed by the formation of an erratic curve. This point is supported by the radiocarbon data of 4930 ± 110 B.P. at 345 cm.

TABLE 2. RADIOCARBON DATES FROM STONE MARSH SB1/1

code	date/a B.P.	depth from surface/cm
Q-1281 SB1/1C1	6970 ± 90	920–934
Q-1335 SB1/1C2	6680 ± 100	912–908
Q-1336 SB1/1C3	4930 ± 110	345–350
Q-1337 SB1/1C4	4085 ± 85	162–166
Q-1338 SB1/1C5	2850 ± 65	135–140

(*d*) *Pollen analysis – Dartford Tunnel*

The general stratigraphy (figure 14) shows the deposits here dipping toward the river (see § 2*c*). Pollen preservation particularly in the wood peats and in the basal layers was poor, with large numbers of corroded, degraded and broken grains. Three local pollen assemblage zones were recognized (figure 17).

l.p.z. height from surface (cm)	description
DTc 260–460	Herb pollen is dominant and species rich, with Gramineae, Cyperaceae and Chenopodiaceae the main taxa. Gramineae 36 % Σ t.l.p. at maximum. Appearance of cereal type pollen. Expansion of *Pteridium aquilinum* 20 % Σ (t.l.p. + pteridophytes). Rise of aquatics, particularly *Typha angustifolia/Sparganium*.
DTb 460–520	Non arboreal pollen and spore frequencies rise at the expense of a.p., Gramineae rising to > 15 % Σ t.l.p. accompanied by Cyperaceae. Chenopodiaceae pollen falls to a presence only. Filicales values rise sharply to exceed 40 % Σ (t.l.p. + pteridophytes). Trees are still important, but *Alnus* pollen has declined with *Quercus*, *Corylus* type and *Tilia* the main taxa.
DTA 520–930	*Alnus*, *Quercus* and *Corylus* type form the main tree taxa with lower but persistent curves for *Ulmus*, *Tilia* and *Pinus* > 5 % Σ t.l.p. Arboreal pollen dominant and generally > 70 % Σ t.p. Shrubs erratic, but *Hedera* forms a continuous curve. Herb values low but persistent, high values of Chenopodiaceae, Gramineae about 5 % Σ t.l.p.

(i) *Local pollen assemblage zone DTa* (Alnus, Quercus *and* Corylus *type*)

The pollen assemblage suggests the formation of a local alder-oak fen wood, with alder carr locally dominant. Formation of the wood peats probably occurred in shallow freshwater pools or under conditions of slow, flowing water. This conclusion is supported by a temperate freshwater and land shell fauna, found in association with the peats. The shells were taken from approximately 10 cm^3 of sediment, giving a guide to the degree of representation and importance of the species found. The land species are indicative of a damp wood or scrub habitat (B. W. Sparks, personal communication) (see appendix 1).

(ii) *Local pollen assemblage zones DTb and DTc* (*Gramineae, Cyperaceae,* Alnus *and Filicales*)

The beginning of biogenic deposition at 500 cm shows a seral vegetational change. A freshwater sedge fen community is replaced by alder-oak carr. A short phase of fen-oak woodland may have existed, with tree pollen dominant and rising above 30 % Σ t.p. and *Quercus* values reaching 30 % Σ t.l.p. Expansion of Cyperaceae to approximately 20 % Σ t.l.p. with Gramineae values, shows a return to sedge fen by 460 cm. Aquatic taxa rise here, for example *Typha angustifolia* and *Ranunculus aquatilis* type. Rising Chenopodiaceae frequencies accompanied by Compositae *Bellis* type, *Artemisia,* Labiatae *Mentha* type and *Plantago maritima* pollen reflects the occurrence of saltmarsh vegetation.

(*e*) *Dating*

The pollen assemblage shows the deposit to have formed during p.z. VII, with biogenic deposition beginning at 7140 ± 110 B.P. Radiocarbon dating here was taken upon wood at the base of organic deposition between 1064–1967 cm. The elm decline occurs at 537 cm, with *Ulmus* values falling from 5–1 % Σ t.l.p. remaining low and sporadic. A radiocarbon assay on an alder stool at 545 cm gives a date of 5484 ± 80 B.P.

(*f*) *Diatom analysis*

The core was barren in diatoms except for the transitional zone of Tilbury IV between 260–295 cm (figure 18). The valves were in a good state of preservation with few signs of corrosion or reworking. This short sequence shows little vertical change with the dominance of brackish to freshwater taxa, the latter element still tolerant of low salinities. The most common and characteristic species found were *Diploneis interrupta, D. ovalis, Caloneis formosa, Cyclotella striata, Navicula cincta, Navicula peregrina, Navicula elegans, Nitzschia navicularis* and *Nitzschia vitrea.* The assemblage shows a resemblance to the brackish intertidal diatom flora of Southampton Water (Hodson & West 1972).

6. Littlebrook Power Station

Site: TQ56227584: 51° 27′ 34″ N: 0° 14′ 51″ E

The sequences here are conformable with the general stratigraphy of the area (figure 14, see § 2*c*). The pollen spectra shown from boreholes 3 and 4 (figure 19) agree with the vegetational description for Stone and the Dartford Tunnel. The deposits formed during p.z. VII; this is confirmed by the radiocarbon date of 6820 ± 55 B.P. for the basal peat.

(*a*) *Inter-relation of sites at Stone Marsh, Dartford Tunnel and Littlebrook*

The deposits here lie upon a hummocky gravel surface, with local altitudinal highs and lows occurring in addition to distinct channels. A channel runs in a north–south trend through this area, as exposed by the tunnel excavations (figure 14). In cross-profile (figure 14) between boreholes 6–11 a possible levee feature can be seen. Tilbury III is least developed here and forms a thinner and more compact deposit upon the top of the apparent levee or bank; borehole 11 (SB1/1) comes from the riverward edge of this bank. Peat growth appears to have

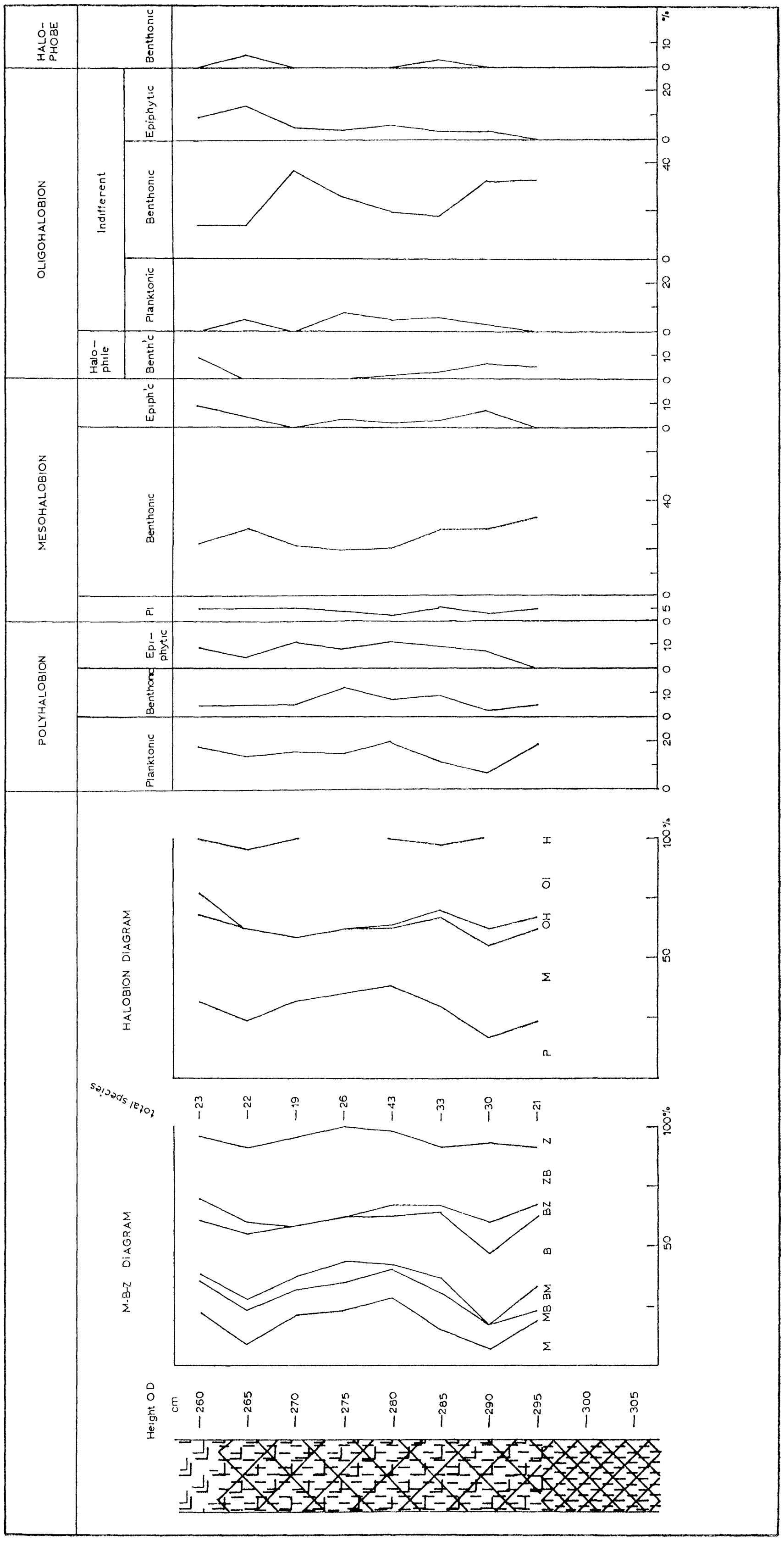


FIGURE 18. Diatom diagram from the New Dartford Tunnel. M, Marine; MB, marine-brackish; BM, brackish-marine; B, brackish; BZ, brackish-fresh; ZB, fresh-brackish; Z, fresh. P, Polyhalobion; M, Messohalobion-OH, Oligohalobion halophile; OI, Oligohalobion indifferent; H, Halophobe. Qualitative diagram 100 n/ total species.

begun at a later date at this point, due largely to the differences in height and relation to the water table. In the lower and more protected tunnel site, peat growth began earlier and was able to form a thicker deposit before inundation by Thames III.

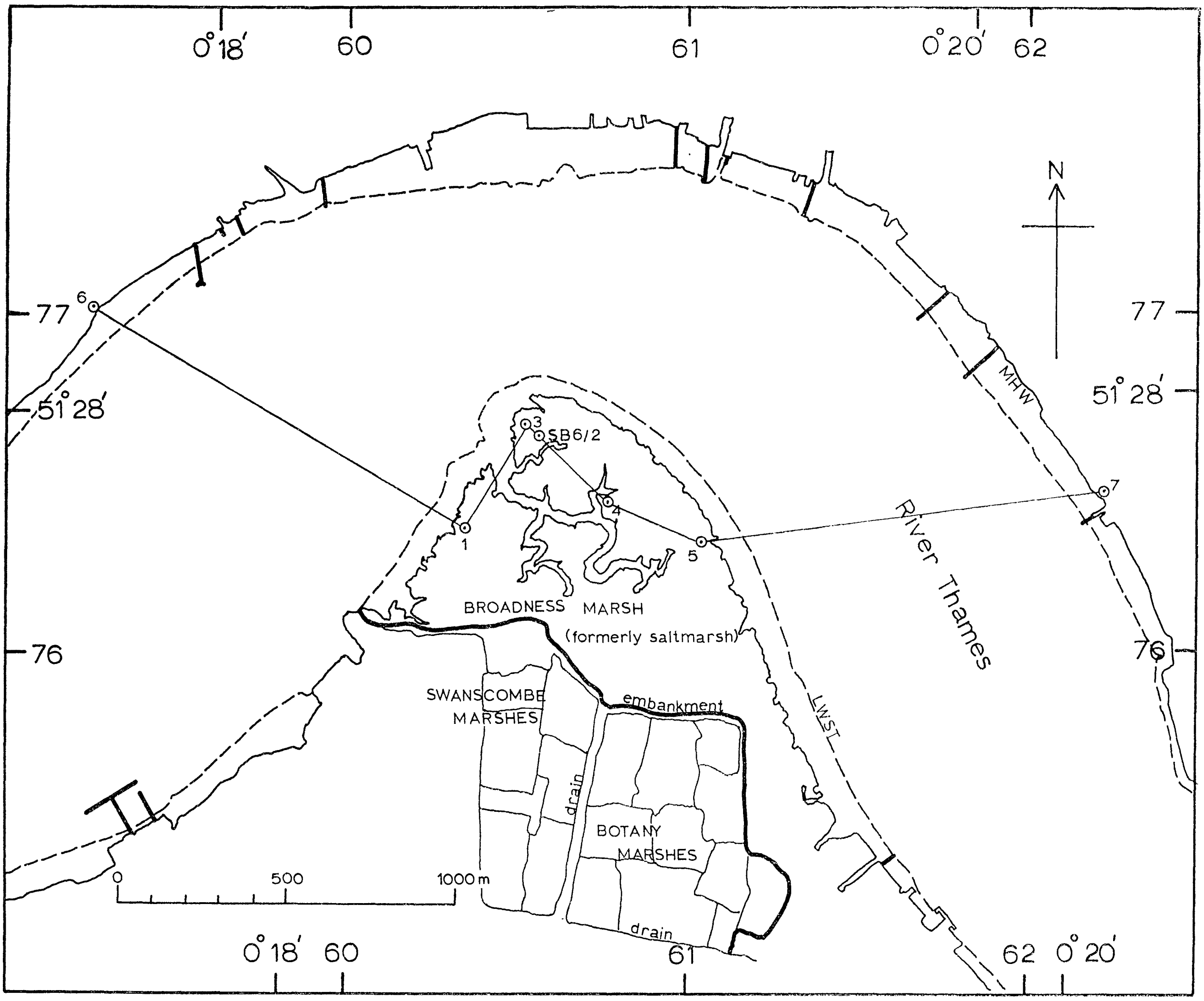


Figure 20. Site map of Broadness Marsh, showing borehole locations (⊙).

7. Broadness Marsh

Site: TQ60577664: 51° 27′ 56″ N; 0° 18′ 40″ E

The marshes here are contained within a meander of the River Thames and bounded in the south by the steep slope of the chalk (figure 20). Inundation during February 1953, necessitated the uniform raising of ground heights of Broadness Marsh to 4–5 m o.d. by the addition of clay and rubble. The sample borehole lies 113 m at 169 ° N from Broadness Lighthouse.

(a) *Stratigraphy*

A layer of dense yellow-grey fine sand caps the gravel over the length of the profile, reaching 0.5–2.5 m in depth. The gravel drops in surface height from −9.5 m o.d. at EB20/1 to a

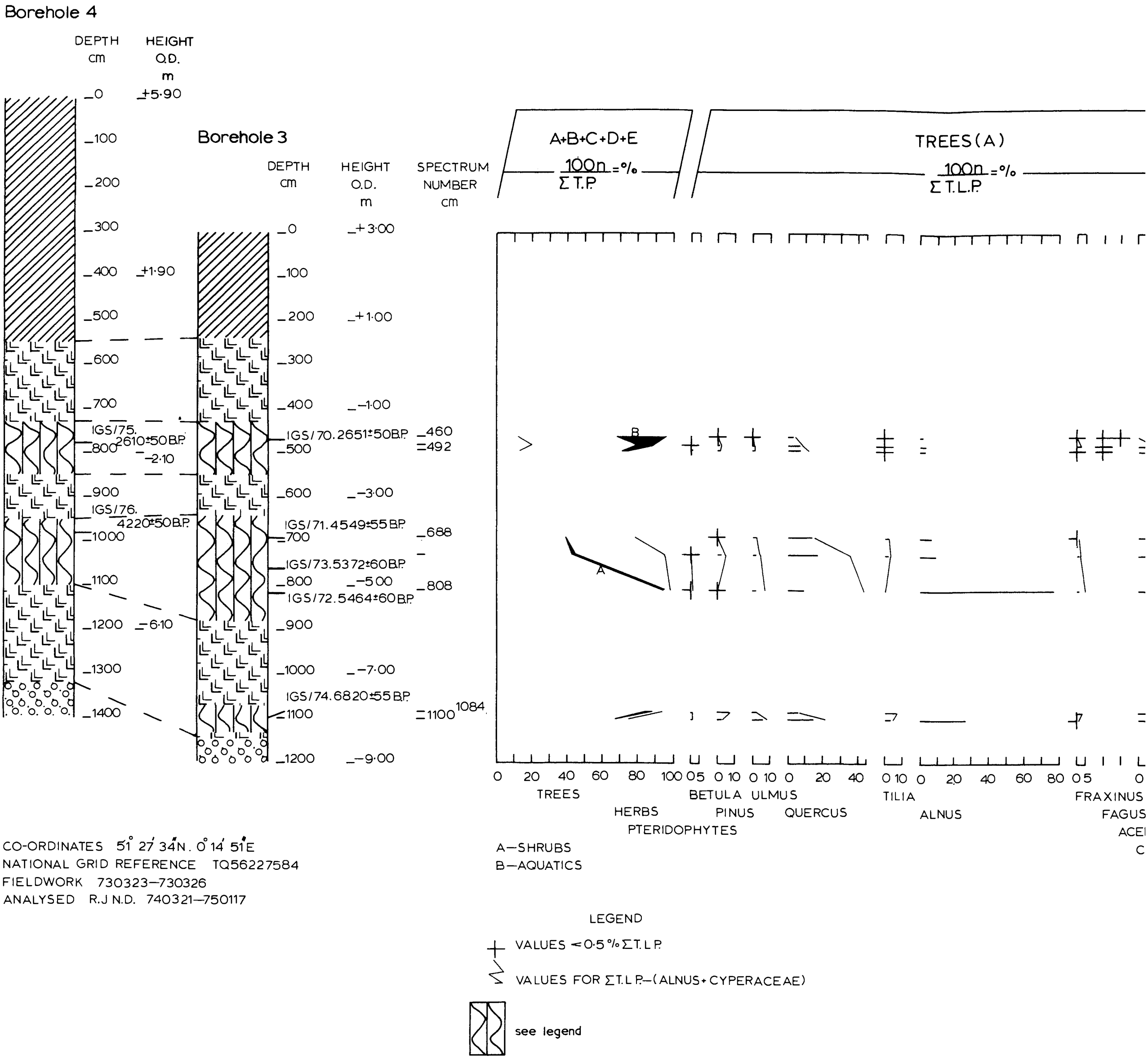
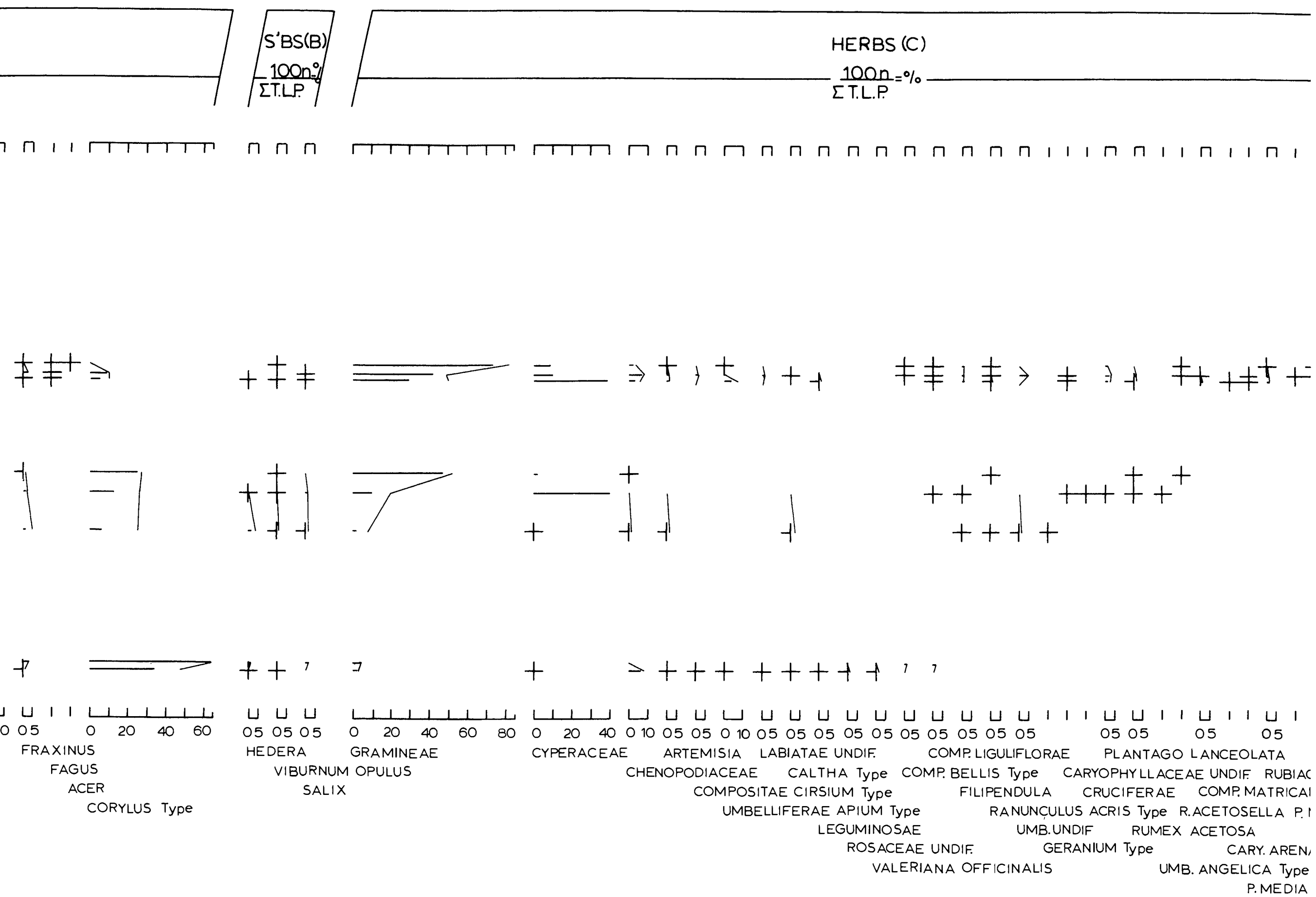
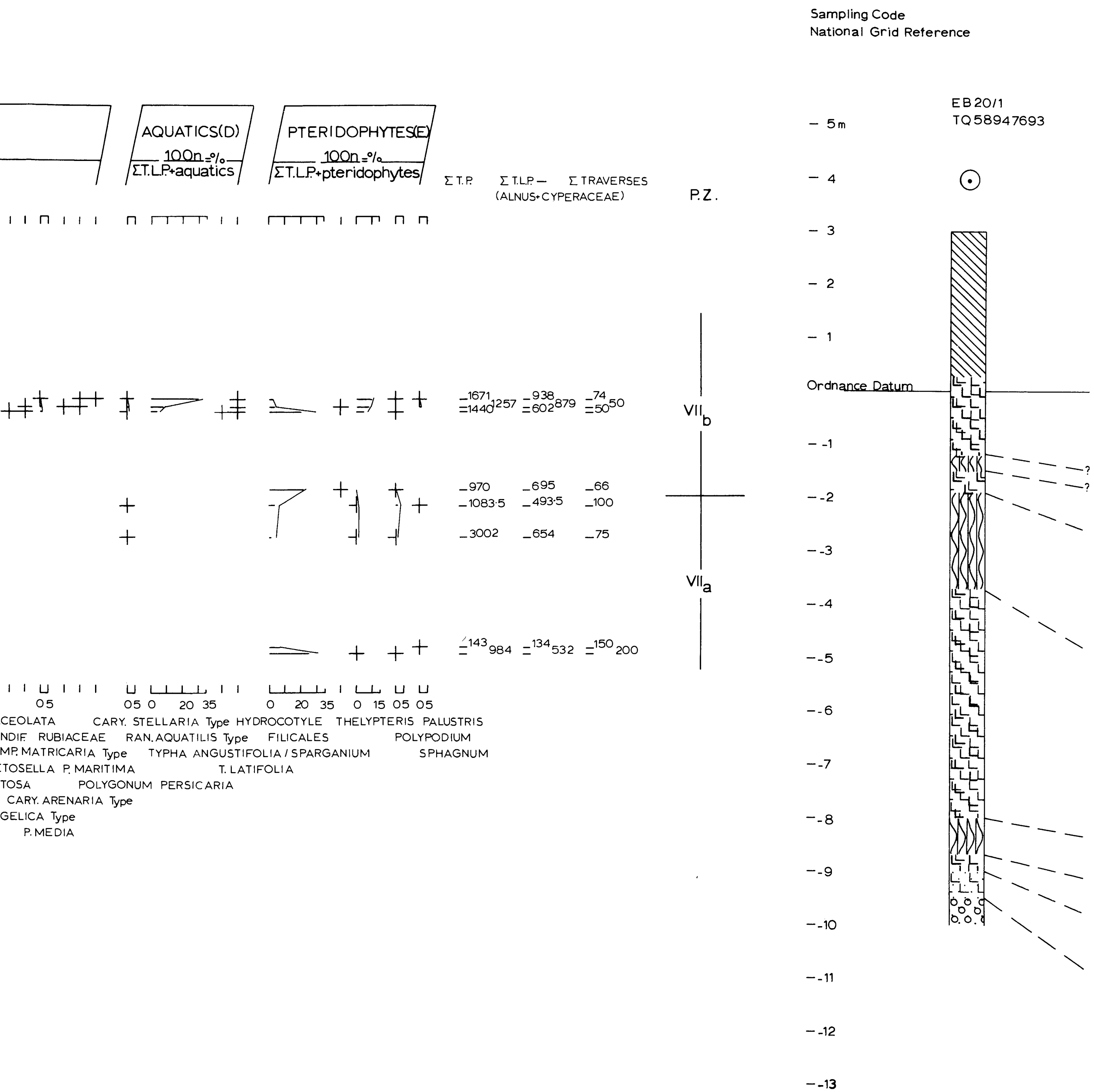


FIGURE 19. Polle
humified red



19. Pollen diagram from Littlebrook Power Station EB 3 and 4. The sediment symbol represents a well
mified red-brown, homogeneous peat with a high monocot fraction and a significant gyttja content.


AQUATICS(D)
100n = % / ΣT.L.P.+aquatics
PTERIDOPHYTES(E)
100n = % / ΣT.L.P.+pteridophytes
Σ T.P.
Σ T.L.P. — (ALNUS+CYPERACEAE)
Σ TRAVERSES
P.Z.
VIIb
VIIa
05
05 0 20 35
0 20 35 0 15 05 05
CEOLATA
NDIF.
MP. MATRICARIA Type
TOSELLA P. MARITIMA
TOSA
CARY. ARENARIA Type
GELICA Type
P. MEDIA
CARY. STELLARIA Type
RUBIACEAE
POLYGONUM PERSICARIA
RAN. AQUATILIS Type
HYDROCOTYLE
TYPHA ANGUSTIFOLIA / SPARGANIUM
T. LATIFOLIA
FILICALES
THELYPTERIS PALUSTRIS
POLYPODIUM
SPHAGNUM
Sampling Code
National Grid Reference
EB 20/1
TQ58947693
Ordnance Datum
5 m
4
3
2
1
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
-11
-12
-13

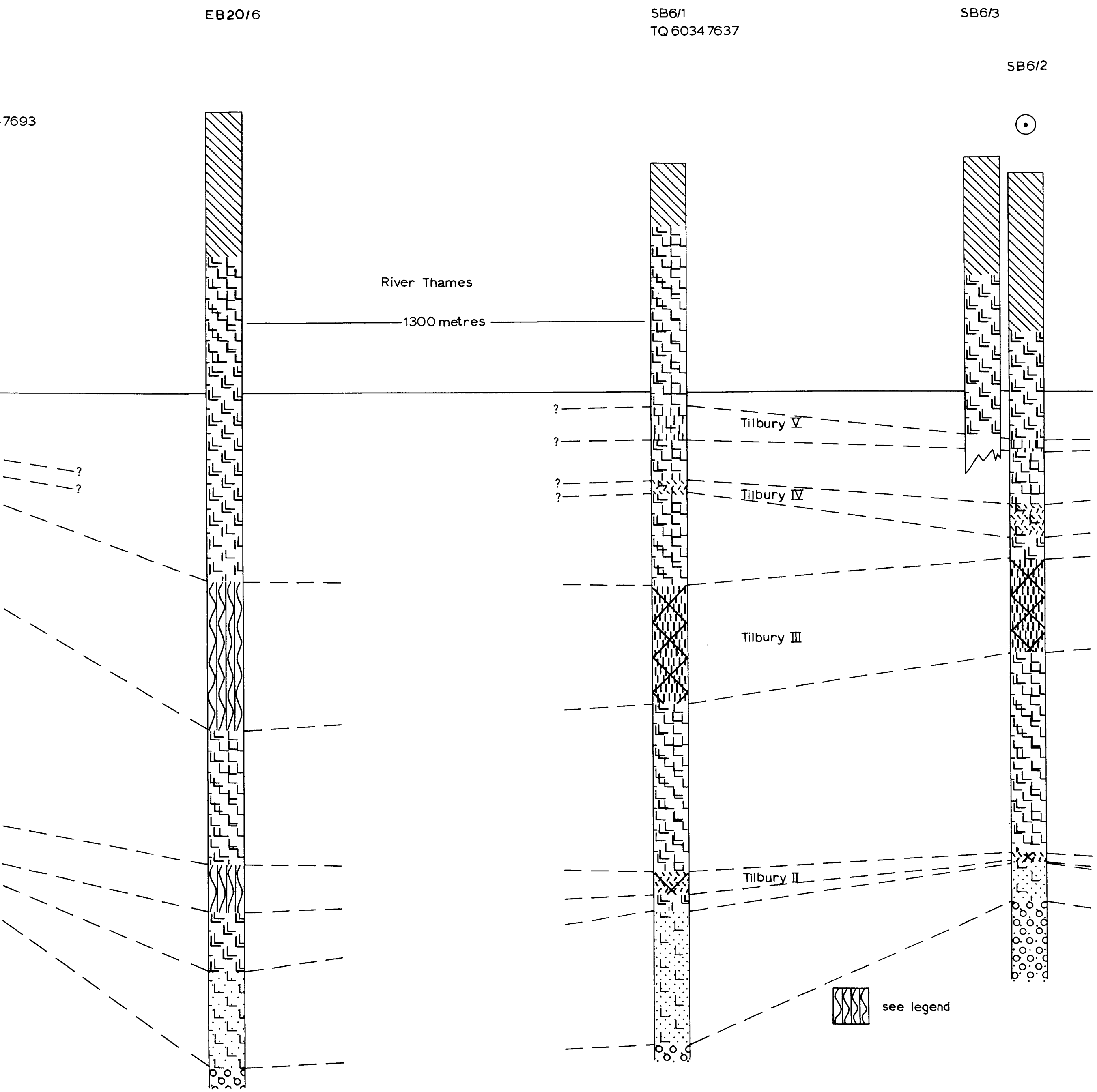
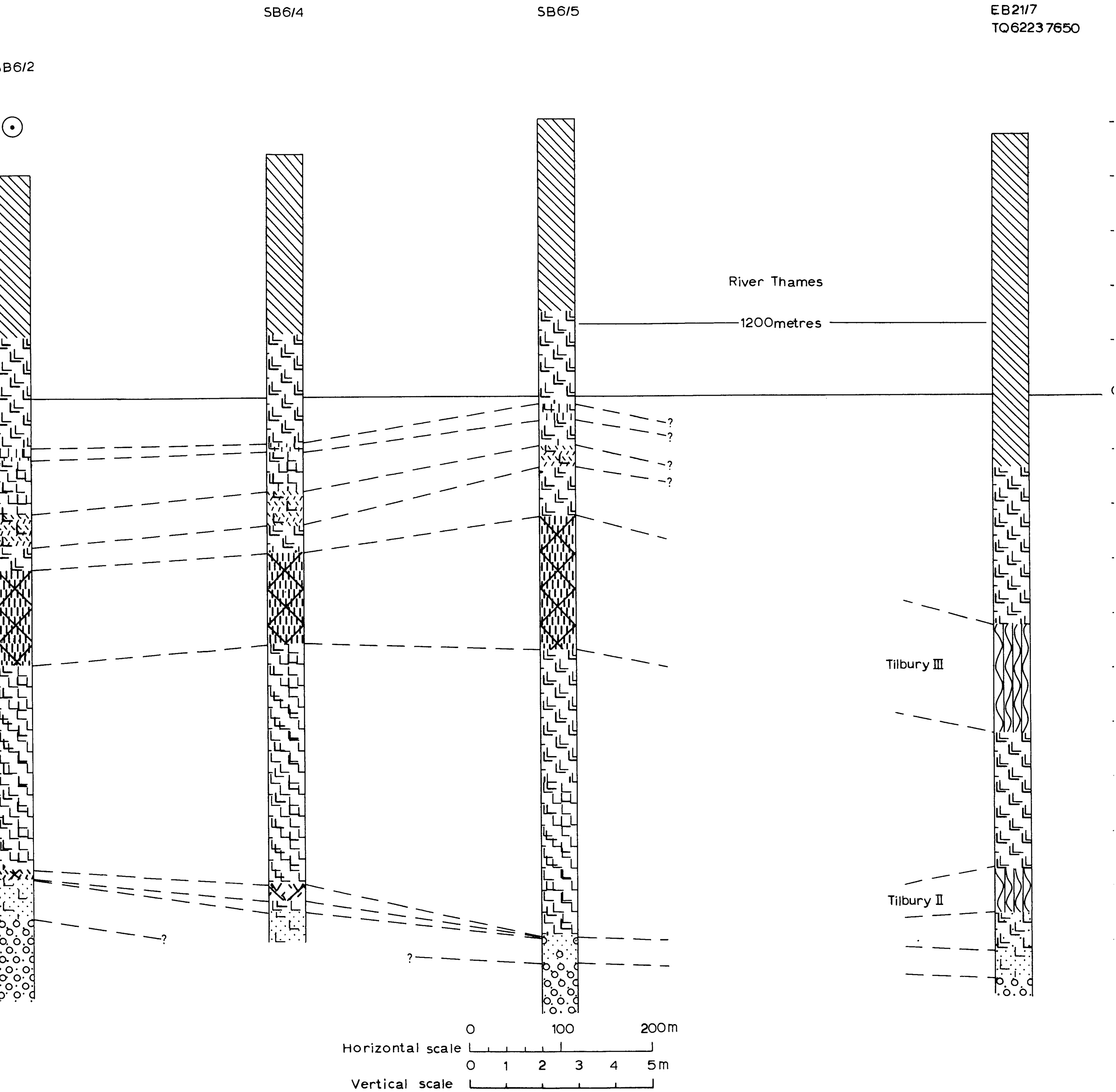


FIGURE 21. Stratigraphic diagram from West Thurrock and Broadness marshes, based
C.E.G.B., A.G. Weeks & Co. Ltd and the author. The sediment symbol represents a
gyttja content. Branches and twigs are common. ⊙, sample borehole.

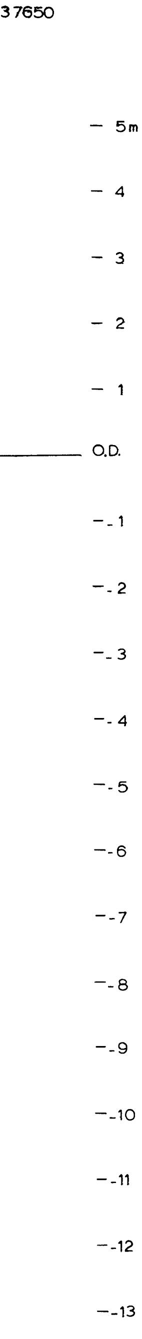


es, based upon borehole data supplied by Binnie and Partners Ltd,
presents a medium brown fen peat, well humified, with a significant

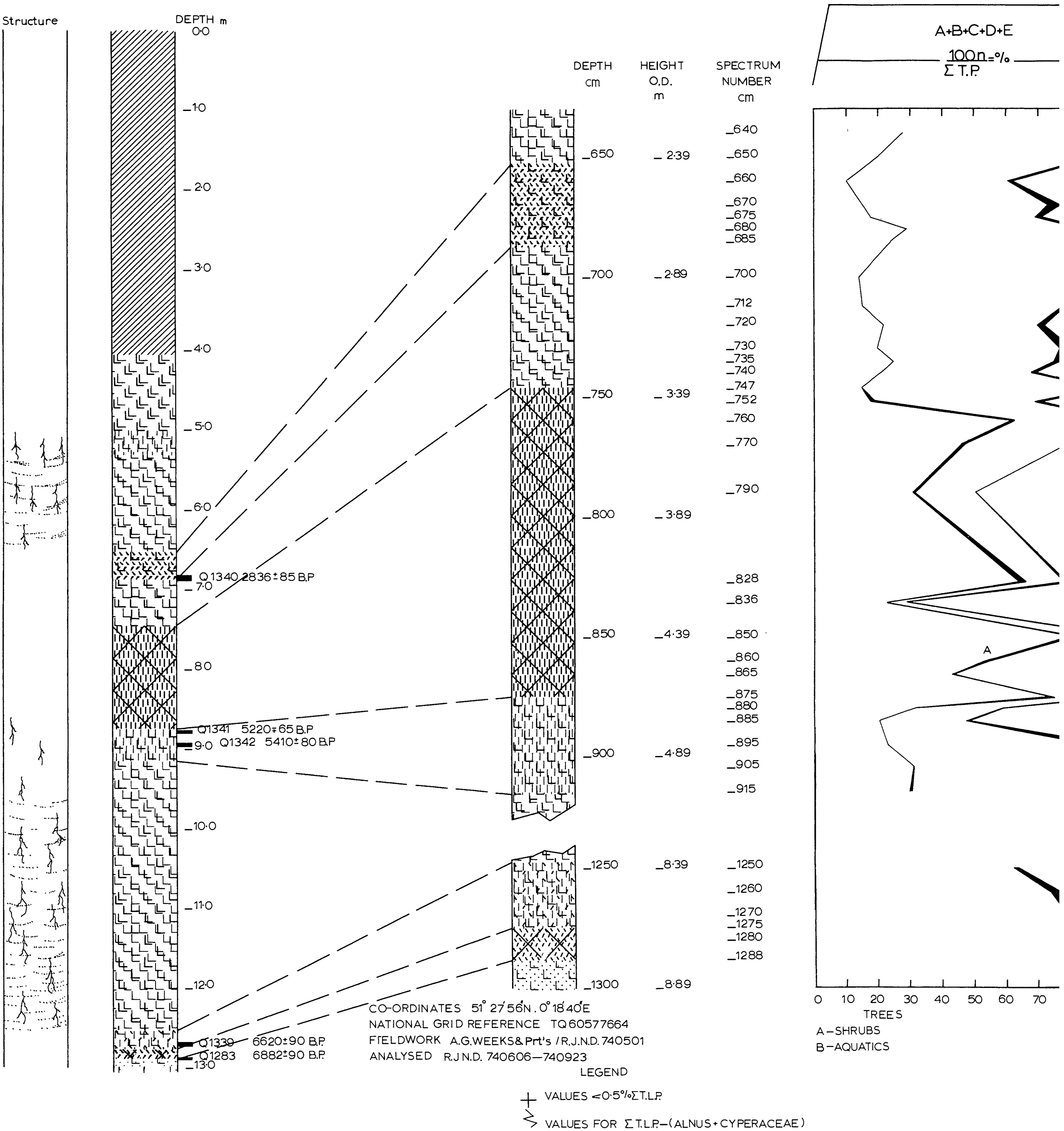
(*Facing p.* 3

pullout 11

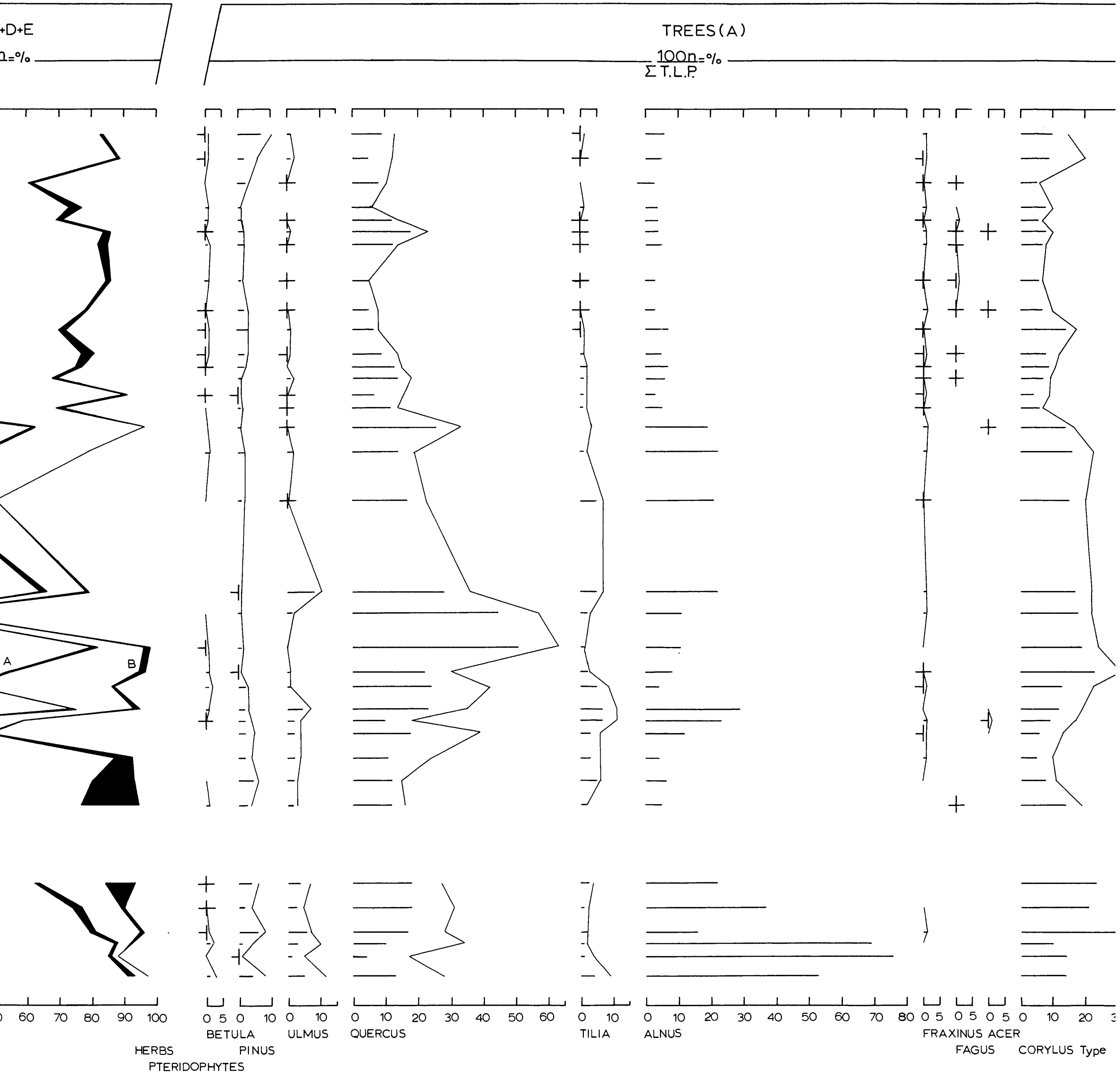
37650



(Facing p. 382)



Structure
DEPTH m
0·0
1·0
2·0
3·0
4·0
5·0
6·0
Q1340 2836±85 B.P
7·0
8·0
Q1341 5220±65 B.P
9·0 Q1342 5410±80 B.P
10·0
11·0
12·0
Q1339 6620±90 B.P
Q1283 6882±90 B.P
13·0
DEPTH cm
HEIGHT O.D. m
SPECTRUM NUMBER cm
640
650 2·39 650
660
670
675
680
685
700 2·89 700
712
720
730
735
740
747
750 3·39 752
760
770
790
800 3·89
828
836
850 4·39 850
860
865
875
880
885
895
900 4·89
905
915
1250 8·39 1250
1260
1270
1275
1280
1288
1300 8·89
CO-ORDINATES 51° 27′ 56″N . 0° 18′ 40″E
NATIONAL GRID REFERENCE TQ 60577664
FIELDWORK A.G.WEEKS & Prt's / R.J.N.D. 740501
ANALYSED R.J.N.D. 740606—740923
LEGEND
VALUES <0·5% ΣT.L.P.
VALUES FOR ΣT.L.P.—(ALNUS+CYPERACEAE)
A+B+C+D+E
100n/ΣT.P. = %
A
0 10 20 30 40 50 60 70
TREES
A—SHRUBS
B—AQUATICS


+D+E
n=%
TREES (A)
100n=%
Σ T.L.P.
A
B
60 70 80 90 100
HERBS
PTERIDOPHYTES
0 5
BETULA
0 10
PINUS
0 10
ULMUS
0 10 20 30 40 50 60
QUERCUS
0 10
TILIA
0 10 20 30 40 50 60 70 80
ALNUS
0 5
FRAXINUS
0 5
FAGUS
0 5
ACER
0 10 20
CORYLUS Type

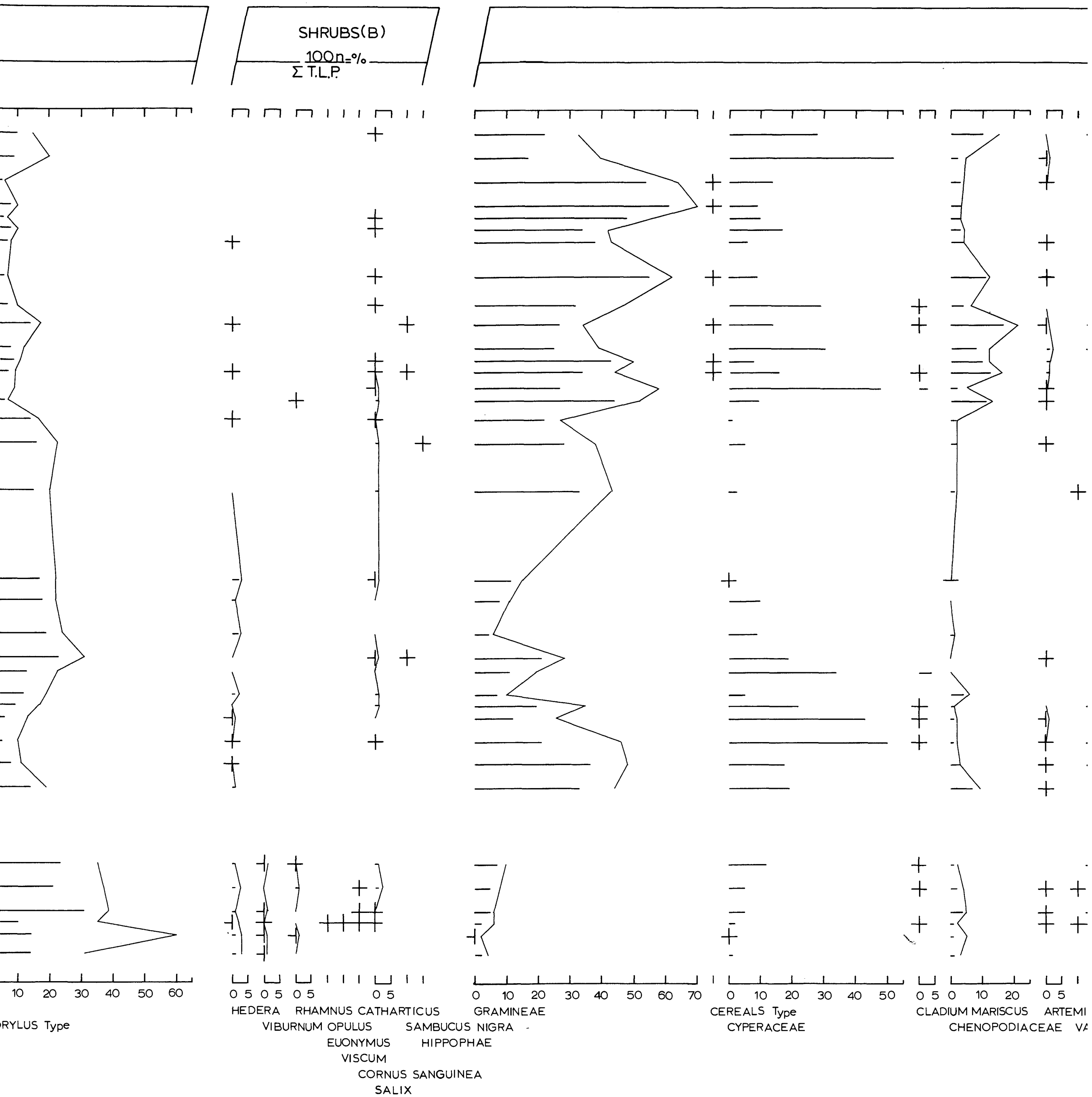
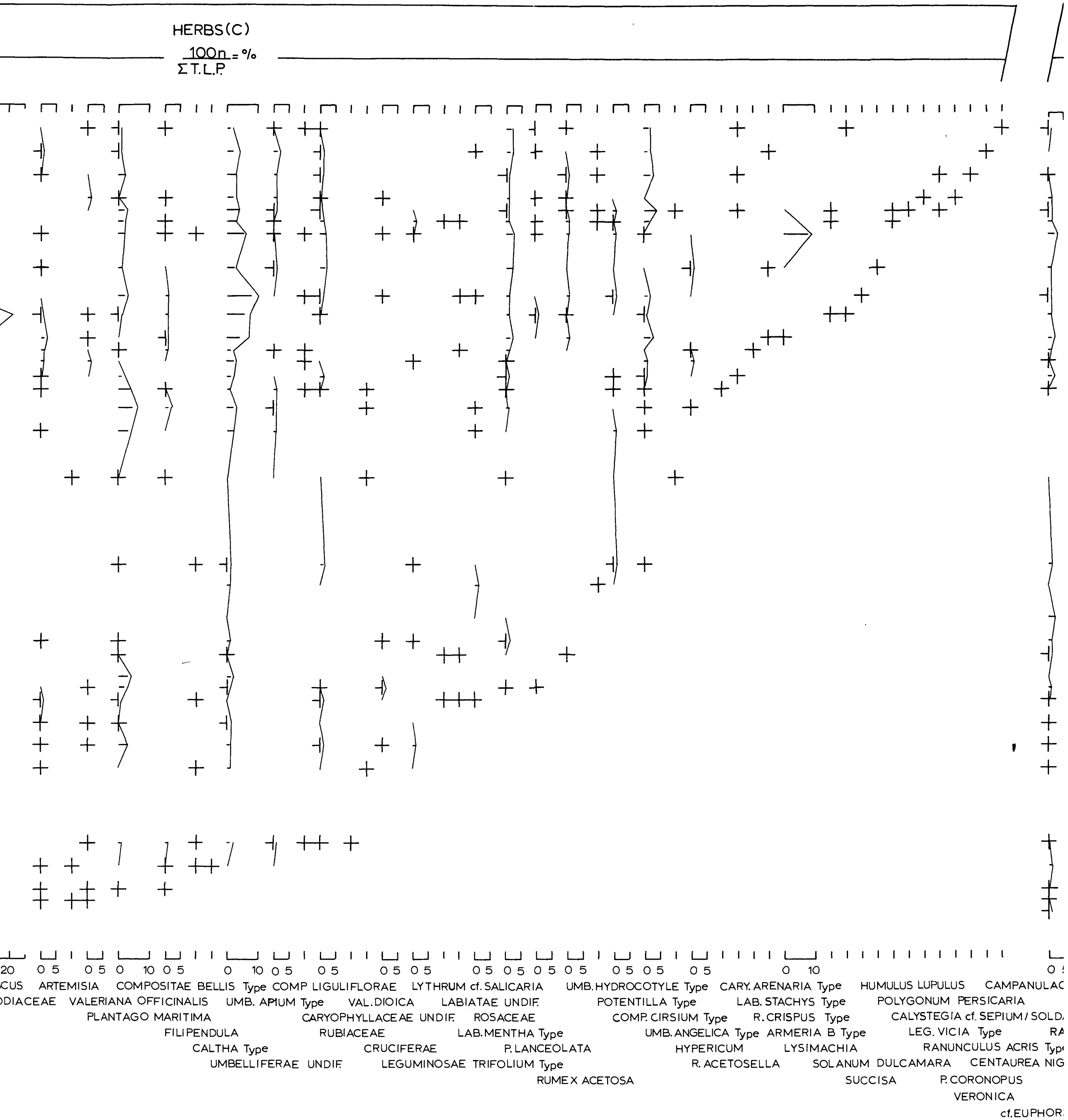
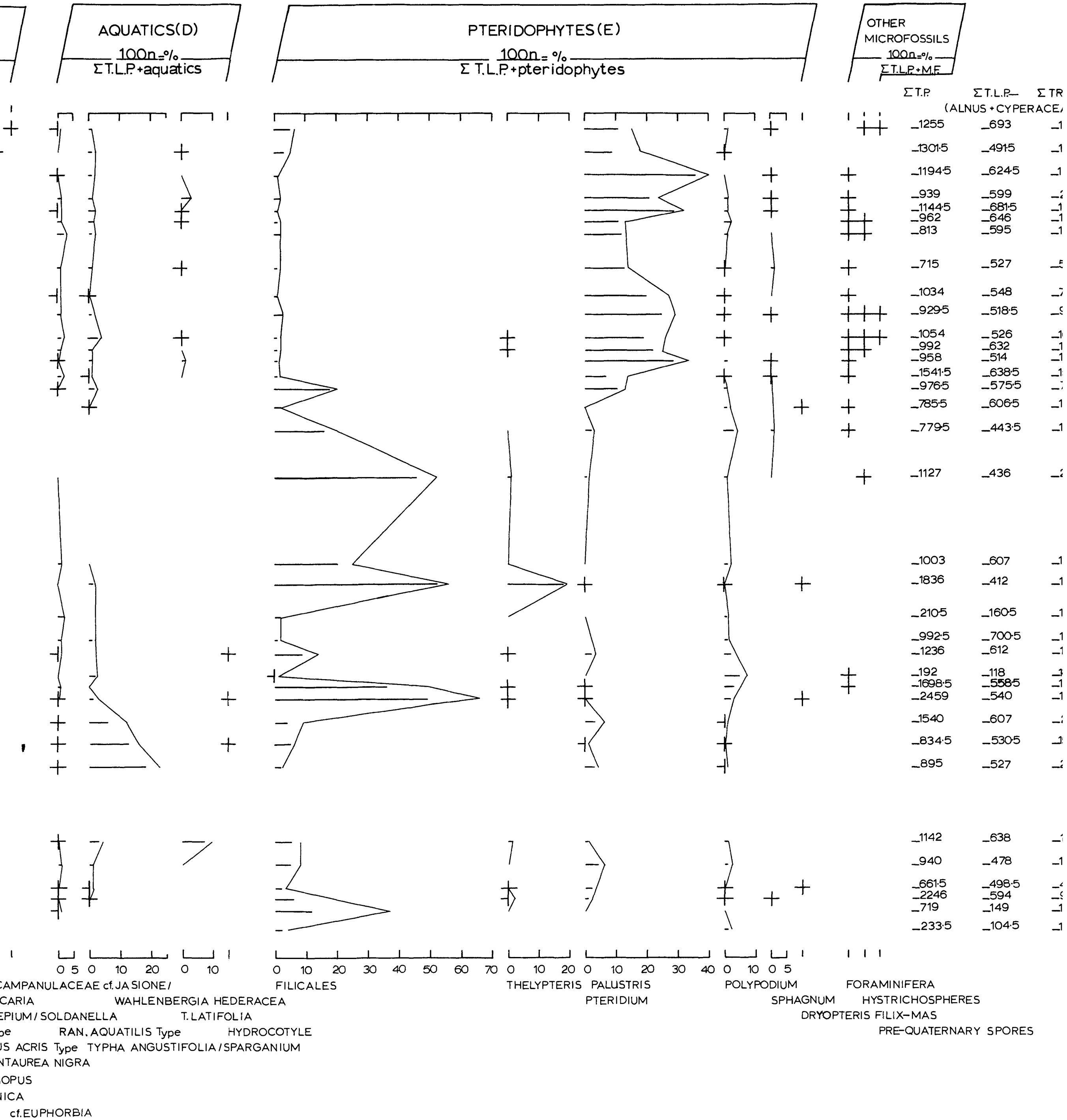


FIGURE 22. Pollen diagram from Broadness Marsh, S.B.2.


HERBS(C)
100n / ΣT.L.P = %
ARTEMISIA
VALERIANA OFFICINALIS
PLANTAGO MARITIMA
FILIPENDULA
CALTHA Type
UMBELLIFERAE UNDIF.
COMPOSITAE BELLIS Type
UMB. APIUM Type
COMP LIGULIFLORAE
VAL. DIOICA
CARYOPHYLLACEAE UNDIF.
RUBIACEAE
CRUCIFERAE
LEGUMINOSAE TRIFOLIUM Type
LYTHRUM cf. SALICARIA
LABIATAE UNDIF.
ROSACEAE
LAB. MENTHA Type
P. LANCEOLATA
RUMEX ACETOSA
UMB. HYDROCOTYLE Type
POTENTILLA Type
COMP. CIRSIUM Type
UMB. ANGELICA Type
HYPERICUM
R. ACETOSELLA
CARY. ARENARIA Type
LAB. STACHYS Type
R. CRISPUS Type
ARMERIA B Type
LYSIMACHIA
SOLANUM DULCAMARA
SUCCISA
HUMULUS LUPULUS
POLYGONUM PERSICARIA
LEG. VICIA Type
P. CORONOPUS
VERONICA


AQUATICS(D)
100n = % / Σ T.L.P.+aquatics
PTERIDOPHYTES (E)
100n = % / Σ T.L.P.+pteridophytes
OTHER MICROFOSSILS
100n = % / Σ T.L.P.+M.F.
Σ T.P.
Σ T.L.P.— (ALNUS + CYPERACE
Σ TR
1255 693
1301·5 491·5
1194·5 624·5
939 599
1144·5 681·5
962 646
813 595
715 527
1034 548
929·5 518·5
1054 526
992 632
958 514
1541·5 638·5
976·5 575·5
785·5 606·5
779·5 443·5
1127 436
1003 607
1836 412
210·5 160·5
992·5 700·5
1236 612
192 118
1698·5 558·5
2459 540
1540 607
834·5 530·5
895 527
1142 638
940 478
661·5 498·5
2246 594
719 149
233·5 104·5
0 5 0 10 20 0 10
0 10 20 30 40 50 60 70 0 10 20 0 10 20 30 40 0 10 0 5
CAMPANULACEAE cf. JASIONE/
CARIA
WAHLENBERGIA HEDERACEA
EPIUM/SOLDANELLA
T. LATIFOLIA
pe
RAN. AQUATILIS Type
HYDROCOTYLE
US ACRIS Type
TYPHA ANGUSTIFOLIA/SPARGANIUM
NTAUREA NIGRA
OPUS
NICA
cf. EUPHORBIA
FILICALES
THELYPTERIS PALUSTRIS
PTERIDIUM
POLYPODIUM
SPHAGNUM
DRYOPTERIS FILIX-MAS
FORAMINIFERA
HYSTRICHOSPHERES
PRE-QUATERNARY SPORES

...T.L.P.— (...S + CYPERACEAE)	Σ TRAVERSES	L.P.Z.	P.Z.
693	198		
491·5	150		
624·5	149		
599	200		
681·5	150		
646	148		
595	150		
527	50	BM_d	
548	75		
518·5	99		
526	100		
632	148		
514	100		
638·5	150		
575·5	75		
606·5	149		
443·5	199		VII_b
436	200		
		BM_c	
607	198		
412	198		
160·5	198		
700·5	100		
612	198		
118	180		
558·5	199		
540	149		
607	200		
530·5	150		
527	200		
		BM_b	VII_a
638	100		
478	100		
498·5	42		
594	90		
149	136		
104·5	190	BM_a	

SPORES

maximum depth of −12.6 m O.D. It is formed by orange-brown fine to coarse, rounded flints with occasional sandstone and chalk pebbles. A coarse brown sand element is present.

A west–east section was taken through Broadness saltmarsh, crossing the river at two points (figure 21). The diagram shows three distinct biogenic levels, correlated with Tilbury IV, III, and II from the surface downwards. A local marsh peat formed above Tilbury IV at Broadness was not immediately traceable in the sequences shown in West Thurrock and Grays-Thurrock Marshes (figure 21), but was correlated with Tilbury V on its position and pollen content. Tilbury V and IV lie between −0.15 and −1.1 m O.D. and −1.66 and −2.75 m O.D. respectively. They form a similar medium grey-brown silty peat with *Phragmites* and Cyperaceae in growth positions. In cross-profile Tilbury III dips toward the east, although the trend is not uniform and is obscured by changes in thickness and surface height. The layer is formed by a medium to dark brown fibrous monocot peat with a muddy gyttja content, generally 2.5–3 m thick. Although bark and twigs are common in the lowest levels, wood remains are conspicuous by their absence. Despite the importance of compaction and consolidation due to the amount of overburden, as shown in EB21/7, it does not appear to have changed the general trend of lower heights eastward. Tilbury II is composed of an *in situ* alder wood peat, with its upper surface at −9 m O.D. upon average.

The interleaving inorganic deposits, Thames V/IV, III, II and I are composed of a light to medium blue-grey clay/silt. *In situ Phragmites* was present and Cyperaceae stems and leaves were found at all levels.

(*b*) *Pollen analysis*

The detailed stratigraphy of the sample borehole SB6/2 is consistant with that of the area as a whole (see § 2*c*, figure 22). Between 770 and 828 cm, the pollen was corroded, degraded and broken, making valid statistical counts here impossible. Figure 22 shows erratic behaviour of Σ t.p. for trees, partly explained by changes in *Quercus* and *Alnus* pollen frequencies. Four l.p.z. are identified:

l.p.z.	height from surface (cm)	description
BMd	640–755	Non arboreal pollen dominant > 50 % Σ t.p. Gramineae followed by Cyperaceae pollen rises sharply. Chenopodiaceae pollen rises to a maximum of 15 % Σ t.l.p. with continuous curve for Compositae *Bellis* type. Herbs are taxa rich with appearance of cereal type pollen and continuous curve for *Plantago lanceolata* pollen. Rise of *Pteridium aquilinum* to > 20 % Σ (t.l.p. + pteridophytes). Appearance of *Acer* and *Fagus* pollen with *Quercus* and *Corylus* type main a.p. taxa. *Pinus* curve rises towards the top of the zone.
BMc	755–880	*Quercus*, *Alnus*, *Corylus* type with Gramineae form the main pollen taxa – the a.p. dominant element reaches 50 % Σ t.p. Values not held due to sporadic behaviour of spores, with Filicales reaching 50 % Σ (t.l.p. + pteridophytes). Cyperaceae values low, declining from high values 34% Σ t.l.p. at base to 5 % Σ t.l.p. Herbs taxa poor. *Tilia* pollen expands.
BMb	880–1272	Non arboreal pollen values dominant with herbs 50 % Σ t.p. Gramineae > 40 % and Cyperaceae 50 % Σ t.l.p., forming the main herb taxa. Chenopodiaceae and Compositae *Bellis* type pollen form continuous curves – herbs more species rich. Trees of continued importance. *Alnus* declines –

	Quercus and *Corylus* type main a.p. taxa. Trees fallen to < 25% Σ t.p. at top of zone. Aquatics rise sharply to decline at top, *Typha angustifolia/Sparganium* 18% Σ (t.l.p. + aquatics). Spores erratic but occasionally high. Filicales rising at top to > 45% Σ (t.l.p. + pteridophytes).
BMa 1272–1290	*Alnus*, *Corylus* type, *Quercus* and *Ulmus* main pollen taxa – arboreal pollen dominant > 80% Σ t.p. Shrub values low, but species rich – *Hedera*, *Viburnum opulus*, *Rhamnus catharticus*, *Euonymus*. Herbs negligible.

(i) *Local pollen assemblage zone BMa* (Alnus, Corylus *type*, Quercus *and* Ulmus)

High *Alnus* values 75% Σ t.l.p. indicates the formation of an alder carr community. Wet, shady conditions are shown by the local abundance of Filicales spores.

TABLE 3. RADIOCARBON DATES FROM BROADNESS MARSH SB6/2

code	date/a B.P.	depth from surface/cm
Q-1283 SB6/2/C1	6882 ± 90	1286–1290
Q-1339 SB6/2/C2	6620 ± 90	1268–1273
Q-1342 SB6/2/C3	5410 ± 80	892–895
Q-1341 SB6/2/C4	5220 ± 65	877–880
Q-1340 SB6/2/C5	2836 ± 85	684–689

(ii) *Local pollen assemblage zone BMb* (*Gramineae*, *Cyperaceae*, Typha angustifolia/Sparganium)

Permanent flooding of the site favoured the growth of base rich sedge fen/reedswamp, with the expansion of Gramineae and Cyperaceae in which the pollen of *Cladium mariscus* was identified. This vegetational development is mirrored in the transitional phase to the main peat. The pollen assemblage also points to the development of local saltmarsh communities, with Chenopodiaceae values > 5% Σ t.l.p. accompanied by Compositae *Bellis* type, *Plantago maritima*, *Artemisia* and Cruciferae pollen.

(iii) *Local pollen assemblage zone BMc* (Quercus, Alnus, Corylus *type and Filicales*)

An expansion in total tree pollen and a rise particularly of *Quercus* and *Corylus* type pollen as the dominant tree taxa with Gramineae pollen, shows the formation of oak-fen woodland. This interpretation is supported by high values for Filicales spores and the poor pollen preservation.

(iv) *Local pollen assemblage zone BMd* (*Gramineae*, *Cyperaceae*, *Chenopodiaceae and* Pteridium aquilinum)

Between 760–752 cm herb pollen frequencies rise sharply, showing a return to reedswamp locally with open saltmarsh communities in the area. The increased richness of herb taxa with a continuous curve for *Plantago lanceolata* and the occurrence of *Rumex* spp., *Artemisia*, cereal type pollen and the rise of *Pteridium aquilinum* values, shows the increasing anthropogenic influence upon the vegetational composition.

(*c*) *Dating*

These deposits formed during p.z. VII, with peat growth beginning at 6882 ± 90 B.P. Five ^{14}C assays were made (see table 3).

The p.z. VII*a*/VII*b* boundary is clear, with the elm decline placed between 875–865 cm.

The sample for Q-1341 was taken a little below the point which finally emerged in the pollen spectra as the elm decline. This gives rather an 'old' date of 5220 ± 65 B.P. in the Thames context but is still conformable with dates for the elm decline.

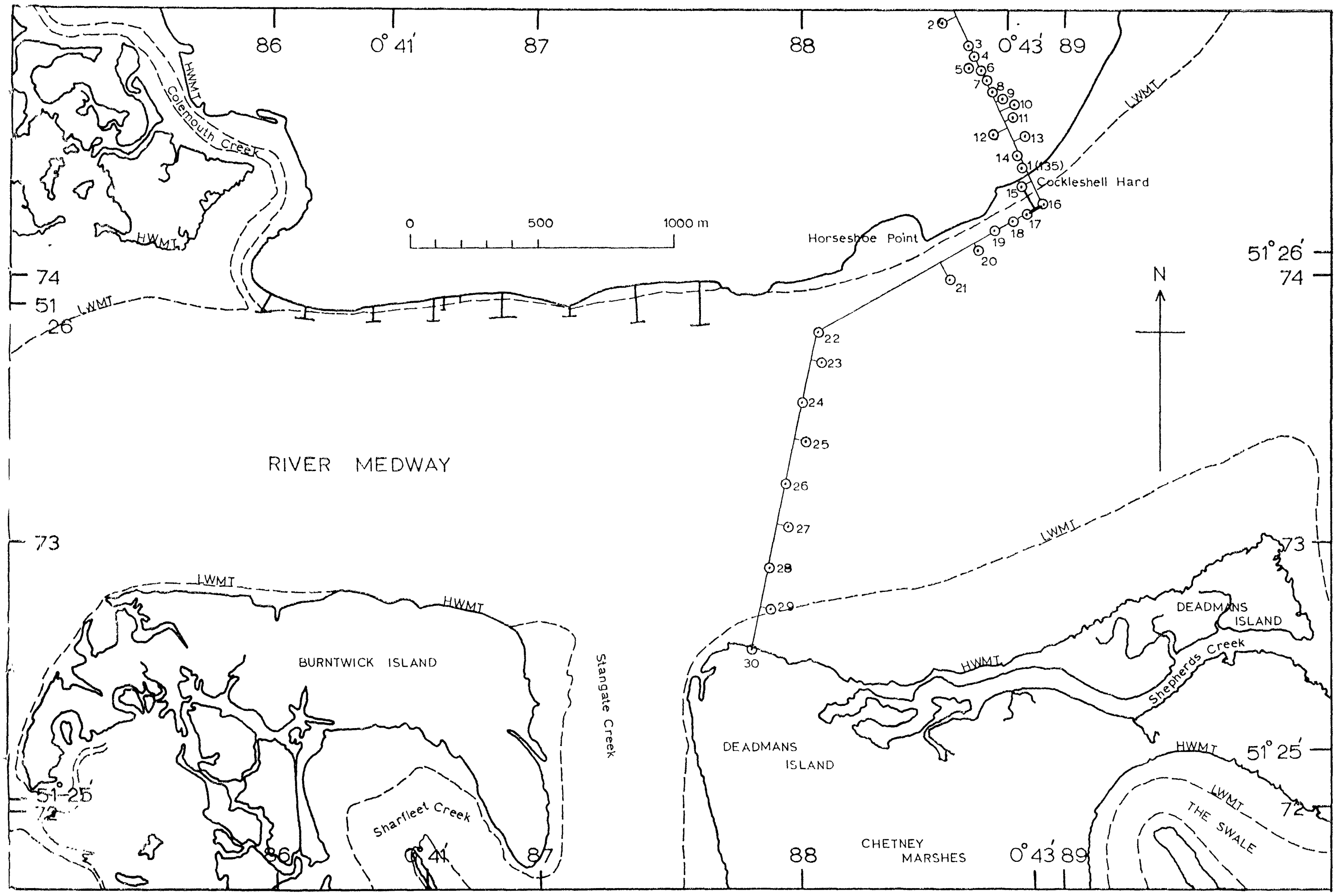


FIGURE 23. Site map of the southern Isle of Grain area, showing borehole locations (⊙).

8. Isle of Grain (Cockleshell Hard)

Site: TQ88847440: 51° 26′ 10″ N; 0° 43′ 3″ E.

Borehole SB2/135 was taken at Cockleshell Hard approximately 427 m at 42° from Horseshoe Point.

This point lies near the confluence of the Thames and Medway river channels (figure 23). Ground heights are low, lying below 2.5 m O.D. To the northwest the basal London Clay rises sharply to the surface, to form a low hill area, at a height of 8 m O.D. central to the present Isle of Grain.

(a) *Stratigraphy*

London Clay underlies the drift sequences, forming a stiff, fissured brown silt/clay with bands of clay and siltstone at depth. The surface shows the same trend as the overlying gravel (figures 24 and 25). Over most of the area shown, the surface lies between the maximum points of −28.4 m to −30 m O.D. The contour map of the surface (figure 26) demonstrates the northward fall of levels from −12 to −19/20 m O.D. over much of the present Medway channel. Altimetric 'highs' and 'lows' occur, as exemplified in cross-profile by EB2/27 and EB2/28. The bank slope of the main buried channel, with a gradient of between 1 : 11 and 1 : 12, is demonstrated by the closely spaced contours near the Isle of Grain. Here the outlet of the channel lies at −29/30 m O.D. The local depressions and 'highs' of the London Clay surface appear to have a northeast to southwest alignment, following the line of channel and stream flow, indicating a possible origin from tidal and river scour.

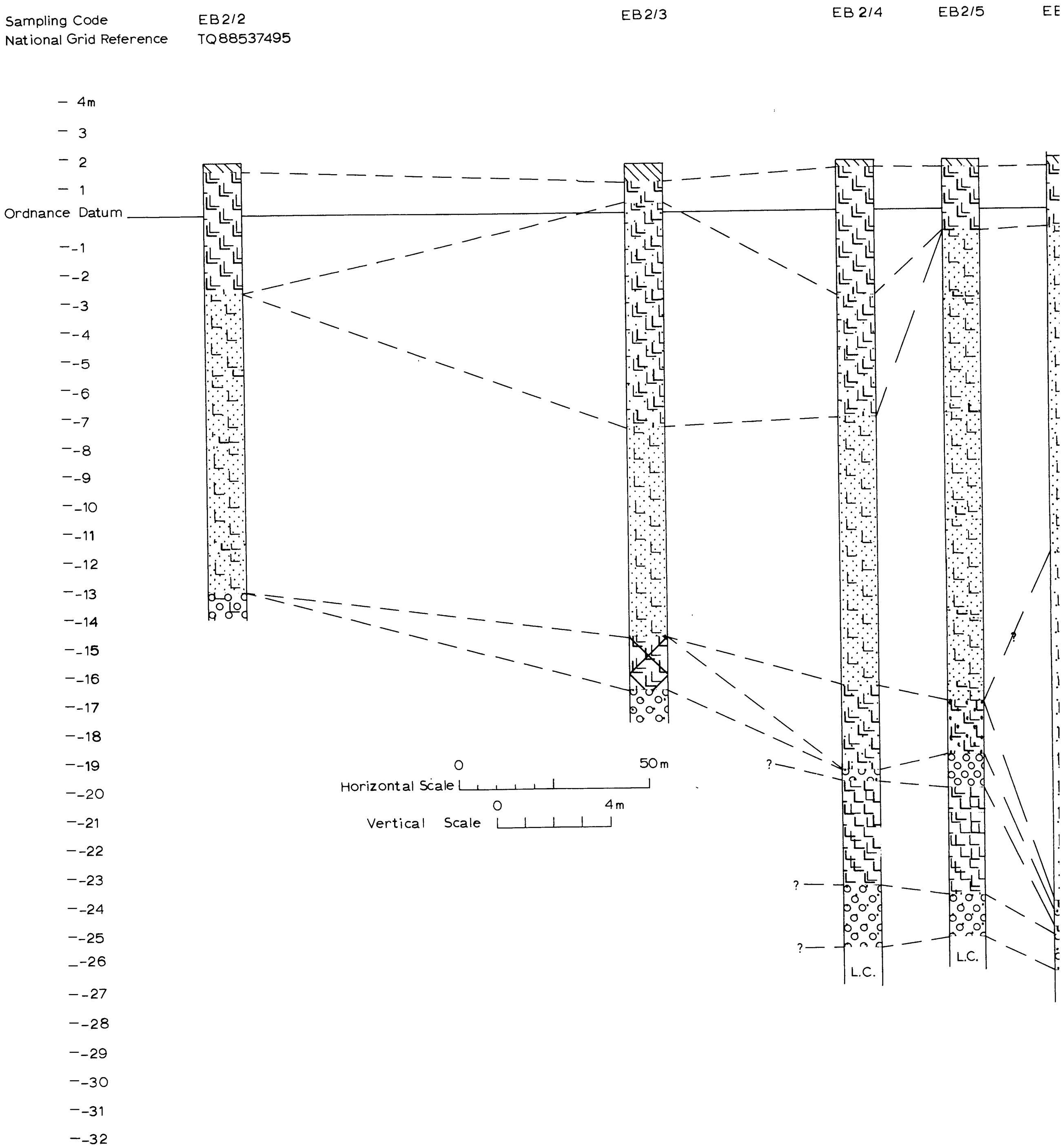
The gravel surface is composed of dense, coarse brown sand with fine/coarse orange-brown flints. Two distinct levels are identified (figure 24) in addition to two gravel layers, separated by a stiff fissured brown silt/clay. The upper gravel falls from −13 to −24.3 m O.D. in height, with a sharp break of slope at EB2/5 before the layer coalesces with the main deposit at EB2/7. The main gravel can be traced as a separate layer in EB2/4–EB2/6. The intercalated silt/clay resembles the basal London Clay and may form a landslip deposit (see § 1). The gravel forms an irregular profile, varying in thickness between 1–4 m. At EB2/22 (figure 25) another abrupt change of slope occurs, the deposit rising from −25.75 m to −18.75 m O.D. in EB2/23. The two major breaks of slope identified in the cross-profile of the gravel surface, may be interpreted as the bank limits of the Medway buried channel.

The drift sequences are composed of a complex of fine sands, silts and clays overlying the basal gravel. A single persistent layer of fine, grey silt/sand can be traced through all boreholes (figure 24), occurring between −0.5 to −28.5 m O.D. Shell fragments and occasional shell beds are commonly found at all levels in the deposit. Above this main sand bed the sequences are dominated by a firm mottled grey-brown silt/clay, changing at a depth of −0.5 to −1.5 m O.D. to a soft medium grey silt/clay. The layer lies between the limits of +2 to −8 m O.D. Biogenic layers are infrequent and poorly developed with only a single silty monocot peat found in EB2/10, between −7.9 to −9 m O.D. This thick sequence of deposits would appear to represent environments typical of intertidal mud/sand flat areas. Large laterally shifting sand bodies, represented by the main silty sand bed, would form in conjunction with the creation of channel features and the deposition of thinner silt and shell layers (Klein 1967; Kirby 1969).

The main silty sand body overlies a 0.5–3 m thick silt/clay. This forms at two distinct levels, at average depths of −16 m and −23 m O.D. (figure 24). At depth the deposit develops into an organic rich silt/clay, composed of a dark brown clay/gyttja 0.5–2 m thick, with inclusions of detrital wood and monocot elements. Again two separate levels can be identified (figure 24) controlled by the basal gravel and London Clay surface. Thus the clay/gyttja lies between −14.7 to −16.6 m O.D. in EB2/2–EB2/5, falling rapidly southward to an average depth of −25 to −26.5 m O.D. over the gravel. This layer may be correlated across the river to a clay/gyttja in EB2/28 and EB2/30 (figure 25). In EB2/12–14 (figure 24) an apparent channel occurs in cross section, indicating possible erosion of the deposit subsequent to deposition. In figure 25 the clay/gyttja disappears abruptly in EB2/23 as the basal gravel surface rises sharply.

(*b*) *Pollen analysis and dating*

The stratigraphy of SB2/135 is presented in figure 24 (see § 2*c*). A 45 cm U-4 piston core was retrieved from between 2758–2803 cm toward the base of the biogenic deposit. Two lithostratigraphic units are identified with recognition of two l.p.z. Changes in pollen frequencies are small and dominated throughout by arboreal pollen (figure 27).



Sampling Code
National Grid Reference
EB2/2
TQ88537495
EB2/3
EB 2/4
EB2/5
EE
– 4m
– 3
– 2
– 1
Ordnance Datum
–-1
–-2
–-3
–-4
–-5
–-6
–-7
–-8
–-9
–-10
–-11
–-12
–-13
–-14
–-15
–-16
–-17
–-18
–-19
–-20
–-21
–-22
–-23
–-24
–-25
–-26
–-27
–-28
–-29
–-30
–-31
–-32
0
50m
Horizontal Scale
0
4m
Vertical Scale
?
?
?
L.C.
L.C.

FIGURE

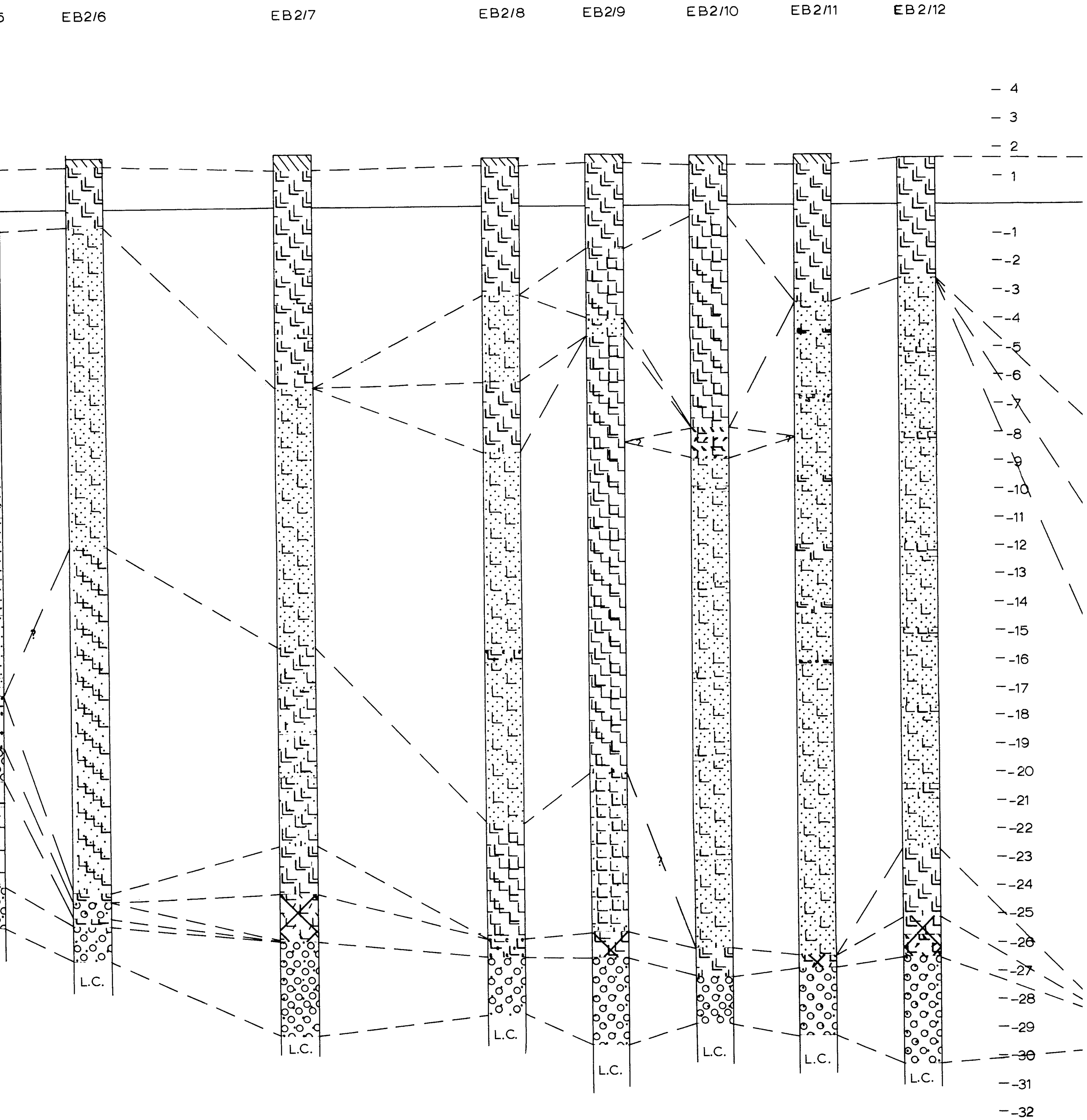
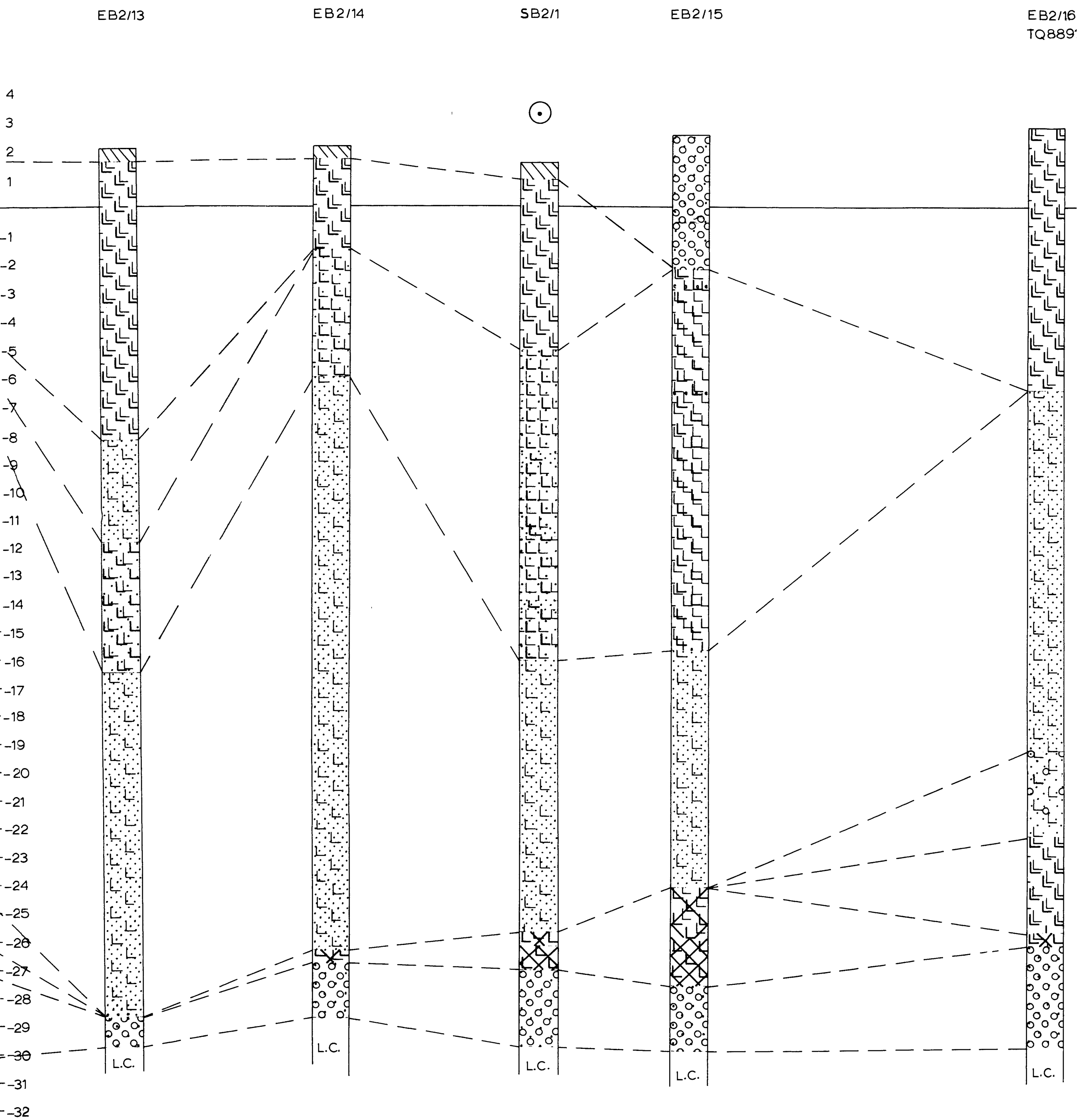


FIGURE 24. Stratigraphic diagram from Cockleshell Hard, Isle of Grain, based upon borehole data from G. Wimpey & Co. L
Research Establishment, Watford. L.C., London Clay, a very stiff and tenacious, fissured brown silty clay; ⊙, sampl



& Co. Ltd, and the Building
⊙, sampled borehole.

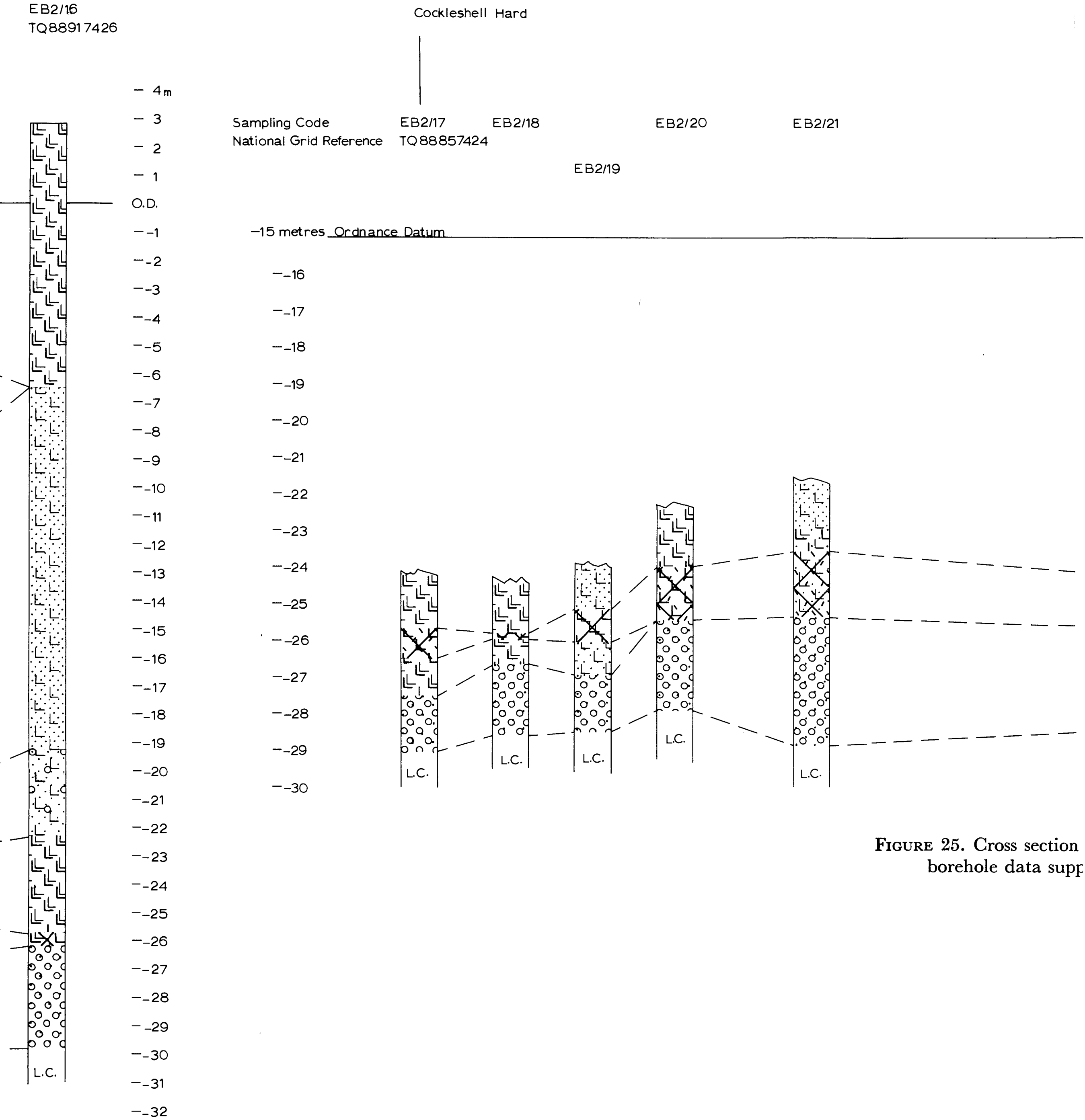
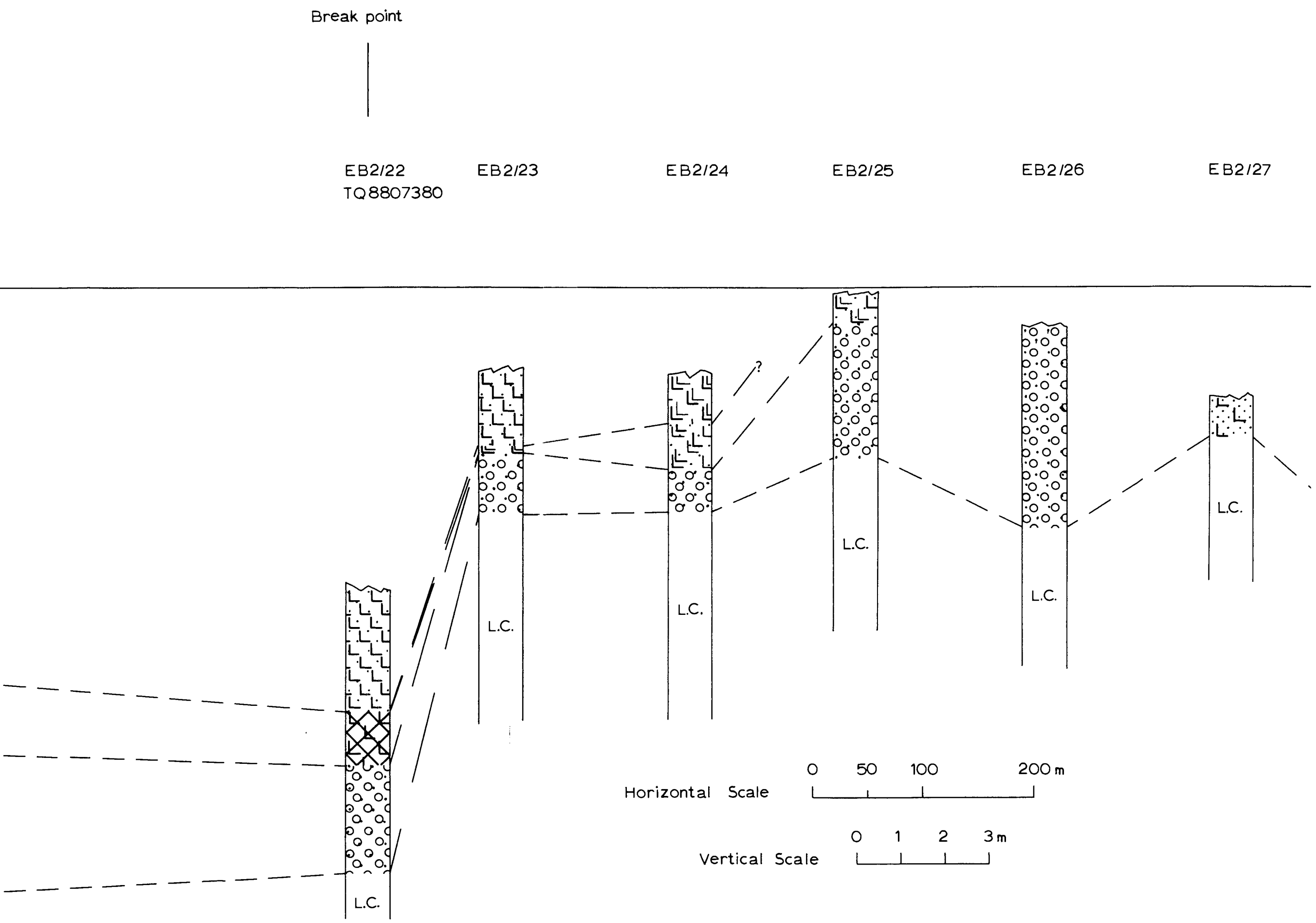
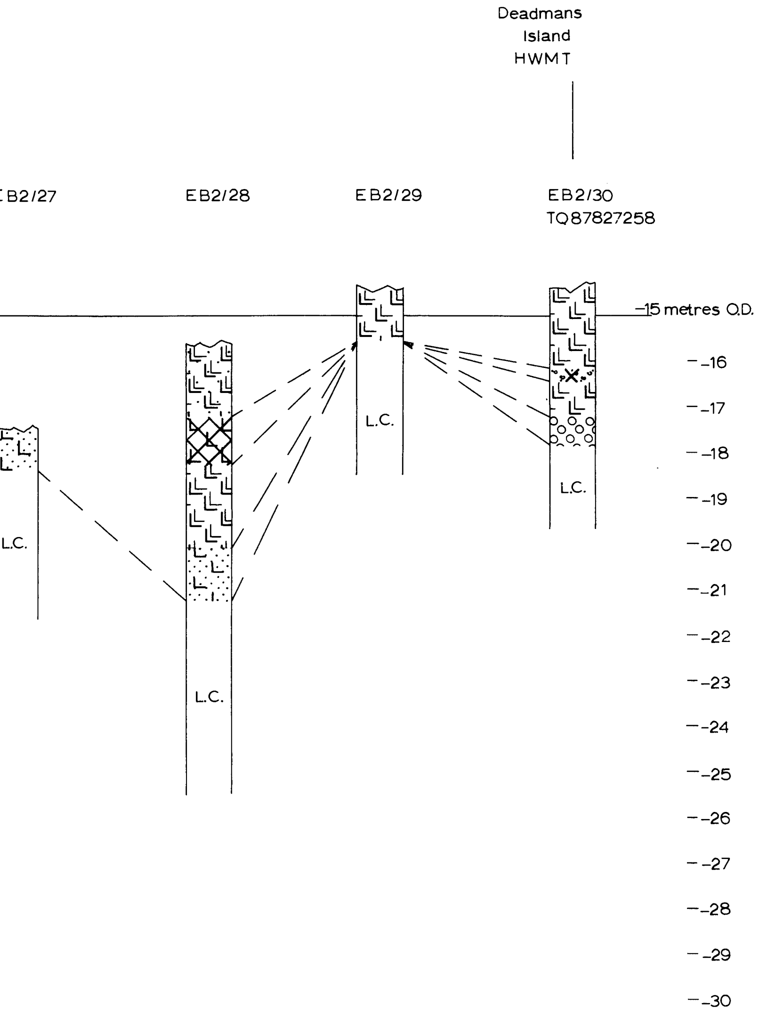
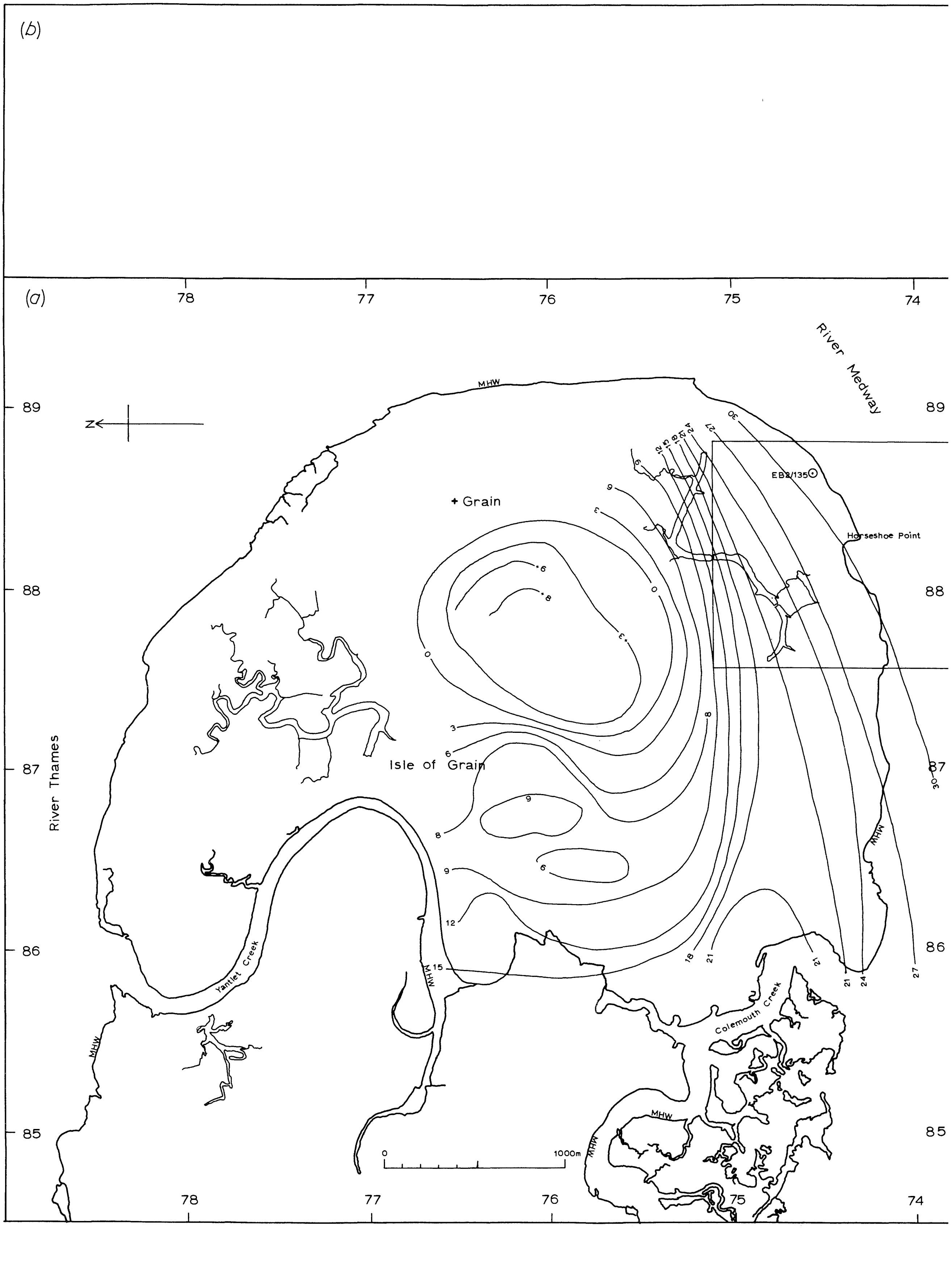


FIGURE 25. Cross section
borehole data supp



ss section of the River Medway, showing the London Clay surface and basal buried channel sediments, based upon data supplied by G. Wimpey & Co. Ltd. L.C., London Clay – a stiff and tenacious, fissured brown silty clay.


Deadmans
Island
HWMT
EB2/27
EB2/28
EB2/29
EB2/30
TQ87827258
-15 metres O.D.
-16
-17
-18
-19
-20
-21
-22
-23
-24
-25
-26
-27
-28
-29
-30
L.C.
L.C.
L.C.
L.C.


(b)
(a)
78
77
76
75
74
89
88
87
86
85
N
River Thames
River Medway
+ Grain
Isle of Grain
EB2/135
Horseshoe Point
MHW
Yantlet Creek
Colemouth Creek
0
1000m

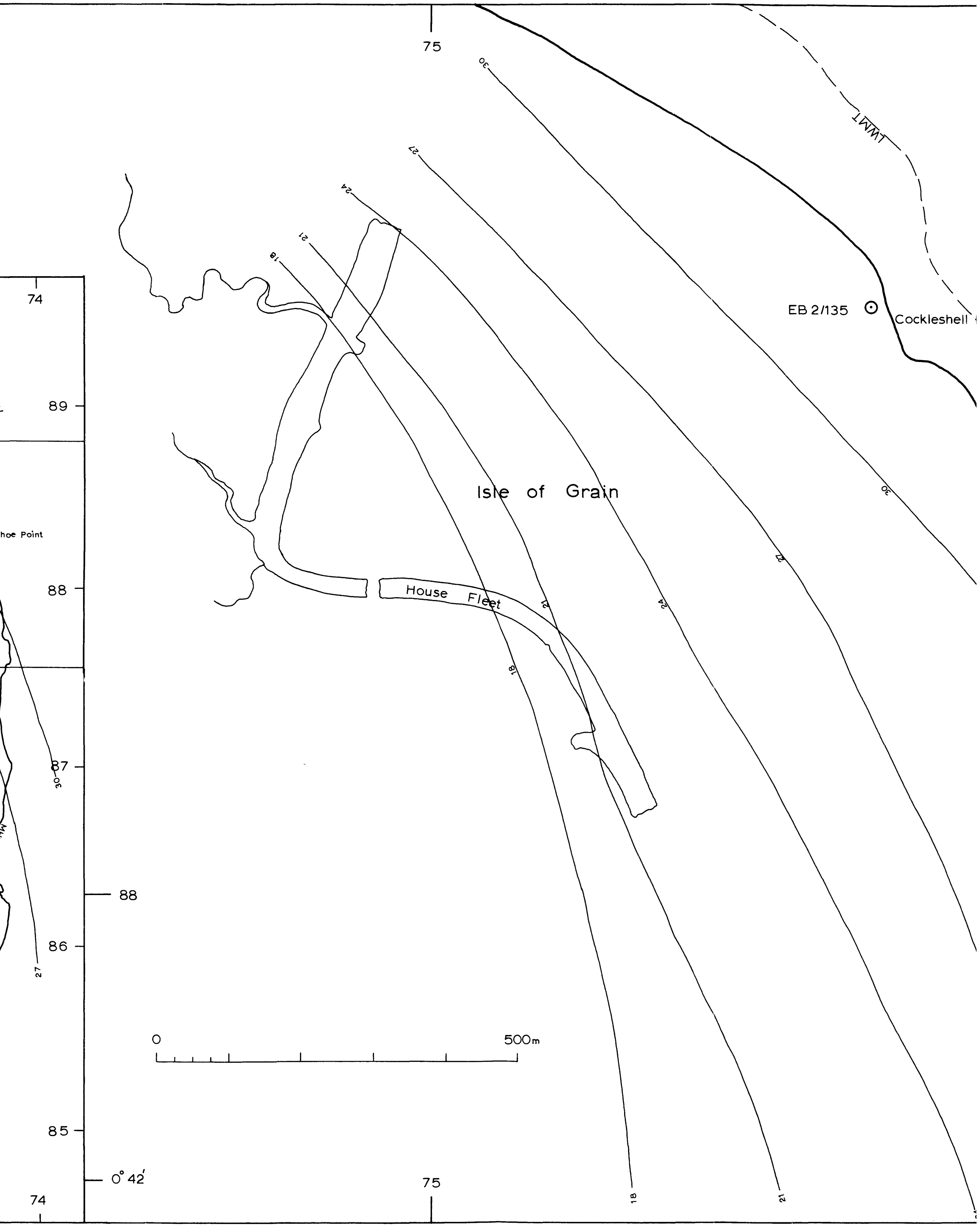
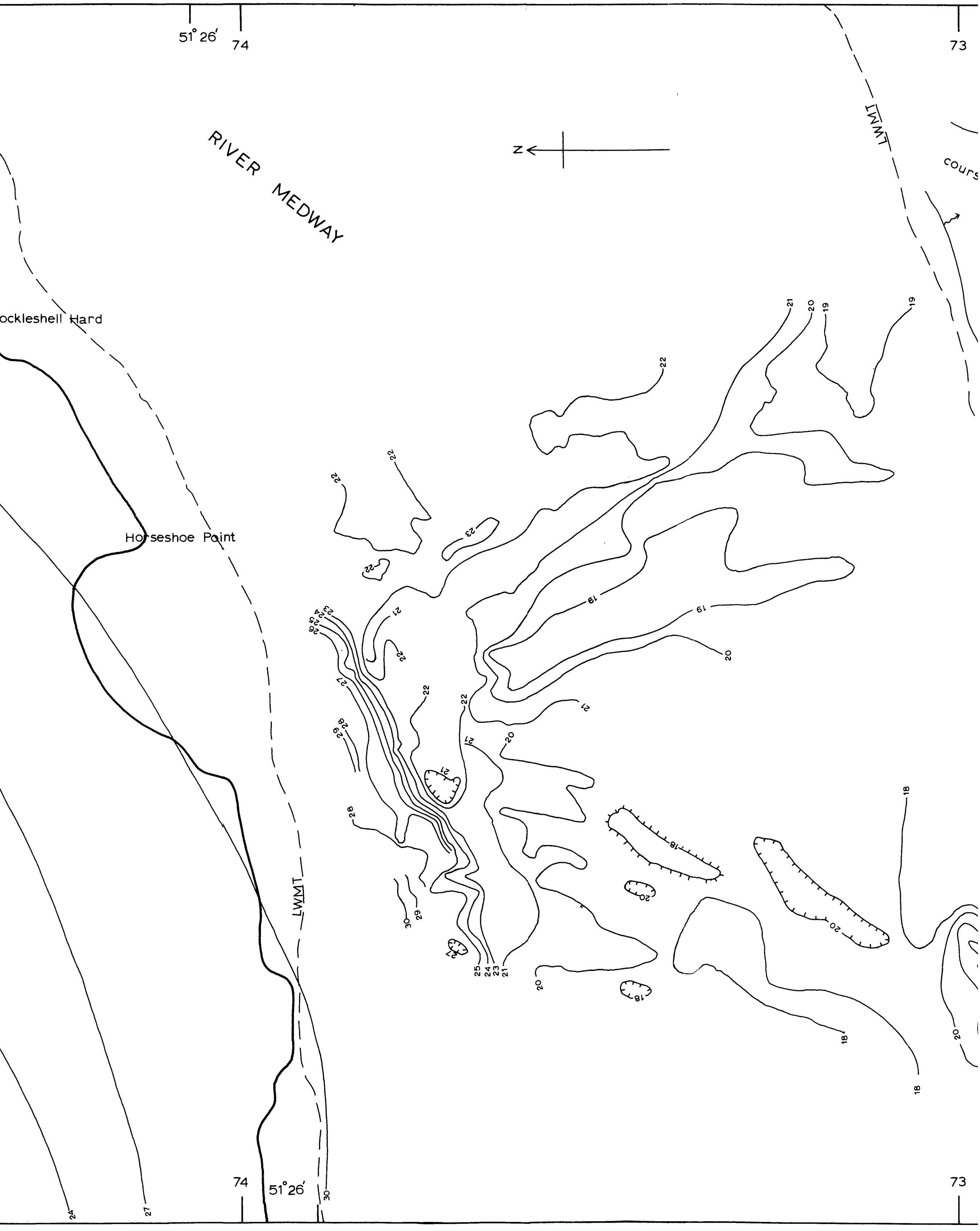
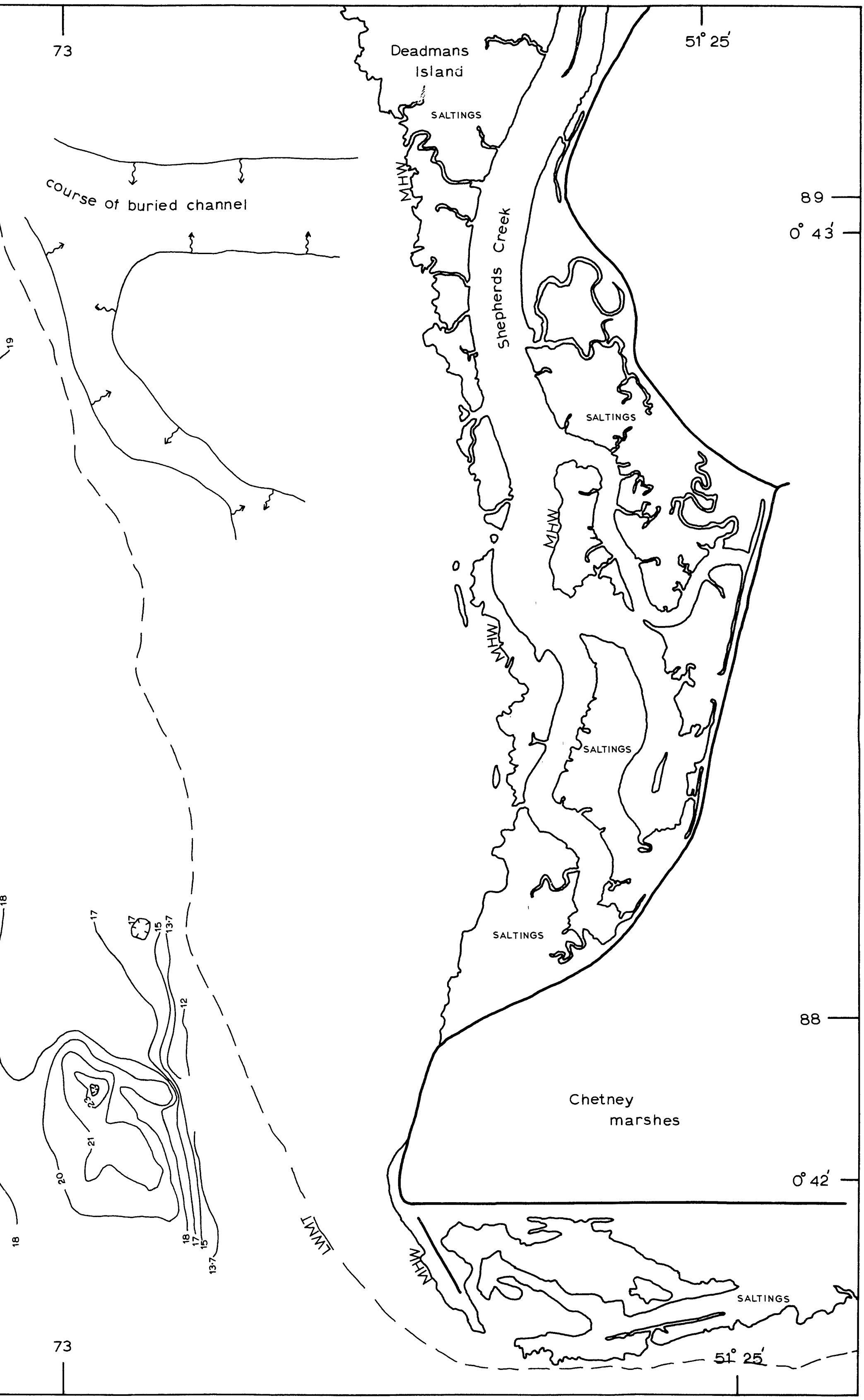


FIGURE 26. Maps of the London Clay surface. (*a*) Isle of Grain; (*b*) The Isle of Grain and th
O.D. (Newlyn), from borehole and geophysical data supplied to the C.E.G.B. by G. W
by Soil Mechanics Ltd. ⤳, Direction of slope; —, embankment.



in and the Medway channel. Contours are plotted in metres below
by G. Wimpey & Co. Ltd (1966–72), and to British Petroleum


73
51° 25′
Deadmans Island
SALTINGS
course of buried channel
MHW
Shepherds Creek
89
0° 43′
SALTINGS
MHW
MHW
SALTINGS
19
18
17
17
15
13·7
12
SALTINGS
88
Chetney marshes
21
20
18
18
17
15
13·7
LWMT
0° 42′
MHW
SALTINGS
73
51° 25′

l.p.z. depth below surface (cm)	description
Gb 2764–2793	Decline of aquatic values and rise of a.p. to > 70 % Σ t.p. *Corylus* type and *Quercus* frequencies at their highest. *Pinus* and *Ulmus* values fall and show little change between levels. Shrubs contribute little to the pollen assemblage, *Hedera* and *Salix* persistent but < 1 % Σ t.l.p. Gramineae pollen expands here to > 20 % Σ t.l.p. but Cyperaceae sporadic. Paucity in herb taxa.
Ga 2793–2803	Arboreal pollen frequencies dominant but with high aquatic and herb pollen values. *Typha angustifolia/Sparganium* pollen reaches a maximum of > 25 % Σ (t.l.p. + aquatics). Sporadic occurrences of *Myriophyllum* spp. and *Typha latifolia*. Cyperaceae and Gramineae are important with herbs relatively rich in taxa, including *Plantago maritima*, *Artemisia*, *Filipendula*, Rosaceae and Umbelliferae pollen.

Dominance of the pollen assemblage by *Corylus* type, *Quercus*, *Pinus* and *Ulmus* with low *Betula* values and the absence or occasional find of *Alnus* and *Tilia* pollen, indicates accumulation during p.z. VI*b*. A radiocarbon date at the base of the core gave a date of 8510 ± 110 B.P. confirming a Boreal age. However, from the rapid rate of deposition in sub-strata 3*a* and 3*b*, suggested by the pollen assemblage showing formation entirely within p.z. VI*b*, it is likely that inundation occurred before the end of p.z. VI*c* (Godwin 1975).

Table 4. Variation in depth of the biogenic deposits in the Thames Estuary

type site code	height taken to top of each level/m O.D.
TV	+ 0.40 to − 0.90
TIV	− 0.80 to − 1.80
TIII	− 1.90 to − 5.20
TII	− 6.80 to − 10.07
TI	− 13.23 to − 25.53 (Isle of Grain)

Table 5. Flandrian marine transgression sequences in the lower Thames Estuary

transgression	age/a B.P.
Thames V	≈ 1750
Thames IV	2600–
Thames III	3850–2800
Thames II	6575–5410
Thames I	8200–6970

9. Evidence for sea level and vegetational changes

The stratigraphic evidence has been summarized and presented in a longitudinal profile along a WNW to ESE axis, from Woolwich to Tilbury (figure 28). An inset diagram (figure 28*a*) shows the relation of the lowest basal deposits found at the Isle of Grain to those of the main sampling sites. Five separate biogenic horizons are identified and equated with regressions of sea level, although the upper two levels taken from Tilbury are impersistent. The variation in depth of the biogenic deposits encountered is presented in table 4 (Devoy 1977*b*). No major anomalies in the height of the layers north to south of the river were found.

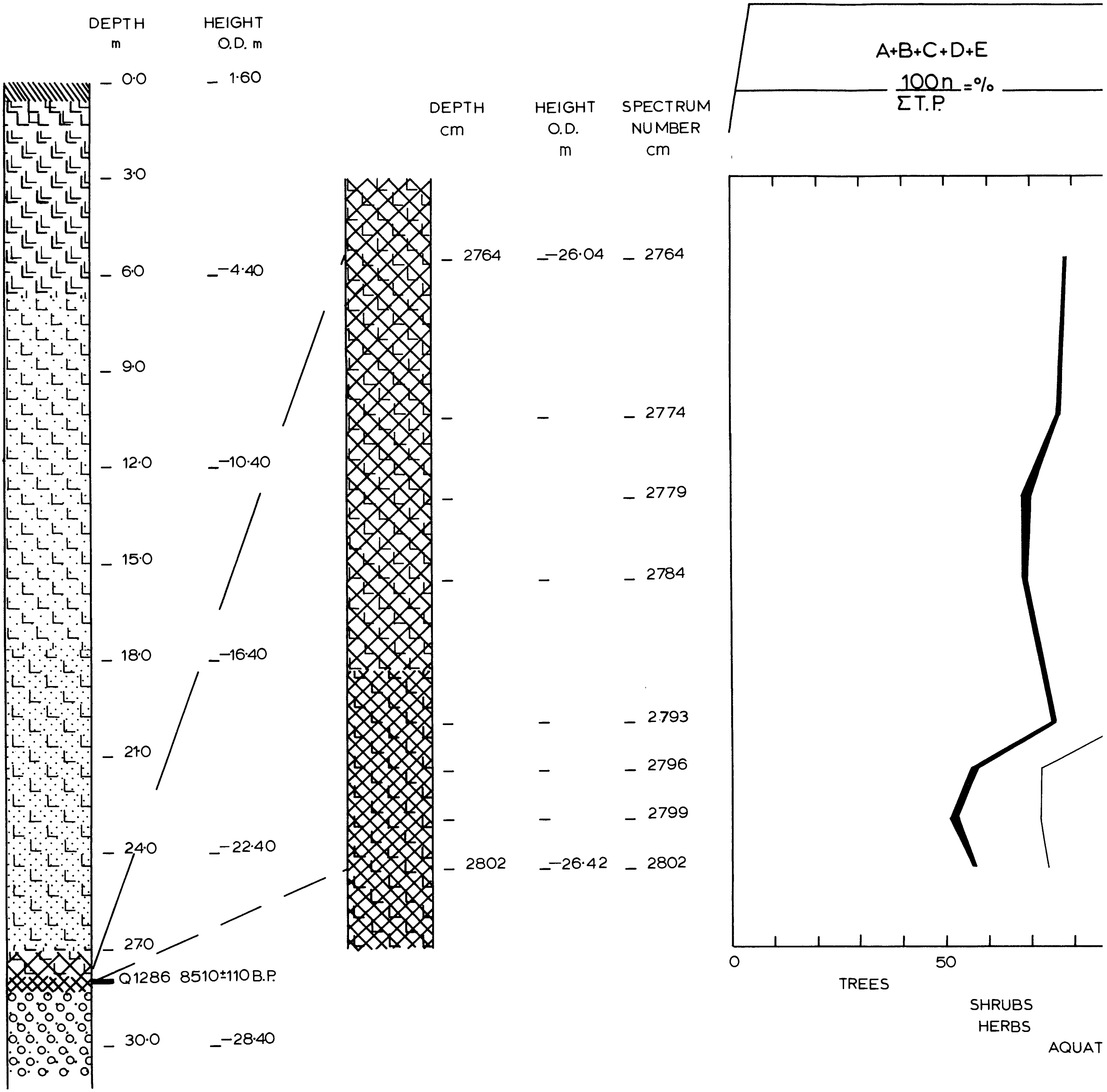
The Flandrian sequences are developed upon a fluvially dissected late Devensian gravel surface, which falls progressively in height from west to east. The intercalated alluvial deposits continue this west–east dip, increasing markedly in degree from Broadness Marsh eastward. The inorganic fraction is composed of fine blue-grey muds < 60 μm in diameter, with silt and clay sized particles dominant. From these phases of inorganic deposition four marine transgressions are recognized (see table 5). A fifth transgression can be identified at Tilbury, although this is dependent upon the recognition of Tilbury V. These deposits formed in a brackish water environment and show the importance of marine tidal influence in the estuary from the outset in Thames I.

The biogenic layers, formed by wood and monocot peats with gyttjas, show distinct internal changes in composition along a transect from west to east. At the eastern, seaward end, *Phragmites* and saltmarsh peats dominate the deposits, changing upstream to form freshwater oak-alder fen wood peats. However, westward from Broadness Marsh, all the sites showed seral vegetational development in the biogenic layers, changing from wood fen peat to *Phragmites* and then saltmarsh peat before the close and also before the onset of a marine transgression. This supports the diatom evidence of an early and increasing salinity influence downstream and the upstream progression of the tidal limit with time. Pollen and macrofossil analyses demonstrate the importance of the local influences of saltmarsh and fen environments upon the vegetational history of the area. Following the recognition of the *Ulmus* decline at the Thames sites at *ca.* 5000 B.P., non-arboreal pollen becomes dominant in the areas' pollen rain, reflecting both the influence of anthropogenic activity and rising sea level. In a regional context the rational limit of *Alnus* (Smith & Pilcher 1973) has been placed between 8510 ± 110 and 8170 ± 110 B.P., with high *Alnus* pollen frequencies occurring in a late Boreal VI*c* pollen context (Godwin 1975).

10. Pattern and rates of relative sea level change in the Thames Estuary

From 17 radiocarbon dated index points, two relative sea level curves have been drawn for the Flandrian deposits of the Thames Estuary (figure 29). The relation and date of each of these points to their contemporary sea levels has been fixed by biostratigraphic analyses and radiocarbon dating. From Tilbury, 7 index points compose curve 1, whilst levels taken from the sampled sites of Crossness, Dartford, Stone and Broadness form the basis for curve 2. The 'best fit' line for the behaviour of sea level shown by the graphs, expressing the positive and negative movements represented by the interleaved clays and peats respectively, is an oscillating curve. However, the amplitude of the regressions or negative movements of sea level is not known precisely. Thus curves 1 and 2 show only the expected trend in downward movement, rather than absolute levels. These two curves describe an almost identical pattern of sea level change, the only difference being that of the height of the movements relative to Ordnance Datum, with curve 2 lying *ca.* 1.5–3 m above curve 1 between 7000–2500 B.P. A mean line for the index points, drawn without reference to the positive and negative interpretation of sea level movements, forming sea level curve 3, is also produced to show the overall trend of a steadily rising sea level with time (figure 29).

From figure 29, some general conclusions about the movement of sea level corresponding to m.h.w.s.t. can be drawn for this area (Devoy 1977*b*).



CO-ORDINATES 51° 26′ 10″ N. 0° 43′ 03″ E
NATIONAL GRID REFERENCE TQ 8884 7440
FIELDWORK R. KIRBY 681021
ANALYSED R.J.N.D. 731214–740123

+ VALUES <0·5% ΣT.L.P.

VALUES FOR ΣT.L.P.–(ALNUS+CYPERACEAE

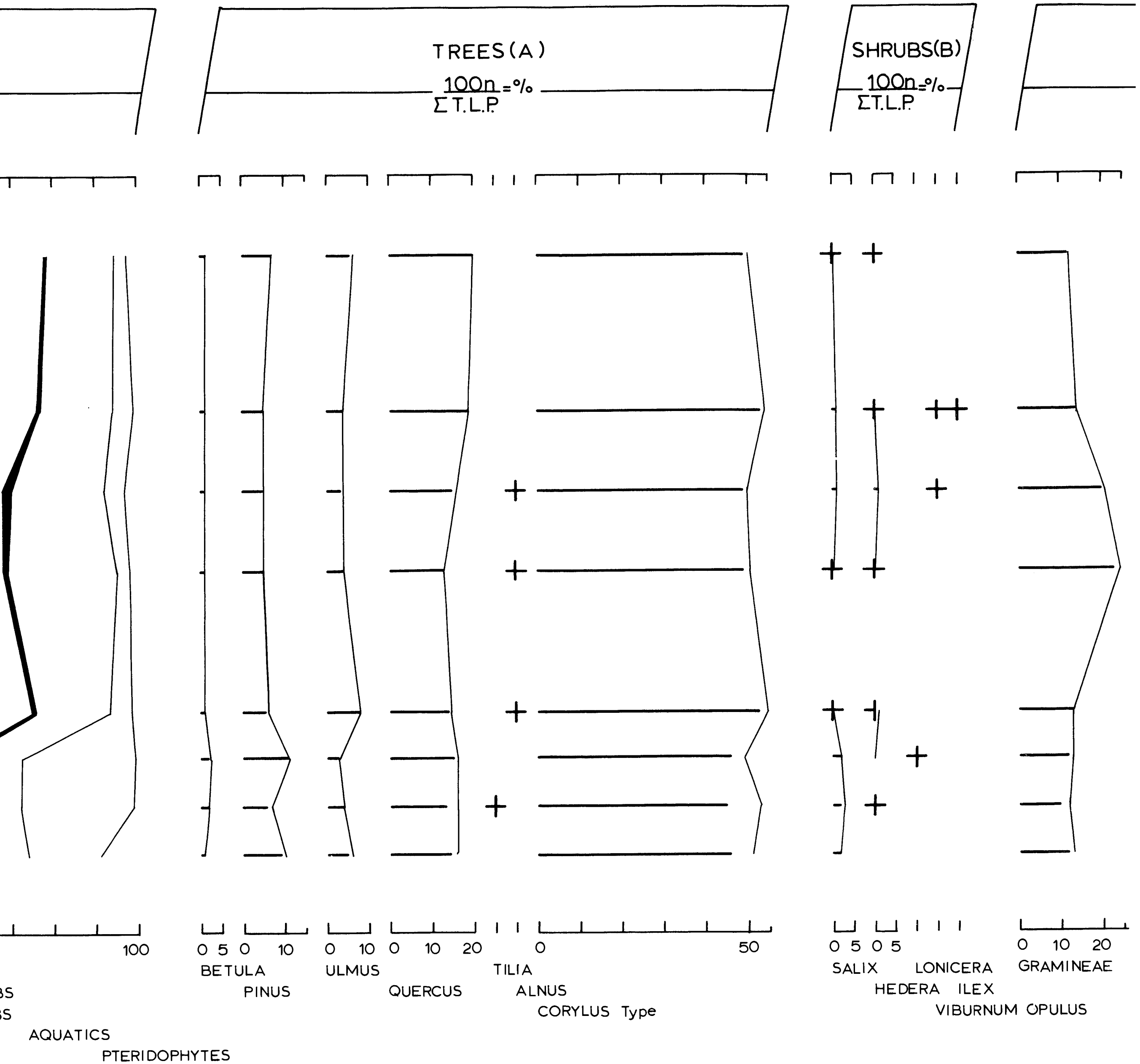
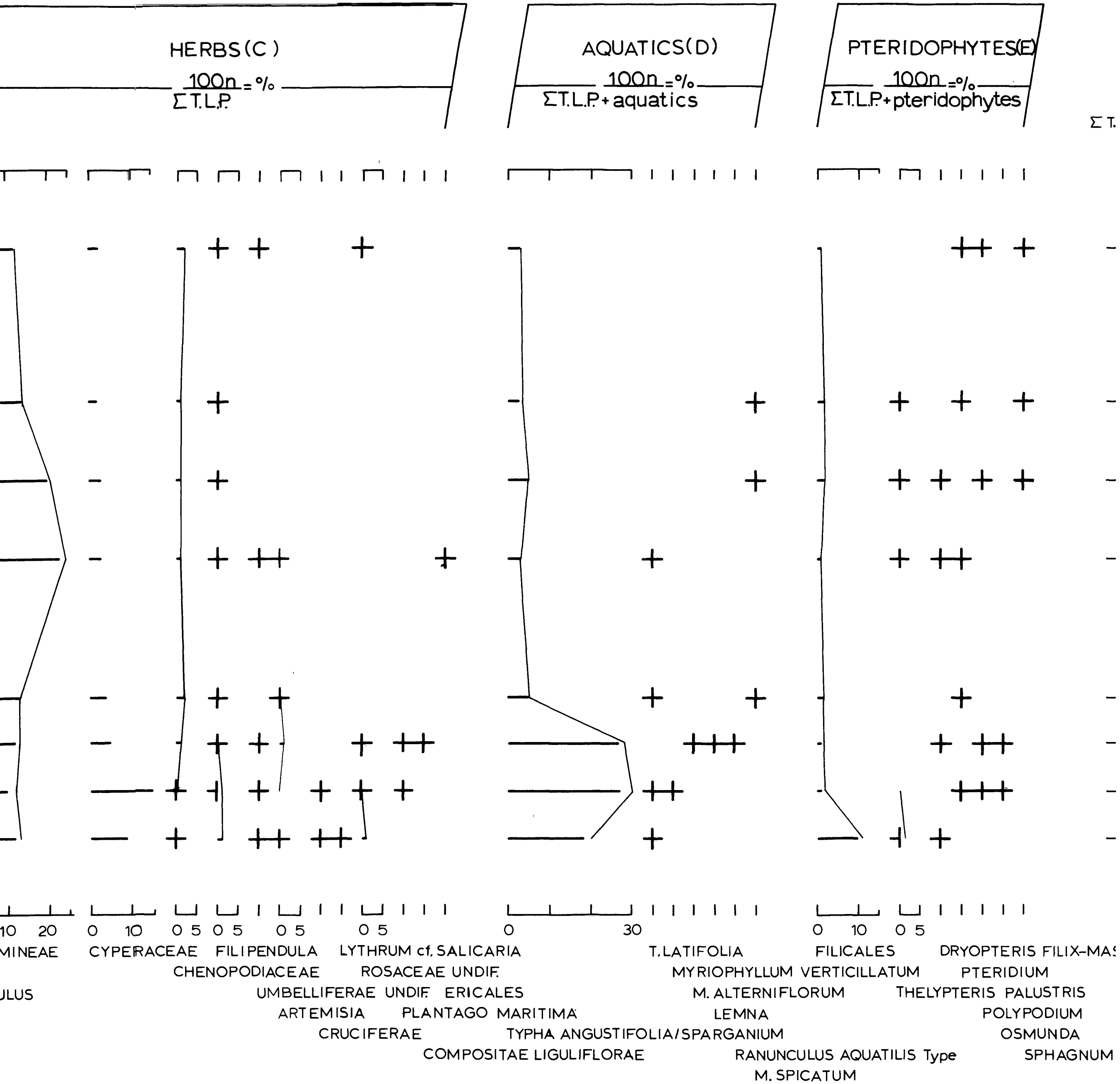
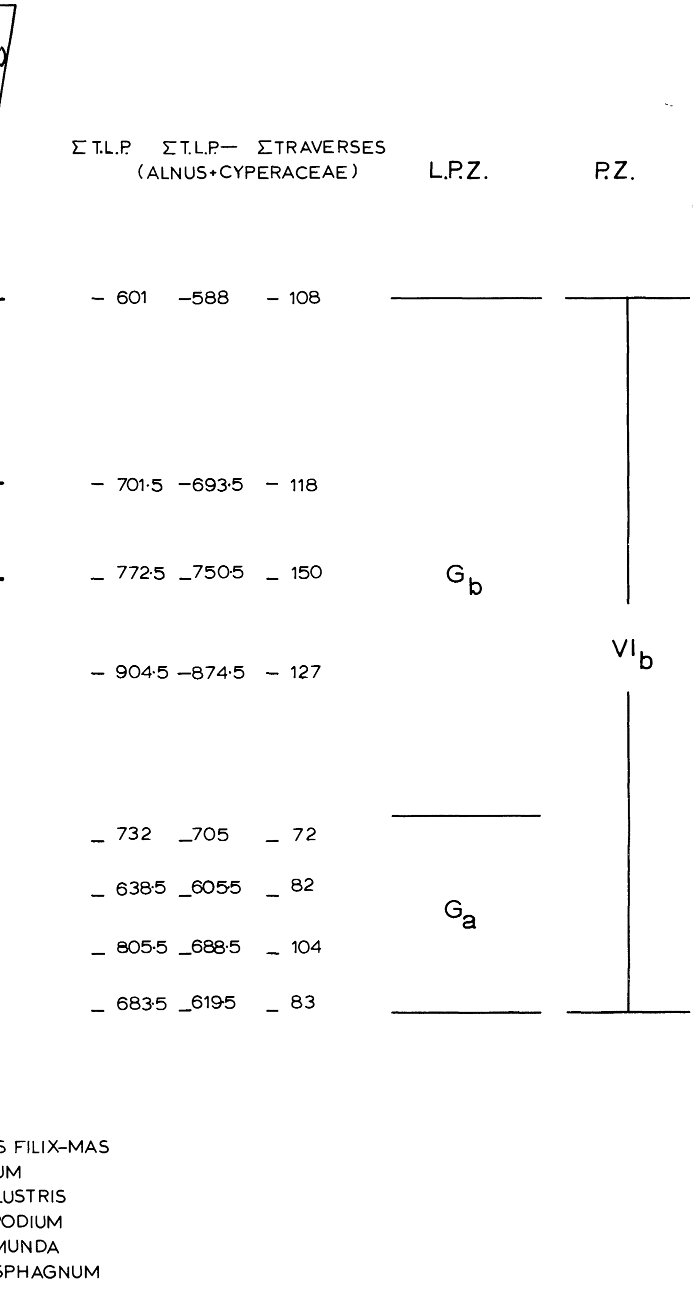
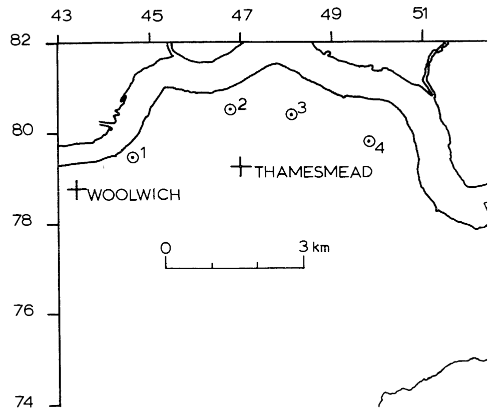


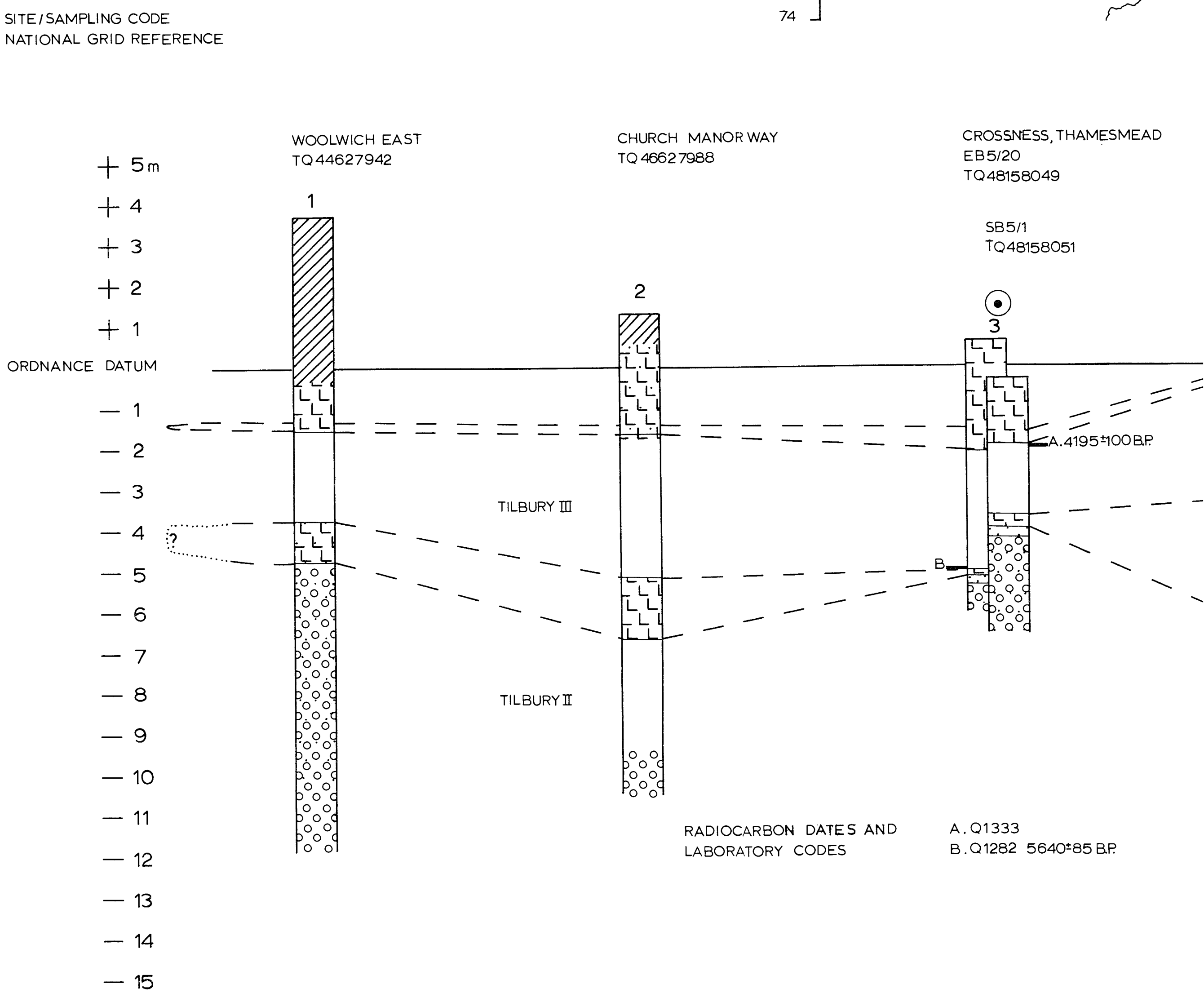
FIGURE 27. Pollen diagram from the Isle of Grain, EB 135 (Cockl



35 (Cockleshell Hard).


ΣT.L.P.
ΣT.L.P.— (ALNUS+CYPERACEAE)
ΣTRAVERSES
L.P.Z.
P.Z.
601 588 108
701·5 693·5 118
772·5 750·5 150
904·5 874·5 127
732 705 72
638·5 605·5 82
805·5 688·5 104
683·5 619·5 83
Gb
Ga
VIb
S FILIX-MAS
UM
LUSTRIS
ODIUM
MUNDA
SPHAGNUM


43
45
47
49
51
82
80
78
76
74
1
2
3
4
THAMESMEAD
WOOLWICH
0
3 km


SITE / SAMPLING CODE
NATIONAL GRID REFERENCE
+ 5m
+ 4
+ 3
+ 2
+ 1
ORDNANCE DATUM
— 1
— 2
— 3
— 4
— 5
— 6
— 7
— 8
— 9
— 10
— 11
— 12
— 13
— 14
— 15
WOOLWICH EAST
TQ44627942
1
CHURCH MANOR WAY
TQ46627988
2
CROSSNESS, THAMESMEAD
EB5/20
TQ48158049
SB5/1
TQ48158051
3
?
TILBURY III
TILBURY II
A. 4195±100 B.P.
B.
RADIOCARBON DATES AND
LABORATORY CODES
A. Q1333
B. Q1282 5640±85 B.P.

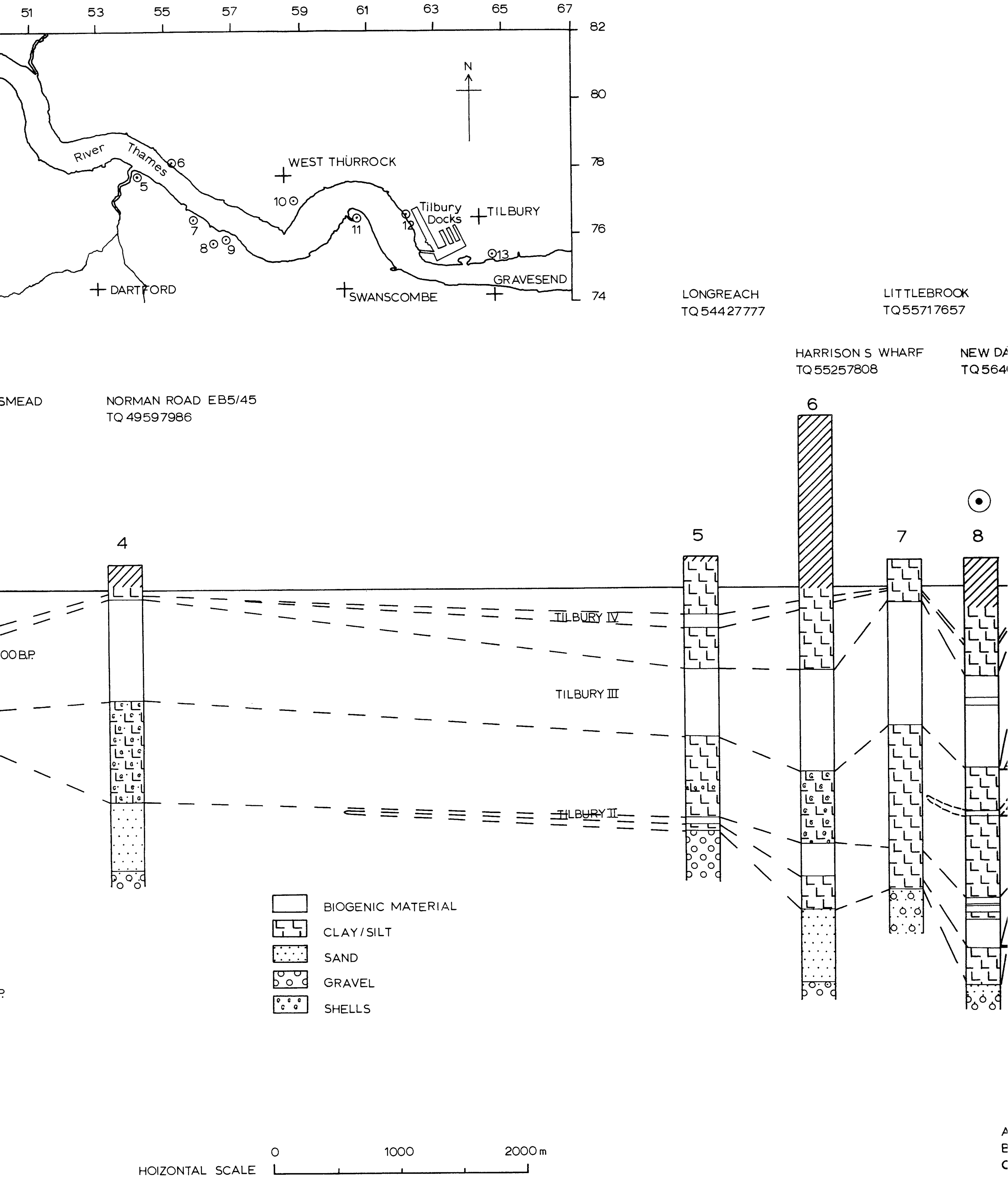
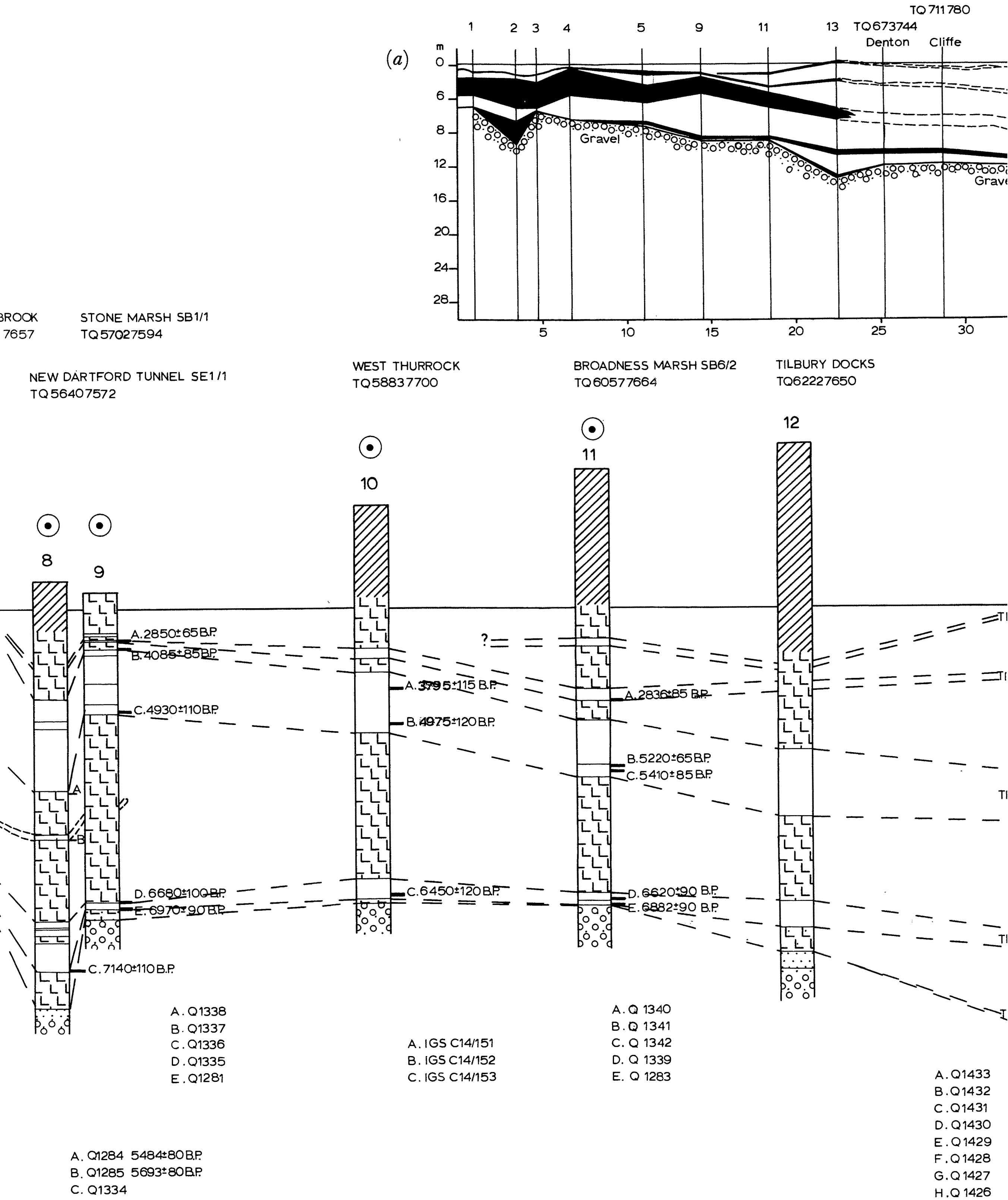
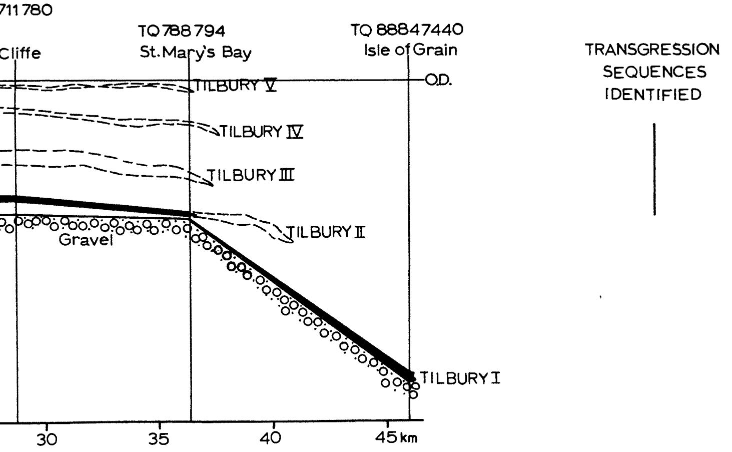
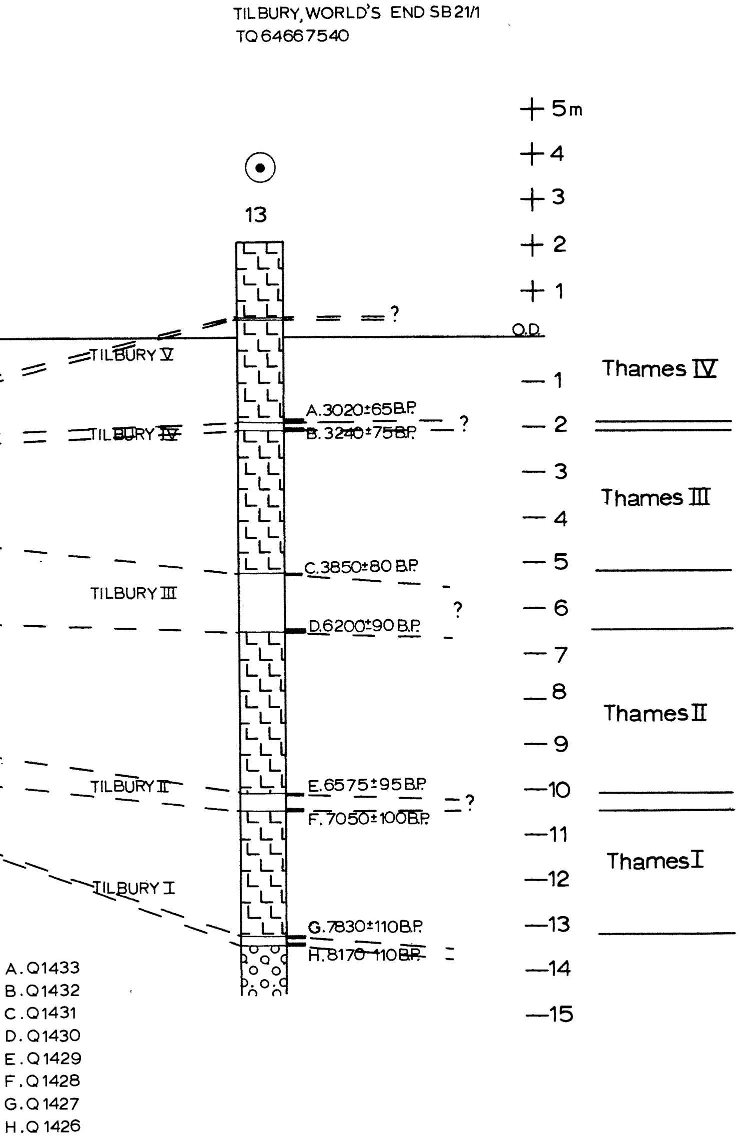


FIGURE 28. Flandrian transgression sequences in the Thames Estuary. Figure 28*a* gives a generalized sec
the distribution of biogenic and inorganic sediments and the relation of the Isle of Grain sequence to



ralized section of the lower Thames Estuary, showing
equence to the Tilbury sequence. ⊙, Sampled borehole.


711 780
TQ 788 794
St. Mary's Bay
TQ 88847440
Isle of Grain
Cliffe
TRANSGRESSION SEQUENCES IDENTIFIED
O.D.
TILBURY V
TILBURY IV
TILBURY III
TILBURY II
TILBURY I
Gravel
30
35
40
45 km


TILBURY, WORLD'S END SB21/1
TQ 64667540
13
+5 m
+4
+3
+2
+1
O.D.
−1
−2
−3
−4
−5
−6
−7
−8
−9
−10
−11
−12
−13
−14
−15
TILBURY V
TILBURY IV
TILBURY III
TILBURY II
TILBURY I
A. 3020±65 B.P.
B. 3240±75 B.P.
C. 3850±80 B.P.
D. 6200±90 B.P.
E. 6575±95 B.P.
F. 7050±100 B.P.
G. 7830±110 B.P.
H. 8170 110 B.P.
Thames IV
Thames III
Thames II
Thames I
A. Q1433
B. Q1432
C. Q1431
D. Q1430
E. Q1429
F. Q1428
G. Q1427
H. Q1426

1. The period of time from 8500/300–7000 B.P. showed a rapid rise of sea level from −25.5 m to −8.9 m O.D. Peat growth occurred on the basal Devensian gravel surface. As yet no provable and clear regression phases have been recorded during this time. The rate of submergence was *ca.* 1.3 compared with *ca.* 1.2 cm/year established for the Netherlands (Jelgersma 1961) and *ca.* 1.5 cm/year for northwest England (Tooley 1976).

2. Sea level fell for about 300 years between 7000–6700 B.P., with formation of an alder wood peat.

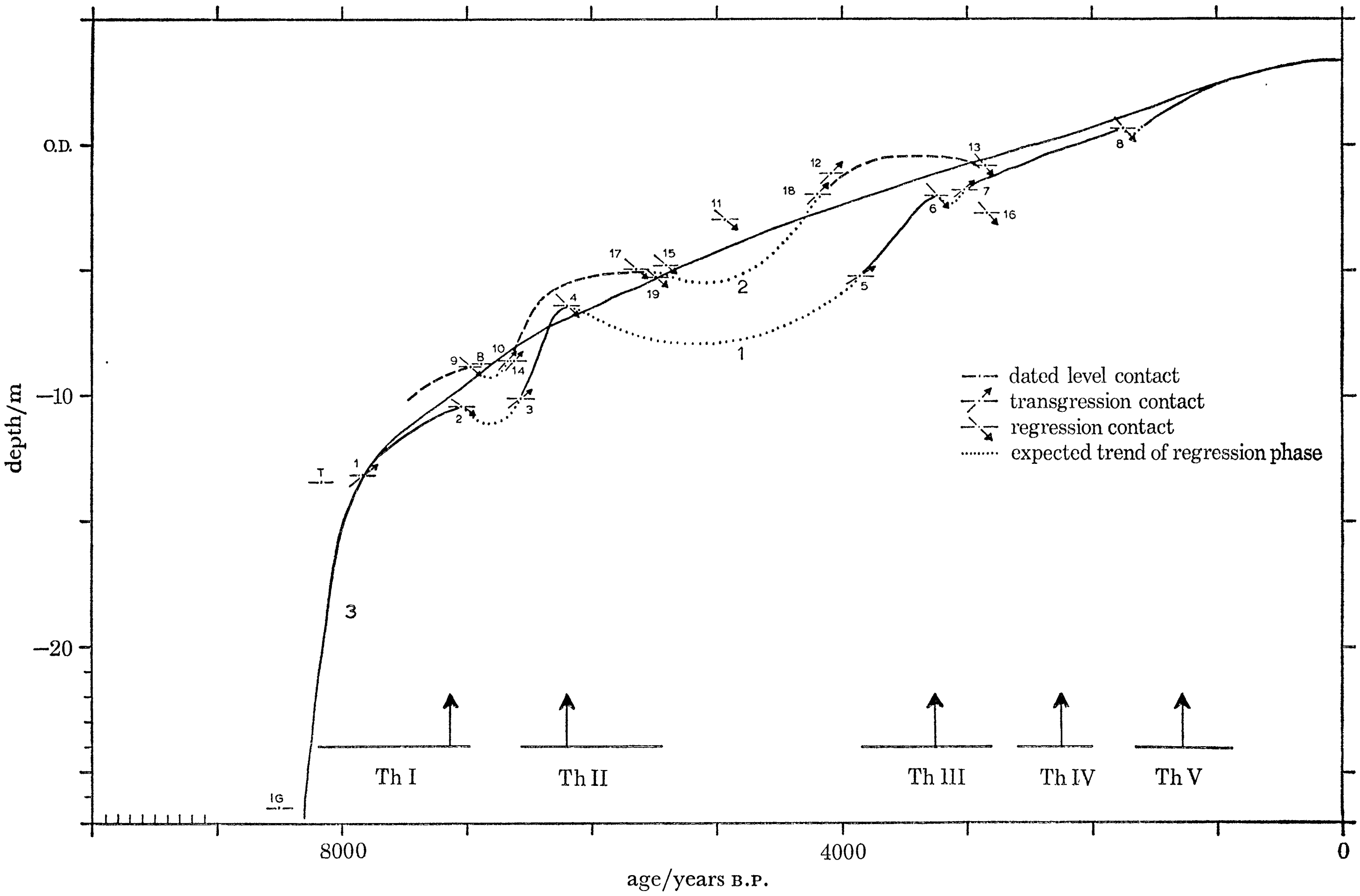


FIGURE 29. Relative sea level curves for the Thames Estuary. 1. Relative movement of mean high water spring tides (m.h.w.s.t.) at Tilbury. 2. Relative movement of m.h.w.s.t. from Crossness, Stone Marsh, Dartford Tunnel and Broadness Marsh. 3. Curve representing the mean line for the sampled contact points. Th I–V are transgression sequences recognized in the Thames Estuary. Index points are as follows: 1–8, Tilbury (T); 9–13, Stone Marsh; 14–16, Broadness Marsh; 17–18, Crossness; 19, Dartford Tunnel; I.G., Isle of Grain.

3. During the Thames II period sea level rose between 6600 and 5500 B.P. from −10.1 m to −5.0 m O.D. This forms the most extensive transgression recorded here, although the rate of relative sea level rise has fallen to 0.5 cm/year as compared with 0.36 cm/year for the Netherlands (Jelgersma 1961).

4. Between 5500/5000 and 4000 B.P. a major regression, Tilbury III, took place with the formation of thick monocotyledonous peat, becoming wood fen peats upstream. Environmental conditions in the estuary would not have been sensitive enough to record more minor fluctuations in sea level, shown for this time in the open coastal sediments of northwest England (Tooley 1976) (see figure 35).

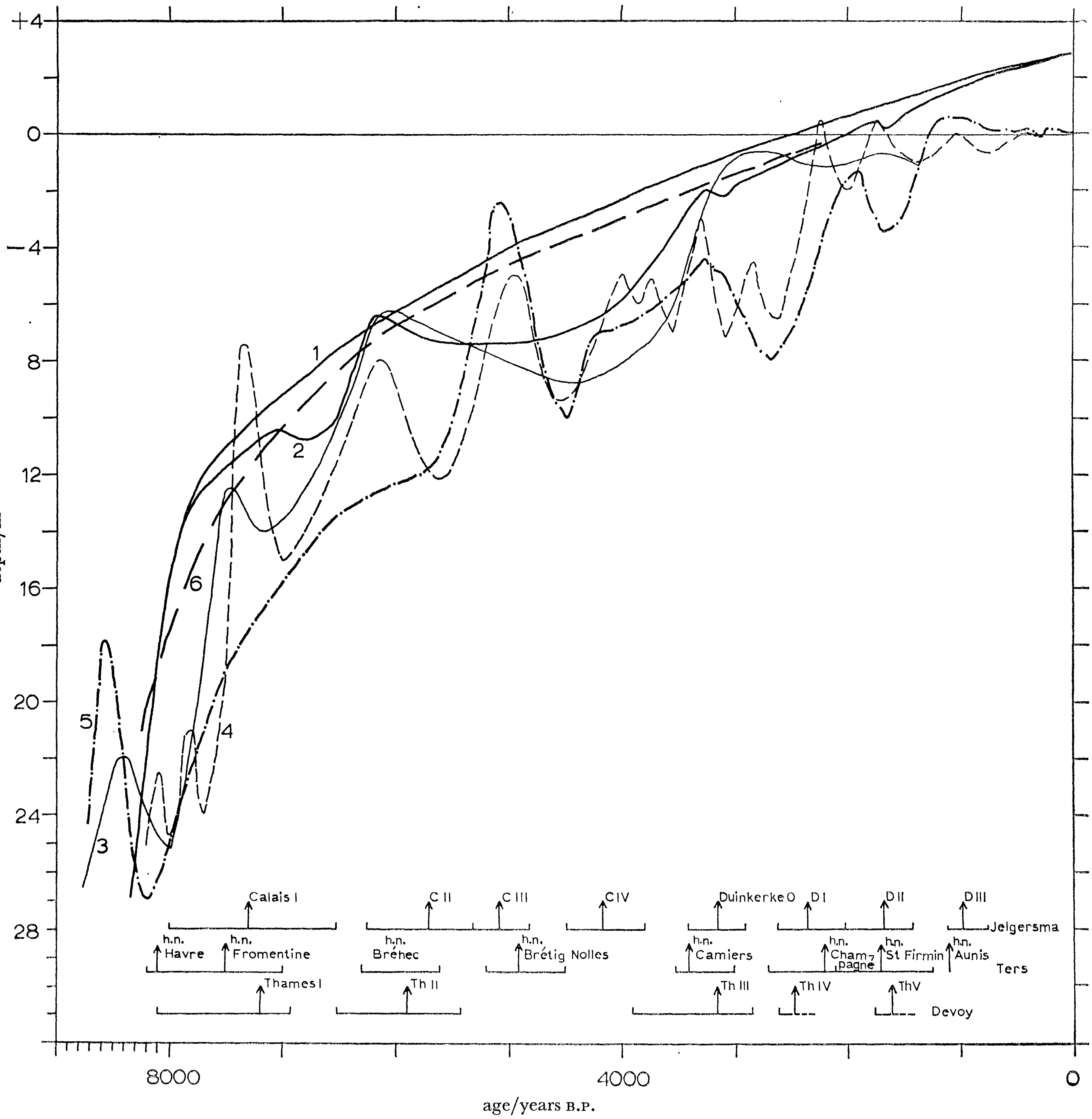


FIGURE 30. Relative sea level curves from the southern North Sea region and the Atlantic coast of France, derived from Flandrian sediments. 1. Thames mean curve (Devoy 1977*a*); 2. Tilbury (Devoy 1977*a*); 3. Morzadec-Kerfourn (1974); 4. Ters (1975); 5. Greensmith & Tucker (1973); 6. Jelgersma (1961). The limits of the transgression sequences identified by Ters, Jelgersma and Devoy are shown at the base. Curve 3 (Morzadec-Kerfourn) represents data from estuaries of northwest France.

5. Thames III shows a rapid rise in sea level between 4000 and 3400 B.P. to levels between −1.4 and −2.5 m O.D. A minor regression phase is recorded in the form of a thin silty peat. The timing and height of this varies in the estuary and may result partly from different rates of sedimentation and relative subsidence between the west and east of the area.

6. Following this regression, sea level for m.h.w.s.t. rises to levels above Ordnance Datum (Newlyn), reaching 0.4 m O.D. at Tilbury at *ca.* 1750 B.P. At this level a thin non-persistent silty peat records a further regression termed Tilbury V.

7. During Thames V, over the last 1000 years, sea level for m.h.w.s.t. continued to rise rapidly, possibly reflecting increased embanking and building in the estuary.

(*a*) *Comparison with relative sea level curves for the southern North Sea and France*

The Thames curves (figure 30) correspond well with each of the others for the southern North Sea region, showing the same trend of sea level rise and timing of transgressive/regressive phases during the Flandrian. The broad synchroneity of these relative sea level movements in NW Europe is well demonstrated in figure 31. The number of events differs, corresponding to changes in the type of source area for the basic data. The Thames mean curve 1 relates closely in rate and form to Jelgersma's curve for the Netherlands. Curve 2 for m.h.w.s.t. at Tilbury agrees well with curve 3, representing estuarine areas along the northwest coast of France. Similarity here, particularly in the form and duration of the long regression phase corresponding to Tilbury III, between 5500 and 4000 B.P., shows the important influence of estuarine sedimentary environments upon the recording of sea level movements.

The transgression/regression sequence shown at ≈ 8600 B.P. in curves 3 and 5, is not recorded in the Thames or in the other areas during this time due to the lack of data. The growth of a biogenic deposit at the Isle of Grain at this time is therefore indicative from this of a sea level regression, rather than from simple formation under the influence of a steadily rising sea level. Between 8200 and 7900 B.P. Ters's (1973) curve 4 records a series of oscillations termed 'Les niveaux du Havre' at a time of overall rapid sea level rise. Generally, the amplitudes of sea level movements shown by Ters (1973) for the Flandrian period are much greater than those recorded by other workers. This may result from the compilation of evidence from a wide area and different environments. Curve 5 is at greatest variance with the other records, including curves 1 and 2 for the neighbouring Thames Estuary. A transgression at 5500 B.P., though supported by Ters, is not recorded in the other curves. The cause may again lie in collection of data from a different form of source area and with the type of environmental evidence used (see § 2). All the curves show a rise to levels close to present day sea level by 1200 B.P. The differences in the sea level and datum level used for each of the countries represented may account for some of the variations in height.

11. Consolidation and compaction of the sediments

Consolidation and compaction, which for practical purposes may be regarded as the same in fine grained silts and clays of Flandrian age, is of importance in calculating sea level movements. For all Flandrian sequences must now occur at lower heights than when they were originally formed.

A full discussion of the methods of calculation and the problems involved is given by Skempton, Smotrych, Hibbert & Haynes (1969), Skempton (1970), and Marsland (1977). There are

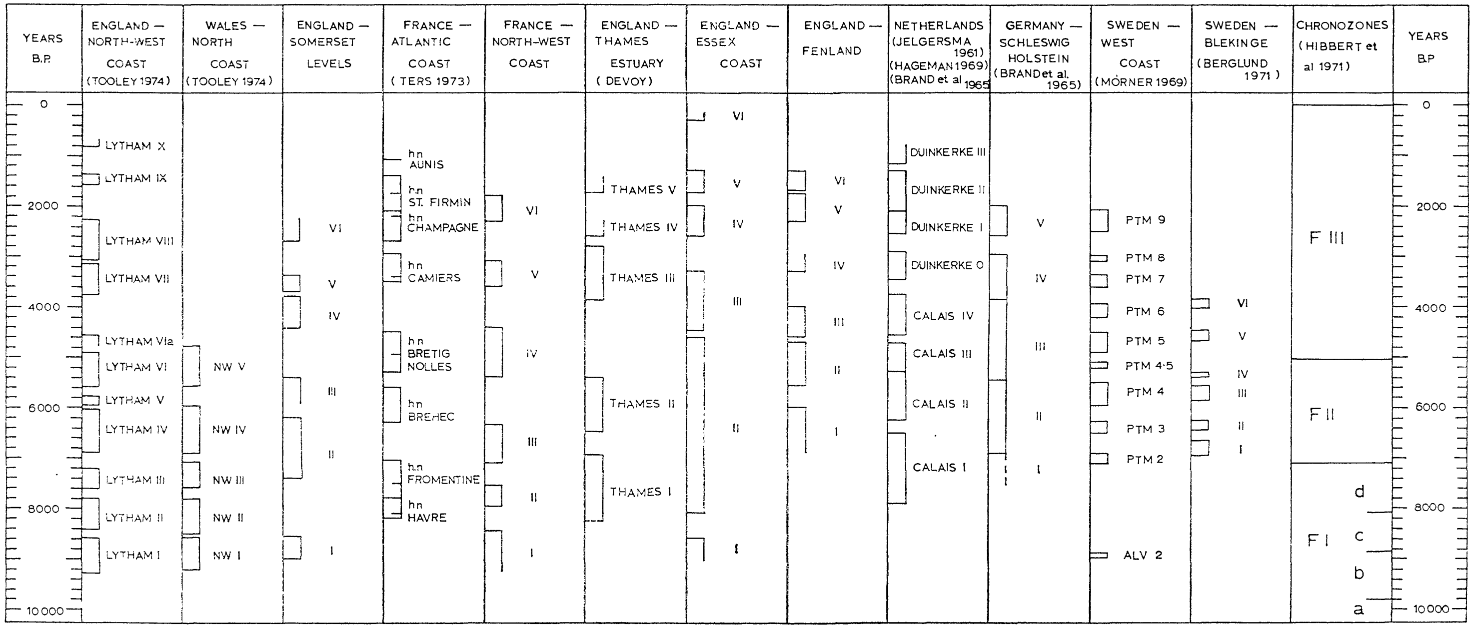


FIGURE 31. Correlation from west to east of Flandrian transgression sequences in northwest Europe (adapted from Tooley 1974, 1976). Data for establishing the sequences for the Somerset Levels has been obtained from Godwin (1941), Hawkins (1971), Kidson (1971) and Kidson & Heyworth (1973, 1976). Data for establishing the sequence for the northwest coast of France has been obtained from Morzadec-Kerfourn (1974), for the Essex coast from Greensmith & Tucker (1973), and for the fenlands from Churchill (1970), Godwin (1940) and Smith (1970).

many variables involved in determining the degree of compaction, for example density of material, pore water pressure, hydrological/ground water conditions, liquid and plastic limits of the sediment and void ratio. Without detailed examination of each of the profiles under consideration, in a field situation, assumptions will have to be made about these variables. As a result the degrees of compaction calculated may have a variation of $\pm 50\,\%$ (Skempton *et al.* 1969), even within a small study area. For it has been found that small changes in the chemical composition and mineral content of deposits can occur even over short distances, resulting in differences in the degree of compaction (Marsland 1977).

Although the total amount of compaction can be assessed for a given level, the rates of compaction will have varied with time. Thus compaction cannot be considered to have occurred uniformly, it depending upon the type of sediment formed and the varying rates of deposition with time. On calculating the gross compaction figures for a profile, this will not be of importance. However, in fixing the height of a biogenic deposit to former sea level, the time differential is of great importance. For example, a measured amount of consolidation/compaction was observed over a given period beneath trial embankments along the south bank of the River Thames. Under natural conditions the same loading would have occurred over a much wider area with compaction at a slower rate, due to resultant changes in hydrological conditions. Complications also arise from the problem of calculating the rates of compaction in peat. Work by Wilson, Radforth, Macfarlane & Lo (1965) showed that compaction in peats was not simply due to expulsion of water. Many variables were involved resulting in different rates of compaction for different peat types, for example with structure, particle size, inorganic composition and plant composition. As a result compaction in peats may show secondary. tertiary and quaternary characteristics over time. When peats were loaded they could show up to 80–90 % change in thickness (Jelgersma 1961), although the influence of organic materials upon the engineering properties of inorganic sediments is regarded as small (Rashid & Brown 1975). The degree of error as a result of these factors may be small, however, when considered in relation to the small amplitude of sea level movements of perhaps 0.5 m, they are of great significance.

The problems of compaction within peats, which vary greatly in structure and form within a profile, has rarely been considered in the reconstruction of heights. This places the validity of uniform compaction corrections for sea-level graphs to date in doubt. Until the problems of consolidation within both biogenic and inorganic deposits can be considered in great detail, compaction corrections cannot yet be employed for the Thames data.

12. Subsidence

(*a*) *Subsidence within the Thames area*

Figure 29 shows the height differential between curves 1 and 2 for index points taken upon the transgression and regression boundaries of deposits forming in the same ecological and environmental position relative to sea level (see § 2). Radiocarbon dating of these contact points places them in corresponding positions on the curves and shows that the deposits represented in each case formed at approximately the same time. Assuming the field data to be accurate, as supported by the consistent trends of the index points for curve 2, three explanations for this differential can be advanced.

1. Compaction and consolidation, although a possible explanation for the difference between the curves, does not appear to have caused major discrepencies or anomalies in the heights of the peat and clay sequences seen in the stratigraphy (see § 3*a*, 4*a*, 5*a*, 7*a* and 8*a*).

2. Progressive increase of tidal amplitude and freshwater discharge upstream causes the deposits here to form at relatively higher levels. At present the effect of river water and bank morphometry upon tidal levels is marked and must be taken into account (see § 13). Decline in the height differential between curves 1 and 2 between *ca.* 3000 and 7000 B.P. may show the efficacy of changing tidal amplitude in influencing depositional levels through the Flandrian. However, the difference of m.h.w.s.t. over the whole length of the study area, from Sheerness to London Bridge is only 1.4 m, whilst for mean tide level (m.t.l.) there is a difference of 0.6 m (Admiralty Tide Tables 1977). Specifically the difference between Tilbury and Woolwich (Royal Albert Docks) is 0.6 m for m.h.w.s.t., taken here as the effective tide for the growth of biogenic deposits (see § 2). This difference is not large enough to explain the differential between curves 1 and 2 in full.

3. This leaves differential downwarping between Crossness and Tilbury as the alternative major explanation. At Tilbury the increased sediment load from tide and river and rates of deposition would have to be absorbed. The site lies close to the major gravity basin identified by geophysical survey at Canvey Island (Shephard-Thorn, Lake & Atitullah 1972), and nearer to the influence of the central focus for land subsidence in the southern North Sea Basin (Dunham 1972). The cross profile of the stratigraphy at the sites from Stone Marsh downstream, each showed a progressive downward dip eastward, particularly marked in the deposits termed Tilbury II and III. This stratigraphic feature supports the theory of relative downwarping having occurred subsequent to formation of the deposit.

A full explanation of the observed height difference between sites probably lies in the joint influence of relative land subsidence and the effect of tidal amplitude and river discharge. However, the influence of compaction and consolidation is operative in the present day and must form a factor. Taking 0.6 m as the maximum height differential for the tidal effect, the amount of relative downwarping between Crossness and Tilbury is placed at *ca.* 1.5 m since 7000 B.P.

The sharp dip of the profile presented in figure 28 showing the sand/gravel surface sloping toward the Isle of Grain, is an exaggeration dependent upon the lack of stratigraphic information. However, a fairly sharp decline in height must occur to cater for the formation of the Medway buried channel at $-29/30$ m O.D. The growth of biogenic deposits here at *ca.* 8500 B.P. and also at Tilbury at *ca.* 8000 B.P. appears to create a height anomaly, with a difference in the height of their respective transgression surfaces of *ca.* 13.0 m. However, land subsidence need not be invoked as an explanation, for the rapid rise of sea level between 8500 and 7000 B.P. adequately explains the height difference. Further, diatom analysis at Tilbury of the basal sediments represented in stratum TI (see § 3*d*, i), shows a weak early marine influence, indicating that the full effect of this rising sea level did not reach this level immediately.

(*b*) *East–west subsidence in southern Britain*

Churchill (1965*a*, *b*) proposed that southeast England has been downwarped relative to southwest England by 6.1 m from about 6500 B.P. He concluded that Britain was tilting on an axis from the Tees to Pembroke, with Scotland rising and southeastern England sinking. Southwest England was identified as a region of relative crustal stability. This work was based upon the analysis of sediments assumed to be intertidal peats formed at *ca.* 6500 B.P., from a small number of isolated studies, often in disjunct coastal areas and differing sedimentary environments. The datum point for this research was based upon deposits at Groenvlei Fen in Cape Province, South Africa. However, Mörner (1976*a*), has highlighted the concept of a geodetic sea level, which changes both horizontally and vertically with time. This sea level, as distinct from eustatic or purely vertical changes of ocean level, is a function of the effects of deviations within the Earth's gravity, rotation, structure, density and astronomical gravity. Because of these spatial and temporal geoid changes, simple eustatic sea level movements cannot be seen as operating uniformly on a global basis. In this context, a world eustatic curve for sea level

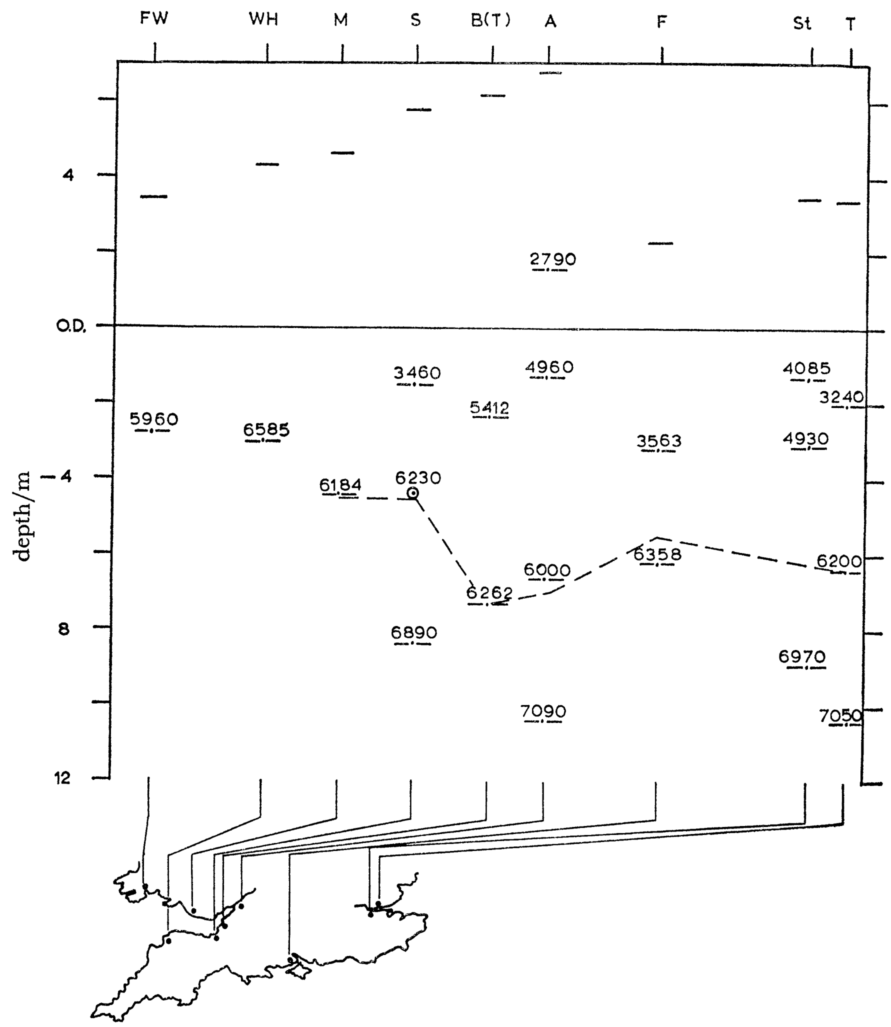


FIGURE 32. West–east height distribution of Flandrian radiocarbon dated biogenic deposits in southern Britain (adapted from Hawkins 1971). FW, Freshwater West; WH, Westward Ho!; M, Margham; S, Stolford; B(T), Burnham-on-Sea/Tealham Moor; A, Avonmouth; F, Fawley; St, Stone Marsh; T, Tilbury. The radiocarbon dates are taken from the contact zones of biogenic deposits situated adjacent to marine (brackish) water sediments in intercalated peat and clay sequences. These are taken to indicate points of change in sea level movement. The height of the datum levels have been adjusted by the differential between m.h.w.s.t. at each point and m.h.w.s.t. at Tilbury for purposes of comparison and then plotted along a non-scalar west–east axis, relative to O.D. (Newlyn). The dashed line joins contact points formed ≈ 6200 B.P. relative to m.h.w.s.t. and is taken to indicate relative land subsidence trends along a west–east axis since that time. The approximate height of present m.h.w.s.t. levels are shown for each site area.

change, for example the curves of Shepard (1963) or Fairbridge (1961), would be meaningless. A further problem arises from the lag effect of hydroisostacy, caused by movements of the geodetic sea level. Whereas changes in ocean surface are immediate, the resulting crustal movements take longer, complicating the overall pattern. Thus from current knowledge of crustal deformation (Walcott 1972) and the positive and negative areas found in the ocean surface on a global basis (Mörner 1976*a*; Gaposchkin 1973; King-Hele 1975), Churchill's work seems now to be unacceptable.

From figure 32, radiocarbon dated Flandrian deposits from southern England when plotted upon a west–east line show a progressively lower trend in height for sequences of the same age. The validity of the data from Westward Ho! (Churchill 1965*a*, *b*) is doubtful, as the deposit may have developed behind an offshore bar, whilst the dating appears to come from an archaeological horizon rather than a position of sea level change. This general criticism of incorrectly used levels may be made for many of the points originally used by Hawkins (1971) to show west–east subsidence trends. The relation of each of the points plotted to their contemporary sea level was not always known. Without the fixed datum of sea level, the deposits could have formed at any height relative to Ordnance Datum and thus have no significance for west–east downwarping. As exemplified by Avonmouth and Fawley, the pattern of subsidence from figure 32 is not uniform, varying both with the areas examined and with time through the Flandrian stage. It would appear from this that the idea of a uniform rate and trend for downwarping is invalid. The submergence history of a region is dependent upon the individual characteristics of the environments contained within it, for example open coast or estuary, each showing differences in the amount and rate of relative land/sea level change. This conclusion is supported by the sea level curves for the southern North Sea and France (see § 10*a*).

The argument for crustal stability in the southwest (Churchill 1965*a*) is supported by detailed biostratigraphic analyses from the Somerset Levels and adjacent areas, for which an extensive literature has been produced (Hawkins 1971; Kidson 1971, 1977; Kidson & Heyworth 1973, 1976). The evidence has contributed to the construction of a sea level curve, showng the movement of mean high water mark of ordinary tides (m.h.w.o.t.) in the Bristol Channel area (Kidson & Heyworth 1973, 1976). The data upon which this curve is based is, however, in part derived from a variety of environmental sources, some of which do not appear to have a direct and observable relation with sea level movement through the Flandrian, and therefore the reliability of the curve is open to question. Many of the index points used, from the interleaved peat and clay deposits of Bridgewater Bay, appear not to be taken from marine transgression and regression contacts, which would have a clear relationship to their contemporary sea level of m.h.w.s.t. (see § 2).

Instead radiocarbon dates from intermediary positions in the biogenic deposits are used. These, together with datings upon Neolithic and Bronze Age trackways from fen wood peats and raised bogs in the Somerset Levels (Godwin & Willis 1959, 1960), are equated with the movement of the basal watertable, taken to approximate with m.h.w.o.t. It seems unlikely in the face of the large amount of stratigraphical and geobotanical evidence (Clapham & Godwin 1948; Godwin 1941, 1948, 1955, 1960*a*, *b*; Coles & Hibbert 1968, 1970) supporting the local nature of sedimentation and origin of biogenic growth in this area, that a regional watertable uniformly equal to m.h.w.o.t. would be operative over the whole area. Pollen analysis is used by Kidson & Heyworth (1973) to reconstruct *in situ* vegetational development, and from this the position of the contemporary watertable is determined. However, in the absence of other published detailed hydrological, microfossil and macrofossil studies, and given the local nature of the sedimentation, pollen analysis is not a precise enough technique for calculation of exact watertable correction factors for incorporation in a curve of sea level change. Their conclusion that the clay surface below the 'O.D.' peat must formerly have been nearly horizontal and formed close to the contemporary watertable (Kidson & Heyworth 1976) is not necessarily supported by findings from similar environments (see § 3 and 4; Jelgersma 1961; Klein 1967). Sediment accumulation in intertidal areas may occur at different rates within short distances, whilst the development of creeks and the general processes of saltmarsh ontogeny may easily create an uneven surface. In this context there is no need to evoke compaction and consolidation as the main cause for deviations of level from a presumed horizontal surface. Use of compaction and consolidation corrections from detailed geotechnical studies upon only isolated cores, cannot reliably be used by themselves to represent regional changes of level, as discussed in § 11. Due to these possible problems with the published curves and since that of Kidson & Heyworth (1976) represents m.h.w.o.t. and not m.h.w.s.t., it was necessary to redraw the curve for this area, to establish comparability with the other sea level curves under consideration.

In the absence of new original data, 18 radiocarbon dated index points have been taken from the published literature upon this area (see appendix 2). These show the apparent positions of marine transgression and regression contacts in interleaved biogenic and inorganic deposits. Choice was made upon the basis of the published stratigraphic position of each, and as far as is known, the points used conform with the criteria established in § 2 for use of data in sea level studies. A relative sea level curve has been drawn for the Bristol Channel area and approximately represents the movement of m.h.w.s.t.

A tentative interpretation has been made showing the transgressive and regressive movements inplicit in the data (Tooley 1977*a*, *b*) and seven marine transgressions are recognized. The varying range of m.h.w.s.t. shown between sites (see figure 32) must influence the height for growth of biogenic deposits (see § 2). Thus transgression and regression sequences formed under the influence of a relatively high m.h.w.s.t. regime, will show a greater height for former sea level positions, by comparison with sites experiencing a lower m.h.w.s.t. level, as in the Thames. Due to the exceptionally high tidal amplitude in the Bristol Channel area, the points have been replotted to represent the m.h.w.s.t. régime at Tilbury. The index points have been lowered by the difference between m.h.w.s.t. at Tilbury and m.h.w.s.t. at each sample point used (information based upon Admiralty Tide Tables 1977). From this a separate curve is drawn to show the mean line and generalized trend for sea level movement. Upon this basis, comparison is then possible with the mean curve for the Thames and for further examination of relative subsidence trends between southwest and southeast England for the Flandrian. Inaccuracies due to difference in estuary shape and the use of a constant m.h.w.s.t. factor through time, based upon present day data, exist and cannot be forgotten. In the absence of detailed time based hydrological and tidal models for these areas, comparison would be impossible without some account being taken of the large tidal differences, however crude, although the method used is not entirely satisfactory.

There appears to be good agreement between the areas upon the form and rate of sea level change (figure 33), with curve 2 describing a course close to that for the Thames from 8300 B.P. onward. From *ca.* 6700 B.P. the Thames data does, however, fall consistently below curve 2, indicating a consistent trend of downwarping for the southeast relative to the southwest. If confidence can be placed in the curves, the value of this relative subsidence may be placed at between 2 and 3 m for the Flandrian (figures 32 and 33). This sharply contradicts the 6.1 m since 6500 B.P., a figure identified by Churchill (1965*a*) and Hawkins (1971). In general height and trend the sea level curves from both areas closely resembles Jelgersma's curve (1961,

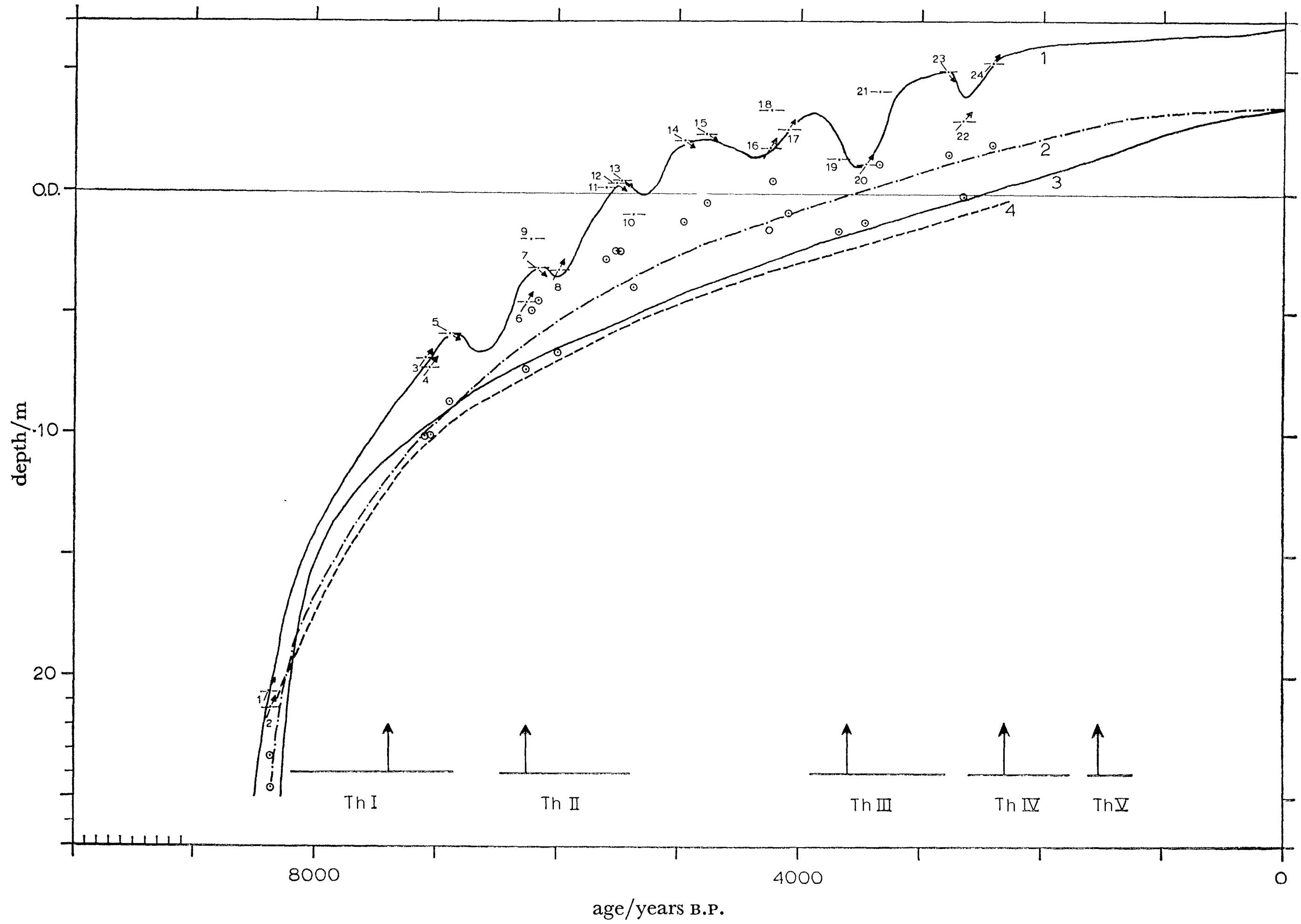


FIGURE 33. Relative Flandrian sea level curves from southwest and southeast England. Transgression (upward arrow) and regression (downward arrow) contacts, with dated levels (un-arrowed bar) from southwest England. 1. Relative movement of m.h.w.s.t. in the Bristol Channel area. 2. The trend of relative sea level change in the Bristol Channel area, taken as the mean line of the index points in 1. These have been adjusted in height to represent the m.h.w.s.t. régime at Tilbury (see 12*b*). 3. The mean line of the Thames index points, representing the trend of relative m.h.w.s.t. movement for the Thames Estuary. 4. Relative sea level movement for the Netherlands (Jelgersma 1961). The timing of the Thames transgression sequences is shown at the base of the diagram. ⊙, Reduced height of index points to m.h.w.s.t.

1966) for the Netherlands (figure 33), coming from an area of marked downwarping (Dunham 1972). All three areas contain large thicknesses of Flandrian sediment, which would indicate the operation of subsidence factors here. It is therefore suggested that land subsidence is a similar feature in the Flandrian history of these three areas. This implies that the Bristol Channel area of the southwest, if not the region as a whole, has not been stable for this stage of the

Quaternary but has been subject to downward crustal movement. This is emphasized by comparison of the curves for m.t.l. from both areas with the eustatic curve for sea level movement in northwest Europe (Mörner 1976*b*) (see figure 34), although the questionable nature of identifying a true eustatic curve is recognized (see § 12*b*).

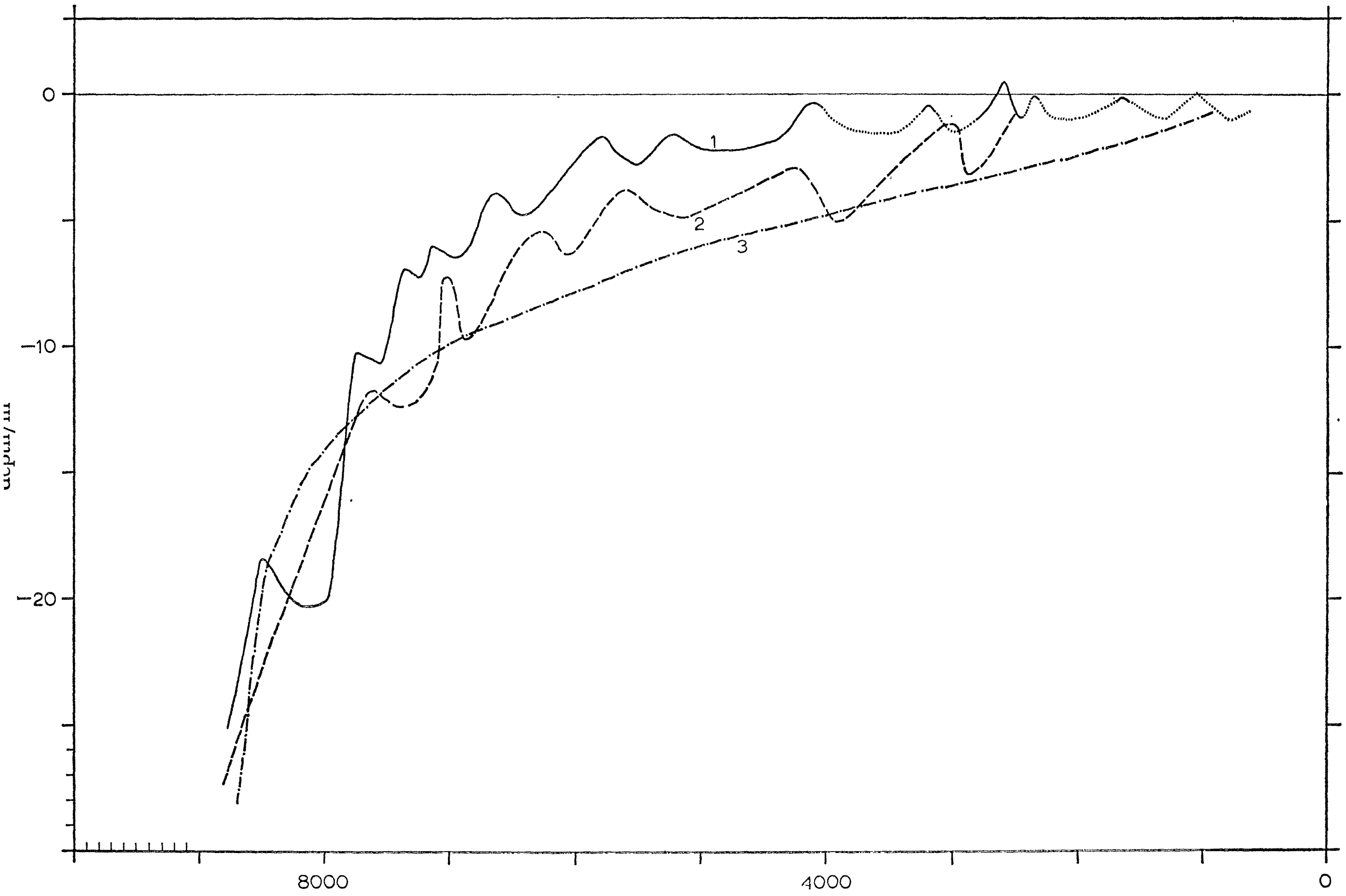


FIGURE 34. Flandrian sea level curves from northwest Europe as indices of relative land subsidence trends in southern Britain. 1. Eustatic curve of sea level movement from southern Sweden (Mörner 1976*b*). 2. Relative movement of mean tide level (m.t.l.) from the Bristol Channel area. 3. Mean line of the Thames index points, representing the trend of m.t.l. movement in the Thames Estuary. All data has been tree ring calibrated, curve 1 as described by Mörner (1976*b*) and curves 2 & 3 according to Switsur (1973) and Hibbert & Switsur (1976).

Both the Bristol Channel and Thames curves consistently fall below the eustatic curve, as would be expected for areas of relative land subsidence. By comparison, Mörner (1976*b*) shows that relative sea level curves from areas of observed uplift, for example northwest England, Sweden and Norway, lie above this line.

Independent evidence in support of this hypothesis is sparse. However, records of tidal observations for the British Isles over a fifty year period, are one possible source. Rossiter (1972) points out that the reliability of these suffers from incomplete and inaccurate field data, and conceptual problems of calculation.

Regression analysis of the available tide data cannot be used in fixing long term trends in the relative position of m.s.l., due to the short period of observation. Annual figures, however, do give a useful picture of the trend of relative sea level movement. Thus secular changes in m.s.l. show an annual rise (mm/year) of 0.1 at Dunbar, 1.6 Felixstowe, 3.4 Southend, 2.5 Hoek van Holland, 2.2 Newlyn and 2.1 Brest (Rossiter 1972). Comparison of the data at Southend (3.4 mm/year) and Sheerness (3.3 mm/year) shows a relative m.s.l. rise of *ca.* 30 cm/century. At Newlyn the m.s.l. rise can be placed at 22 ± 1.0 cm/century for the period 1915–62 or 25 cm/century between 1916–62 (Gordon & Suthons 1963). By comparison the figures for Felixstowe (16 cm/century), or an average m.s.l. rise for the northern hemisphere of 15 cm/century (Gordon & Suthons 1963), accounts for only 60 % of the total m.s.l. rise at Newlyn. Similarly, a eustatic component of 1.0 mm/year or 10 cm/century of the m.s.l. rise, used as a working basis (Rossiter 1972), accounts for only 45 % of the rise at Newlyn. This suggests that tectonic downwarping must still be active to account satisfactorily for the difference in figures, although variations in the slope of the mean sea surface between sampling points may be of importance (Rossiter 1967, Mörner 1976*a*). Lennon's (1975) examination of tidal data

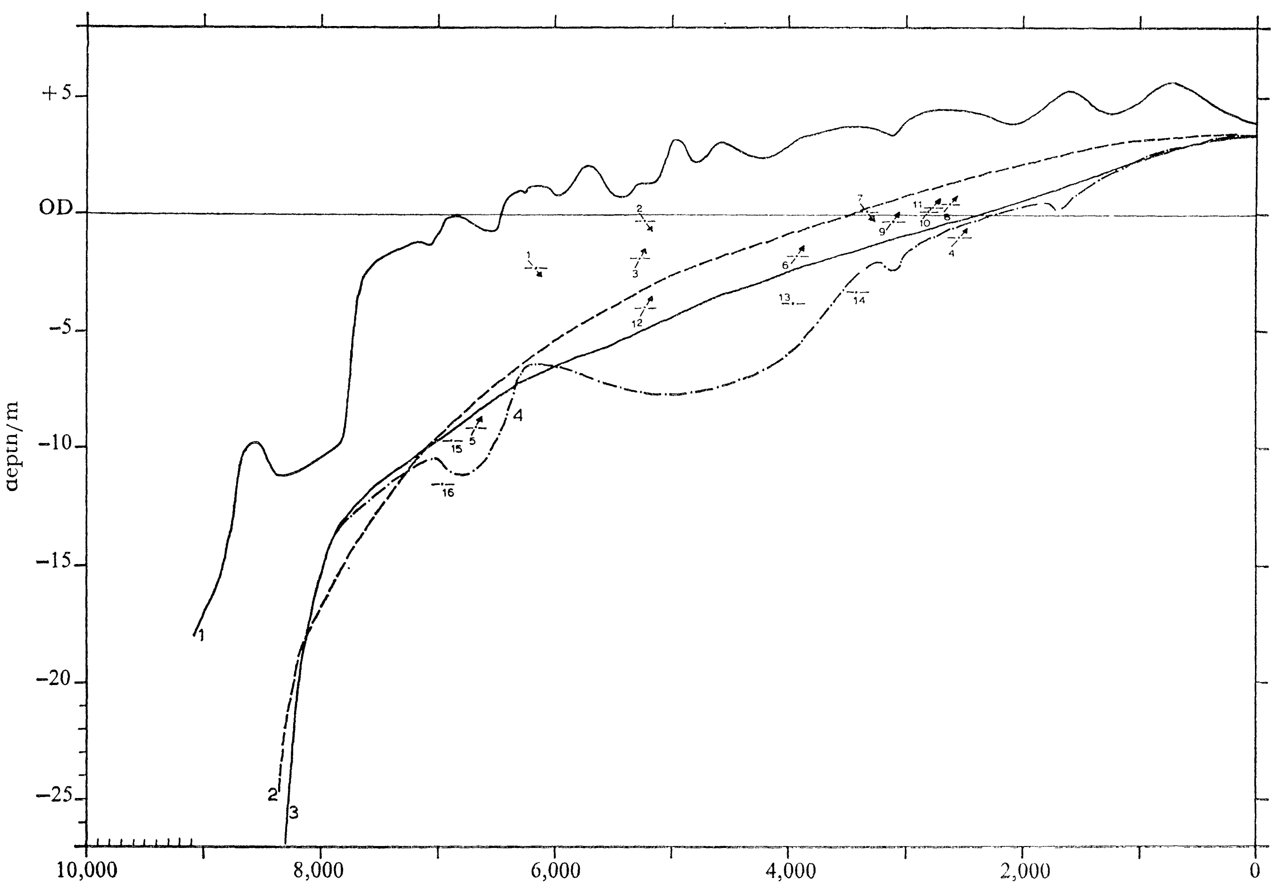


FIGURE 35. Relative Flandrian sea level curves indicating subsidence trends in southern Britain. The figure shows transgression (upward arrow) and regression (downward arrow) contacts with dated levels (unarrowed bar) from intercalated peat and clay deposits in northeast and eastern England (Gaunt & Tooley 1974). Curve 1, is from northwest England (Tooley 1976), curve 2 from southwest England (see figure 33, curve 2), and curve 3, from the lower Thames Estuary (see figure 29). Curve 4 represents the movement of m.h.w.s.t. at Tilbury, lower Thames Estuary (see figure 29).

across northwest Europe confirms this trend of subsidence in southern England, with land elevation calculated as falling at *ca.* 1 mm/year throughout this area.

(*c*) *North–south subsidence trends*

Figure 35 gives a comparison of relative sea level curves from northwest England, northeast and eastern England to the Thames Estuary and Bristol Channel. Radiocarbon dated transgression and regression sequences in the regions (figure 31) are broadly synchronous for the Flandrian, giving a similar trend and pattern of sea level change, though differing in detail. The Bristol Channel area excepted, the curves lie uniformly at progressively lower heights relative to each other toward the southeast, with the difference between north and south most marked in the present day. The curve for m.h.w.s.t. for northwest England (Tooley 1974) rises above O.D. after *ca.* 6500 B.P., indicating the importance of tectonic upwarping here, probably due to isostatic recovery. Although the sea level data for the Humber and northeast England (Gaunt & Tooley 1974) has not been resolved into a sea level curve, the index points fall at intermediate heights between those of the Thames and the northwest. The slower rate of downwarping indicated here for the Humber area is supported by the tide gauge data (Rossiter 1972). Toward the present day the index points lie at levels more conformable with those for the Thames. This suggests a decrease in the influence of the eustatic or sea level component of subsidence, with continuing importance of tectonic downwarping on the east coast. The closer position of the plotted data to that of the northwest between about 6500 and 5000 B.P. (figure 35), may indicate the increasing importance of isostatic recovery in the latter area. The similarity in height between the mean line for the Bristol Channel and the contact points for eastern England is noteworthy. Recognition of a hinge line for land subsidence between the Humber and the Bristol Channel (Churchill 1965) upon this evidence, however, would be tenuous. For the subsidence trends represented by the sea level curves are purely relative and it is more likely that both areas exhibit similar subsidence histories, rather than zero movement. Overall, these curves confirm the generalized north to south dip of the British Isles, observed by Valentin (1953), Churchill (1965), Taylor & Smalley (1969), Rossiter (1972) and Dunham (1972). The pattern of tectonic subsidence is not a uniform and simple one and must vary within the types of environment examined, as shown by comparison of west–east subsidence trends. Dunham (1972) suggests the subsidence evidence today shows a general arching of the country along a Caledonoid (northeastern) axial trend. Due to these inter-regional differences, definite figures for the relative rates of tectonic downwarping would be meaningless.

13. Influence of changes in tidal amplitude and embanking upon sea level trends

Detailed work upon the changes in the tidal patterns for the Thames is presented by Bowen (1972) and Rossiter (1969). The strong relation between estuary, channel and river bank shape with changes in the timing and amplitude of the tides has been demonstrated (see § 12*a*). For example (figure 32) shows the increase in the height of m.h.w.s.t. progressively upstream in the Severn Estuary. In the Thames the influence of alterations in the shape of the estuary and river by dredging, embanking and removal of barriers upon the tidal régime, was noted in the 19th century (Bowen 1972).

The trend in recent decades of higher tides (see Bowen 1972) correlates most easily with the continuing processes of channel change. Natural causes of rising sea level, changes in salinity and freshwater input or tidal input are not regarded as important in the long term, although the data is inadequate. Alterations in wind and air pressure patterns must have an influence, as seen in storm surges, instanced in the floods of 1953. Such storm surges, although effective in raising tidal levels (Prandle 1975), operate as an additive factor to the overall tidal rise rather than a cause. Lamb (1969) demonstrates that longer term changes, in the order of fifty or sixty years, do occur in the wind and air pressure patterns. Such changes over the North Sea result in a weakening of the westerly winds, which would indirectly, through changes in direction of wind stress, influence the tides in the Thames area. In perspective, observed increases in tidal amplitude owe more to man than to natural causes and must be regarded as an additional factor to the long-term trends of sea level change.

This work was undertaken in the Sub-department of Quaternary Research, Cambridge, and was funded by an N.E.R.C. research grant which I gratefully acknowledge.

I wish to express my sincere thanks to my supervisor Professor R. G. West, F.R.S. for all his help and advice throughout the course of this project and to Dr V. R. Switsur for the radiocarbon dating of samples from the Thames sites. I also wish to thank Mr A. Marsland and members of the Building Research Establishment for their useful information, facilities and provision of coring material, without which this work would not have been possible. Also, the President of University College, Cork, Dr M. D. McCarthy and the National University of Ireland, for the provision of financial aid toward the publishing costs of this paper.

I am grateful to many people for their invaluable advice and information, in particular to Dr M. J. Tooley, Mr B. W. Conway, Dr R. Shephard-Thorn, Dr R. W. Hey, Dr V. R. Switsur, Miss R. Andrew and Mrs G. Wilson; also to Mr H. de Wolf, Rijks Geologische Dienst, Haarlem, for his help and tuition in diatom analysis, to Dr A. Hall, Dr W. Williams and members of the Quaternary Sub-department for their interest and valuable assistance with fieldwork. I especially wish to thank Mr B. W. Sparks and Mr B. W. Conway for their identification of the shell fauna from the Thames sites. I gratefully acknowledge the help, information and provision of borehole records from members of the Institute of Geological Sciences, Mr D. H. Duvall (C.E.G.B.), the G.L.C. (Housing Department), members of the Southern River Authority, the Ordnance Survey, A. G. Weeks and Partners and G. Wimpey & Co. Ltd.

References

Admiralty 1977 *Admiralty tide tables; European waters including the Mediterranean Sea* (vol. 1). Hydrographer of the Navy. Admiralty Hydrographic Department: Taunton.

Akeroyd, A. V. 1966 Changes in relative land and sea level during the post-glacial in southern Britain with particular reference to the post-Mesolithic period. M.A. thesis, University of London.

Alhonen, P. 1971 The stages of the Baltic Sea as indicated by the diatom stratigraphy. *Acta bot. fenn.* **92**, 1–18.

Berglund, B. 1971 Littorina transgressions in Blekinge, south Sweden: a preliminary survey. *Geol. För. Stockh. Förh.* **93**, 625–652.

Bowen, A. J. 1972 The tidal regime of the River Thames; long-term trends and their possible causes. *Phil. Trans. R. Soc. Lond.* A **272**, 187–199.

Birks, H. J. B., Deacon, J. & Peglar, S. 1975 Pollen maps for the British Isles 5000 year ago. *Proc. R. Soc. Lond.* B **189**, 87–105.

Buckley, J. D. & Willis, E. H. 1969 Isotopes' Radiocarbon Measurements VII. *Radiocarbon* **11**, 53–105.

Callow, W. J. & Hassall, G. I. 1968 National Physical Laboratory Radiocarbon Measurements. *Radiocarbon* **10**, 115–118.

Carreck, J. N. 1976 Pleistocene mammalian and molluscan remains from 'Taplow' Terrace deposits at West Thurrock, near Grays, Essex. *Proc. geol. Ass.* **87**, 83–92.

Chapman, V. J. 1964 *Coastal Vegetation.* Oxford & London: Pergamon.

Churchill, D. M. 1965*a* The displacement of deposits formed at sea level, 6500 years ago in southern Britain. *Quaternaria* **7**, 239–249.

Churchill, D. M. 1965*b* The kitchen midden site at Westward Ho!: ecology, age and relation to changes in land and sea level. *Proc. Prehist. Soc. Lond.* (N.S.) **31**, 74–84.

Clapham, A. R. & Godwin, H. 1948 Studies of the Post-glacial history of British vegetation. VIII Swamping surfaces in the peats of the Somerset Levels. IX Prehistoric trackways in the Somerset Levels. *Phil. Trans. R. Soc. Lond.* B **233**, 233–273.

Cleve-Euler, A. 1951–3 Die Diatomeen von Schweden und Finnland. *Kungl. Svens. Vetensk. Akad. Handl.* (Ser. 4) 2, 139–163., 3, 144–153., 4, 150–158., 4, 240–255.

Coles, J. M. & Hibbert, F. A. 1968 Prehistoric roads and tracks in Somerset, England: 1. Neolithic. *Proc. Prehist. Soc. Lond.* **34**, 238–258.

Coles, J. M. & Hibbert, F. A. 1970 Prehistoric roads and tracks in Somerset, England: 2. Neolithic. *Proc. Prehist. Soc. Lond.* **36**, 125–151.

Conway, B. W. & McCann, D. M. 1972 *A geophysical and geological investigation at Barking Creekmouth, Essex.* London: National Environmental Research Council (Institute of Geological Sciences).

Cushing, E. J. 1967 Evidence for differential pollen preservation in late Quaternary sediments in Minnesota. *Rev. Palaeobot. Palyn.* **4**, 87–101.

Devoy, R. J. N. 1977*a* Flandrian sea level changes and vegetational history of the lower Thames Estuary. Ph.D. thesis, University of Cambridge.

Devoy, R. J. N. 1977*b* Flandrian sea level changes in the Thames Estuary and the implications for land subsidence in England and Wales. *Nature, Lond.* **270**, 712–715.

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

Donkin, A. S. 1871 *The natural history of the British Diatomaceae.* (1–3) London: J. van Voorst.

Dunham, K. C. 1972 The regional setting. In *A discussion on problems associated with the subsidence of southeastern England* (ed. K. C. Dunham & D. A. Gray). *Phil. Trans. R. Soc. Lond.* A **272**, 81–86.

Eronen, M. 1974 The history of the Littorina Sea and associated Holocene events. *Commentat. physico.-math.* **44**, 79–195.

Faegri, K. & Iversen, J. 1975 *Textbook of pollen analysis.* Oxford: Blackwell.

Fairbridge, R. H. 1961 Eustatic changes in sea level. In: *Physics and chemistry of the Earth*, vol. 4. (ed. L. H. Ahrens, S. K. Runcorn & H. C. Urey), 99–185. London: Pergamon Press.

Flint, R. F. 1971 *Glacial and Quaternary Geology.* London: Wiley.

Franks, J. W. 1960 Interglacial deposits at Trafalgar Square, London. *New Phytol.* **59**, 145–152.

Gaposchkin, E. M. 1973 *Smithsonian standard earth* (III). Smithsonian Astronomical Observatory, Special Report **353**, Washington.

Gaunt, G. D. & Tooley, M. J. 1974 Evidence for Flandrian sea level changes in the Humber Estuary and adjacent areas. *Bull. Inst. geol. Sci.* **48**, 25–41.

Ginsberg, R. N. (ed.) 1975 *Tidal deposits – a casebook of recent examples and fossil counterparts.* New York: Springer-Verlag.

Godwin, H. 1941 Studies of the Post-glacial history of British vegetation. VI Correlations in the Somerset Levels. *New Phytol.* **40**, 108–132.

Godwin, H. 1943 Coastal peat beds of the British Isles and North Sea. *J. Ecol.* **31**, 199–247.

Godwin, H. 1948 Studies of the Post-glacial history of British vegetation. X Correlation between climate forest composition, prehistoric agriculture and peat stratigraphy in the Sub-boreal and Sub-atlantic peats, of the Somerset Levels. *Phil. Trans. R. Soc. Lond.* B **233**, 275–286.

Godwin, H. 1955 Studies of the Post-glacial history of British vegetation. XIII The Meare Pool region of the Somerset Levels. *Phil. Trans. R. Soc. Lond.* B. **239**, 161–190.

Godwin, H. 1960*a* Radiocarbon dating and Quaternary history in Britain. *Proc. R. Soc. Lond.* B **153**, 287–320.

Godwin, H. 1960*b* Prehistoric wooden trackways of the Somerset Levels: their construction, age and relation to climatic change. *Proc. Prehist. Soc. Lond.* **26**, 1–36.

Godwin, H. 1964 Late Weichselian conditions in southeastern Britain: organic deposits at Colney Heath, Herts. *Proc. R. Soc. Lond.* B **160**, 258–275.

Godwin, H. 1975 *The history of the British flora.* Cambridge University Press.

Godwin, H. & Willis, E. H. 1959 Cambridge University natural radiocarbon measurements (I). *Radiocarbon* **1**, 63–75.

Godwin, H. & Willis, E. H. 1961 Cambridge University natural radiocarbon measurements (III). *Radiocarbon* **3**, 60–76.

Godwin, H. & Willis, E. H. 1964 Cambridge University natural radiocarbon measurements (IV). *Radiocarbon* **6**, 116–137.

Godwin, H., Willis, E. H. & Switsur, V. R. 1965 Cambridge University natural radiocarbon measurements (VII). *Radiocarbon* **7**, 209–210.

Gordon, D. L. & Suthons, C. T. 1963 *Mean sea level in the British Isles.* (Admiralty Mar. Sci. Publ. 7) London: Admiralty Hydrographic Department.

Greensmith, J. T. & Tucker, E. V. 1971 *a* Overconsolidation in some fine grained sediments; its nature, genesis and value in interpreting the history of certain English Quaternary deposits. *Geol. en Mijnb.* **50**, 743–748.

Greensmith, J. T. & Tucker, E. V. 1971 *b* The effects of late Pleistocene and Holocene sea level changes in the vicinity of the river Crouch, East Essex. *Proc. geol. Ass.* **82**, 301–322.

Greensmith, J. T. & Tucker, E. V. 1973 Holocene transgressions and regressions on the Essex coast outer Thames estuary. *Geol. en Mijnb.* **52**, 193–202.

Harland, W. B., Ager, D. V., Ball, H. W., Bishop, W. W., Blow, W. A., Curry, D., Deer, W. A., George, T. N., Holland, C. A., Holmes, S. C. A., Hughes, N. F., Kent, P. E., Pitcher, W. S., Ramsbottom, W. H. C., Stubblefield, C. J., Wallace, Peigi & Woodland, A. W. 1972 A concise guide to stratigraphical procedure. *J. geol. Soc.* **128**, 295–305.

Hartman, A. A. 1968 A study on pollen dispersal and sedimentation in the western part of the Netherlands. *Acta bot. neerl.* **17**, 506–549.

Hawkins, A. B. 1971 The late Weichselian and Flandrian transgression of southwest Britain. *Quaternaria* **14**, 115–130.

Hendey, N. I. 1951 Littoral diatoms of Chichester Harbour, with special reference to fouling. *J. R. microsc. Soc.* **71**, 1–86.

Hendey, N. I. 1964 *An introductory account of the smaller algae of British coastal waters. Bacillariophyceae (diatoms).* London: H.M.S.O.

Hendey, N. I. 1974 A revised check-list of British marine diatoms. *J. mar. biol. Ass. U.K.* **54**, 277–300.

Hibbert, F. A. & Switsur, V. R. 1976 Radiocarbon dating of Flandrian pollen zones in Wales and northern England. *New Phytol.* **77**, 793–807.

Hibbert, F. A., Switsur, V. R. & West, R. G. 1971 Radiocarbon dating of Flandrian pollen zones at Red Moss, Lancashire. *Proc. R. Soc. Lond.* B **177**, 161–176.

Hodson, F. & West, I. M. 1972 Holocene deposits of Fawley, Hampshire and the development of Southampton Water. *Proc. geol. Ass.* **83**, 421–441.

Hollin, J. T. 1977 Thames interglacial sites, Ipswichian sea levels and Antarctic ice surges. *Boreas* **6**, 33–52.

Huddart, D. & Tooley, M. J. (eds) 1972 *The Cumberland Lowland May* 26–28 1972 *Handbook.* Quaternary Research Association.

Hustedt, F. 1927–66 Die Kieselalagen Deutschlands, Öesterreichs und der Schweiz. (I–III). In: *Kryptogamen-Flora VII* (ed. L. Rabenhorst). Leipzig.

Hutchinson, J. N. & Gostelow, T. P. 1976 The development of an abandoned cliff in London Clay at Hadleigh, Essex. *Phil. Trans. R. Soc. Lond.* A **289**, 557–605.

Janssen, C. R. 1959 *Alnus* as a disturbing factor in pollen diagrams. *Acta bot. neerl.* **8**, 55–58.

Jelgersma, S. 1961 Holocene sea level changes in the Netherlands. *Meded. geol. Sticht.* (Ser. C 6) **7**, 1–100.

Jelgersma, S. 1966 Sea level changes during the last 10000 years. In: *World climate* 8000 *to* 0 B.C. (ed. J. S. Sawyer), pp. 54–71. Royal Meteorological Society.

Johnson, D. S. & York, H. H. 1915 The relation of plants to tide levels: a study of factors affecting the distribution of marine plants; publication 206. Washington: Carnegie Institute.

Kellaway, G. A., Redding, J. H., Shephard-Thorn, E. R. & Destombes, J-P. 1975 The Quaternary history of the English Channel. *Phil. Trans. R. Soc. Lond.* A **279**, 189–218.

Kidson, C. 1971 The Quaternary history of the coasts of southwest England with special reference to the Bristol Channel coast. In: *Exeter essays in geography* (ed. K. J. Gregory & W. L. D. Ravenhill). Exeter University Press.

Kidson, C. 1977 The coast of southwest England. In: *The Quaternary history of the Irish Sea* (ed. C. Kidson & M. J. Tooley) pp. 257–298. Liverpool: Seel House Press.

Kidson, C. & Heyworth, A. 1973 The Flandrian sea level rise in the Bristol Channel. *Proc. Usher Soc.* **2**, 565–584.

Kidson, C. & Heyworth, A. 1976 The Quaternary deposits of the Somerset Levels. *Q. Jl engng Geol.* **9**, 217–237.

King-Hele, D. 1975 Sea level changes and the Geoid. In: *Geodynamics today: a review of the Earth's dynamic processes.* London: The Royal Society.

Kirby, R. 1969 Sedimentary environments, sedimentary processes and river history in the Lower Medway Estuary, Kent. Ph.D. thesis, University of London.

Klein, G. de Vries. 1967 Comparison of recent and ancient tidal flat and estuarine sediment. In: *Estuaries* (ed. G. H. Lauff) Washington: American Association for the Advancement of Science.

Körber-Grohne, U. 1967 *Geobotanische Untersuchungen auf der Feddersen Wierde.* Weisbaden: F. Steiner.

Lake, R. D., Ellison, R. A., Henson, M. R. & Conway, B. W. 1975 *South Essex geological and geotechnical survey.* 2. *Geology.* London: National Environmental Research Council (Institute of Geological Sciences).

Lamb, H. H. 1969 On the problem of high waves in the North Sea and neighbouring waters and the possible future trend of the atmospheric circulation. Unpublished paper.

Lennon, G. W. 1975 Coastal geodesy and the relative movement of land and sea levels. In: *Geodynamics today: a review of the Earth's dynamic processes*, pp. 97–104. London: The Royal Society.

Marsland, A. 1977 The evaluation of the engineering design parameters for glacial clays. *Q. Jl engng Geol.* **10**, 1–26.

Mitchell, G. F., Penny, L. F., Shotton, F. W. & West, R. G. 1973 A correlation of Quaternary deposits in the British Isles. *Geol. Soc. Lond.* Spec. Rep. No. 4.

Mörner, N.-A. 1976*a* Eustacy and Geoid changes. *J. Geol.* **84**, 123–151.

Mörner, N-A. 1976*b* Eustatic changes during the last 8,000 years in view of radiocarbon calibration and new information from the Kattegatt region and other northwest European coastal areas. *Palaeogeog., Palaeoclimatol., Palaeoecol.* **19**, 63–85.

Morzadec-Kerfourn, M. T. 1974 Variations de la ligne de rivage Armoricaine au Quaternaire. *Mém. Soc. géol. mineral. Bretagne.* **17**, 1–208.

Oldfield, F. 1965 Problems of mid-Post-glacial pollen zonation in part of northwest England. *J. Ecol.* **53**, 247–260.

Paepe, R., Sommé, J., Cunat, N. & Baeteman, C. 1976 Flandrian, a formation or just a name? *Newslett. Stratigr.* **5**, 18–30.

Patrick, R. & Reimer, C. W. 1966 The diatoms of the United States, exclusive of Alaska and Hawaii. *Acad. Nat. Sci. Philadelphia.* **1**, 1–698.

Peragallo, H. & Peragallo, M. 1887–1908 *Diatomees marines de France et des districts maritimes voisins Grez-sur-Loing.* (vols. 1–3), reimpression 1965. Amsterdam: Asher.

Prandle, D. 1975 Storm surges in the southern North Sea and River Thames. *Proc. R. Soc. Lond.* A **344**, 509–539.

Ranwell, D. S. 1972 *Ecology of Salt Marshes and Sand Dunes.* London: Chapman & Hall.

Rashid, M. A. & Brown, J. D. 1975 Influence of marine organic compounds on the engineering properties of remoulded sediment. *Engng. Geol.* **9**, 141–154.

Reineck, H. E. 1967 Layered sediments of tidal flats, beaches and shelf bottoms of the North Sea. In: *Estuaries* (ed. G. H. Lauff) Washington: American Association for the Advancement of Science.

Rossiter, J. R. 1967 An analysis of annual sea level variations in European waters. *Geophys. J. R. astr. Soc.* **12**, 259–299.

Rossiter, J. R. 1969 *Thames flood prevention, first report of studies, Appendix* 6. London: G.L.C.

Rossiter, J. R. 1972 Sea level observations and their secular variation. *Phil. Trans. R. Soc. Lond.* A **272**, 131–139.

Royal Netherlands Geological and Mining Society 1954 Symposium: Quaternary changes in level, especially in the Netherlands. *Geol. en Mijnb* N.S. **16**.

Shepard, F. P. 1963 Thirty-five thousand years of sea level. In: *Essays in marine geology in honour of K.O. Emery* (ed. T. Clements), pp. 1–10. Los Angeles: University of Southern California Press.

Shephard-Thorn, E. R. 1975 The Quaternary of the Weald – a review. *Proc. geol. Ass.* **86**, 537–547.

Shephard-Thorn, E. R., Lake, R. D. & Atitullah, E. A. 1972 Basement control of structures in the Mesozoic rocks of the Strait of Dover region, and its reflexion in certain features of the present land and submarine topography. *Phil. Trans. R. Soc. Lond.* A **272**, 99–110.

Sherlock, R. L. 1962 *British regional geology: London and Thames Valley* (3rd. ed.) London: H.M.S.O.

Skempton, A. W. 1970 The consolidation of clays by gravitational compaction. *Q. Jl Geol. Soc. Lond.* **125**, 373–412.

Skempton, A. W., Smotrych, S. W., Hibbert, F. A. & Haynes, J. R. 1969 Holocene stratigraphy and sea level changes near Avonmouth, Gloucestershire. Unpublished paper.

Smith, A. G. & Pilcher, J. R. 1973 Radiocarbon dates and vegetational history of the British Isles. *New Phytol.* **72**, 903–914.

Spurrell, F. C. J. 1889 On the estuary of the Thames and its alluvium. *Proc. geol. Soc. Lond.* **11**, 210–230.

Stratigraphy Committee of the Geological Society of London 1969 Recommendation on stratigraphic usage. *Proc. geol. Soc. Lond.* **1656**, 139–166.

Stuart, A. J. 1974 Pleistocene history of the British vertebrate fauna. *Biol. Rev.* **49**, 225–266.

Sutcliffe, A. J. 1976 The British glacial – interglacial sequence. *Quaternary Newslet.* **18**, 1–7.

Switsur, V. R. 1973 The average of corrected dates presented at the New Zealand Radiocarbon conference in 1972. In: *Radiocarbon: calibration and prehistory.* pp. 112–115. (ed. T. Watkin), Edinburgh: University Press.

Ters, M. 1973 Les variations du niveau marin depuis 10,000 ans, le long du littoral Atlantique Francais. In: *Le Quaternaire: geodynamique, stratigraphie et environment.* Christchurch N.Z.: Congress International de l'Inqua pp. 114–135.

Tooley, M. J. 1974 Sea level changes during the last 9000 years in northwest England. *Geog. J.* **140**, 18–42.

Tooley, M. J. 1976 Flandrian sea level changes in west Lancashire and their implication for the 'Hillhouse Coastline'. *Geol. J.* **11**, 137–152.

Tooley, M. J. 1977*a* Holocene sea level changes: problems of interpretation. *Geol. Fören. Stockh. Förh.* **100**.

Tooley, M. J. 1977*b* *Sea level changes: the coast of north-west England during the Flandrian stage.* Oxford University Press.

Troels-Smith, J. 1955 Karakterising af løse jordarter. *Danm. Geol. Undersøgelse IV.* **3**, 1–73.

Valentin, H. 1953 Present vertical movements of the British Isles. *Geog. J.* **119**, 299–305.

Walcott, R. 1972 Past sea levels, eustacy and deformation of the Earth. *Quat. Res.* **2**, 1–14.
Walker, D. 1966 The post-glacial forest period. In The late Quaternary history of the Cumberland Lowland. *Phil. Trans. R. Soc. Lond.* B **251**, 1–210.
Welin, E., Engstrand, L. & Vaczy, S. 1972 Institute of Geological Sciences radiocarbon dates III. *Radiocarbon* **14**, 331–335.
Welin, E., Engstrand, L. & Vaczy, S. 1974 Institute of Geological Sciences radiocarbon dates V. *Radiocarbon* **16**, 95–104.
Welin, E., Engstrand, L. & Vaczy, S. 1975 Institute of Geological Sciences radiocarbon dates VI. *Radiocarbon* **17**, 157–159.
van der Werff, A. & Huls, H. 1958–74 *Diatomeënflora van Nederland* (1–10). A. van der Werff, Westzijde 13a, De Hoef (U.), The Netherlands.
West, R. G. 1964 Interglacial deposits at Ilford, Essex. *Phil. Trans. R. Soc. Lond.* B **247**, 185–212.
West, R. G. 1968 *Pleistocene geology and biology*. London: Longmans.
West, R. G. 1969 Pollen analyses from interglacial deposits at Aveley and Grays, Essex. *Proc. geol. Ass.* **80**, 271–282.
West, R. G. 1970 Pollen zones in the Pleistocene of Great Britain and their correlation. *New Phytol.* **69**, 1179–1183.
Whitaker, W. 1889 Geology of London. *Mem. geol. Surv.* **1**, 454–477.
Wilson, N. E., Radforth, N. W., Macfarlane, I. C. & Lo, M. B. 1965 The rates of consolidation for peat. *Proc. 6th Internat. Conf. Soil Mech.*
Wooldridge, S. W. 1927 The Pliocene history of the London Basin. *Proc. geol. Ass.* **38**, 49–132.
Wooldridge, S. W. 1957 Some aspects of the physiography of the Thames Valley in relation to the Ice Age and early man. *Proc. prehist. Soc. Lond.* **23**, 1–19.
Wooldridge, S. W. 1960 The Pleistocene succession in the London Basin. *Proc. geol. Ass.* **71**, 113–129.
Wooldridge, S. W. & Linton, D. L. 1955 *Structure surface and drainage in southeast England*. London: Geoffrey Philip & Son.
Wright, H. E. & Patten, H. L. 1963 The pollen sum. *Pollen et Spores*. **5**, 445–450.
Wymer, J. 1968 *Lower Palaeolithic archaeology in Britain*. London: John Baker.
Zeuner, F. E. 1954 Riss or Würm? *Eisz. u. Gegenw.* **4**, 98–105.
Zeuner, F. E. 1959 *The Pleistocene Period*. London: Hutchinson.

Appendix 1. Species list for shells from the Dartford Tunnel, face 3

	number of valves counted
(*a*) land species	
Carychium sp.	1
'*Succinea*' *sp.* (putris/*pfeifferi*)	3
Discus rotundatus (Müller)	6
Vitrea crystallina (Müller)	3
Aegopinella nitidula (Draparnaud)	1
Arianta arbustorum (Linné)	fragments
Cepaea sp.	3
(*b*) freshwater species	
Valvata cristata Müller	9
Bithynia tentaculata (Linné)	2
Lymnaea palustris (Müller)	23
Planorbis planorbis (Linné)	1
Anisus leucostoma (Millet)	2
Pisidium personatum Malm	17

Appendix 2. Index points for sea level changes in the Bristol Channel

number	site borehole	height m O.D.	radiocarbon date a B.P.	laboratory number	literature sources
1	Dunball	−20.7	8360 ± 145	I-4315	Hawkins (1971)
2	Highbridge 212/3	−21.3	8360 ± 140	I-4403	Kidson & Heyworth (1973, 1976)
3	Avonmouth	−6.91	7090 ± 120	GX-1112	Skempton *et al.* (1969)
4	Stolford 6J	−7.3	7060 ± 160	I 2688	Kidson & Heyworth (1973, 1976)
5	Stolford 6P	−5.95	6890 ± 120	I-2689	Kidson & Heyworth (1973, 1976)
6	B-on-S	−4.57	6262 ± 130	Q-134	Godwin & Willis (1959)
7	Margham	−3.2	6184 ± 143	Q-275	Godwin & Willis (1961)
8	Avonmouth	−3.29	6000 ± 120	GX-1111	Skempton *et al.* (1969)
9	Stolford 5C	−2.0	6230 ± 95	NPL-148	Kidson & Heyworth (1973, 1976)
10	Stolford 5B	−1.0	5380 ± 95	NPL-147	Kidson & Heyworth (1973, 1976)
11	Kingston Seymour	+0.15	5600 ± 110	I-4844	Hawkins (1971)
12	Shapwick Heath	+0.3–+0.61	5510 ± 120	Q-423	Godwin & Willis (1961)
13	Tealham Moor	+0.3–+0.61	5412 ± 130	Q-120	Godwin & Willis (1959)
14	Avonmouth	+2.06	4960 ± 140	GX-1203	Skempton *et al.* (1969)
15	Stolford 6V	+2.3	4790 ± 120	I-3395	Kidson & Heyworth (1973, 1976)
16	Avonmouth	+1.76	4250 ± 160	GX-1110	Skempton *et al.* (1969)
17	Avonmouth	+2.52	4110 ± 120	GX-1202	Skempton *et al.* (1969)
18	Portbury	+3.35	4240 ± 105	I-4842	Hawkins (1971)
19	Kingston Seymour	+1.33	3690 ± 110	I-4846	Hawkins (1971)
20	Stolford 5A	+1.02	3460 ± 90	NPL-146	Kidson & Heyworth (1969)
21	Kingston Seymour	+4.1	3350 ±	—	Hawkins (1971)
22	Llanwern	+2.9	2660 ± 110	Q-691	Godwin & Willis (1964)
23	Avonmouth	+4.96	2790 ± 120	GX-1200	Skempton *et al.* (1969)
24	Avonmouth	+5.26	2410 ± 130	GX-1109	Skempton *et al.* (1969)

Explanation of abbreviations used throughout the paper

a.p.	arboreal pollen
h.w.m.t.	high water mark of medium tides
l.p.z.	local pollen assemblage zone
l.w.m.t.	low water mark of medium tides
l.w.s.t.	low water mark spring tides
m.h.w.	mean high water mark
m.h.w.o.t.	mean high water mark of ordinary tides
m.h.w.s.t.	mean high water mark for spring tides
m.l.w.s.t.	mean low water mark for spring tides
m.s.l.	mean sea level
m.t.l.	mean tide level
n.a.p.	non-arboreal pollen
p.z.	pollen assemblage zone
t.d.	total diatom count
t.l.p.	total land pollen
t.p.	total pollen

FIGURE 4. Stratigraphic diagram from the Tilbury Docks and West Tilbury Marshes area, based upon borehole data supplied by Binnie and Partners Ltd, the Institute of Geological Sciences, Le Grande Sutcliffe & Co. and the author. The sediment symbol represents a medium brown fibrous fen peat, which is well humified with a significant gyttja component; branches, twigs and leaves are common, particularly in Tilbury I and II. Appropriate Troels-Smith symbols and proportions have been used where the inorganic element in the biogenic deposits exceeded 25 % of the total.

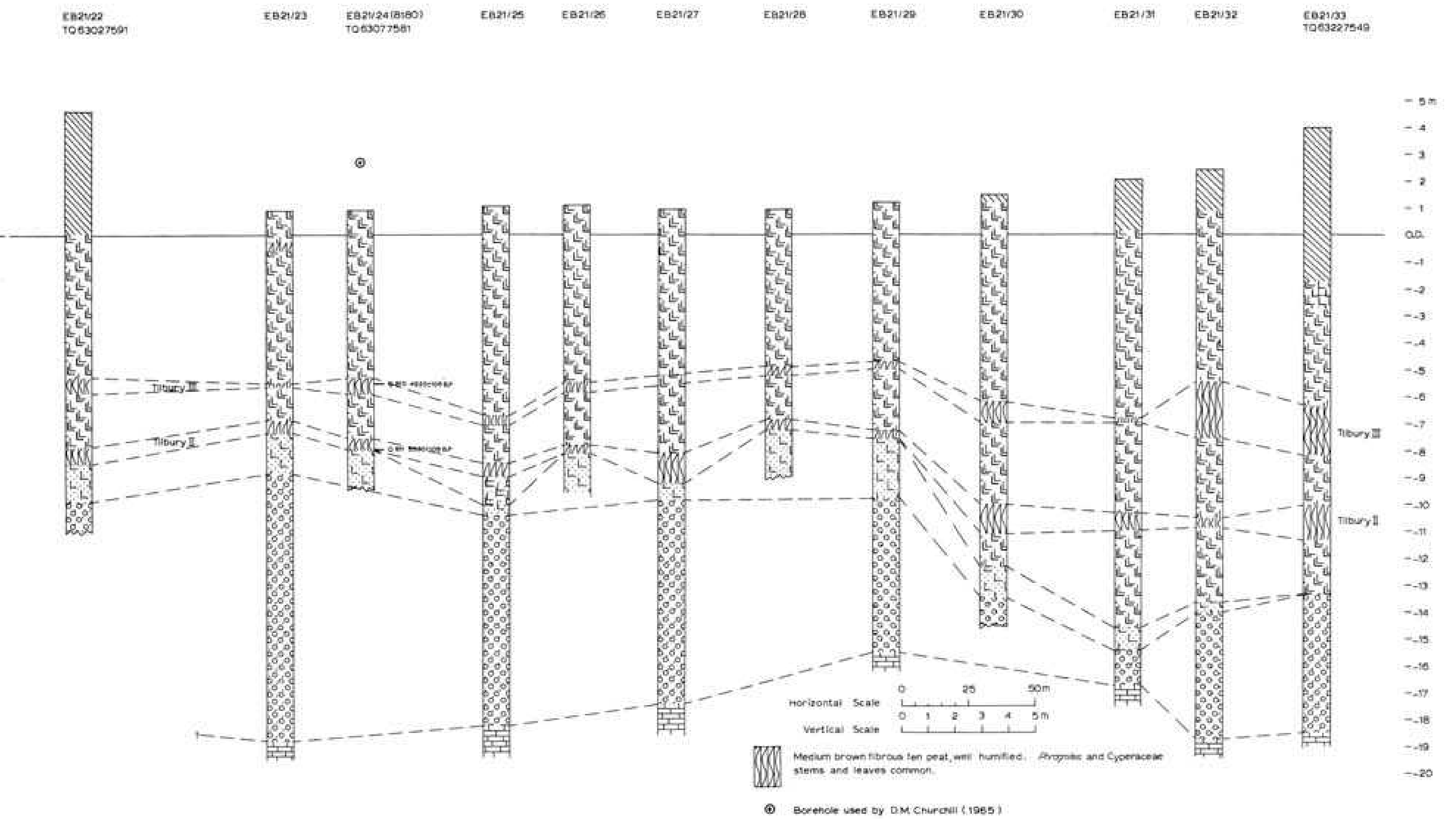


FIGURE 5. Stratigraphic diagram from the New Branch Dock Extension, Tilbury Dockz, based upon borehole data supplied by Soil Mechanics Ltd.

Figure 6. Pollen diagram from Tilbury (The World's End), S.B.I.

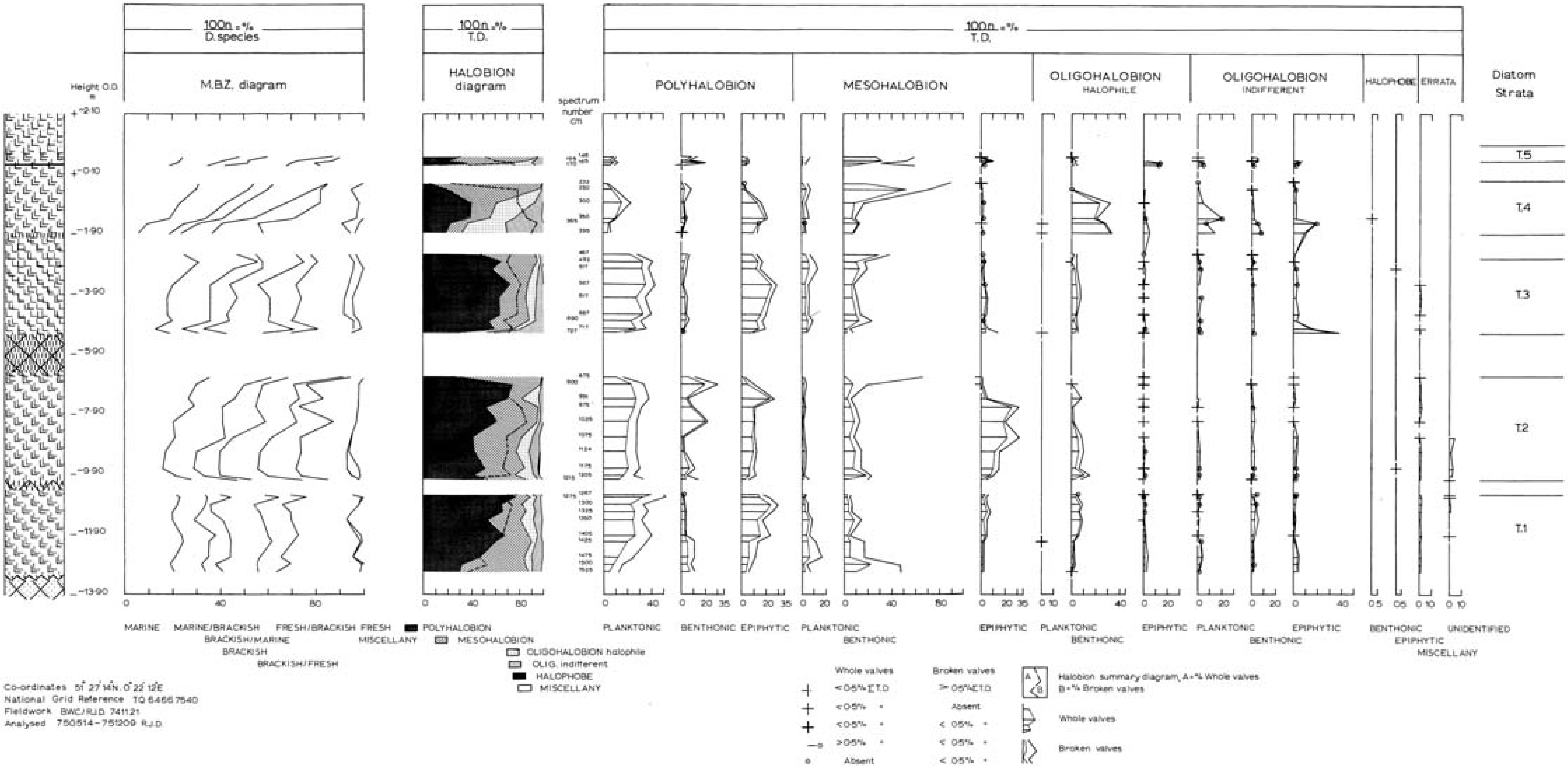


FIGURE 7. Diatom diagram from Tilbury (The World's End), S.B.I.

FIGURE 9. Stratigraphic diagram from Plumstead Marshes, based upon borehole data supplied by Foundation Eng. Ltd and the author. The sediment symbol represents a medium brown fen peat, well humified with a significant gyttja component, branches and twigs are common. Stratigraphic lines (---) above the basal gravel are tentative, used only as a visual guide. ⊙, Sample borehole.

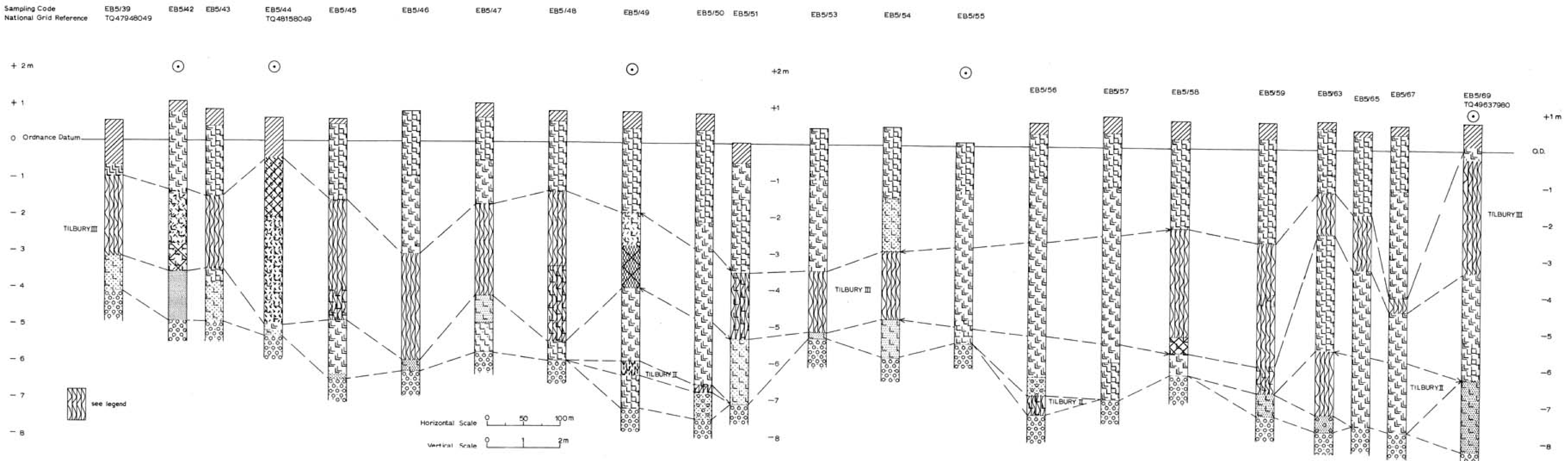


FIGURE 10. Stratigraphic diagram from Erith Marshes, based upon borehole data supplied by Foundation Eng. Ltd and the author. Stratigraphic lines (---) above the basal gravel are tentative, used only as a visual guide. The sediment symbol represents a medium brown fen peat, well humified with a significant gyttja component; branches and twigs are common. ⊙, Sampled borehole.

FIGURE 11. Stratigraphic diagram from Barking Level and Erith Marshes, based upon borehole data from Binnie & Partners Ltd, C.E.G.B., G.L.C. and the author. The sediment symbol represents a medium red-brown fen peat, well humified with a significant component; branches, twigs, bark and fruits of *Alnus*, *Quercus* and *Corylus* are common, particularly at the base of Tilbury III. Appropriate Troels-Smith symbols and proportions are used where the inorganic element in the biogenic deposit exceeds 25% of the total.

FIGURE 12. Pollen diagram from Crossness, S.B.I.

FIGURE 15. Sections from the New Dartford Tunnel, constructed from exposures observed during 1974. Sediment symbols, the proportion of component elements and terminology have been used in accordance with Troels-Smith (1955).

Figure 18. Pollen diagram from Stone Marsh, S.B.I.

FIGURE 17. Pollen diagram from the New Dartford Tunnel.

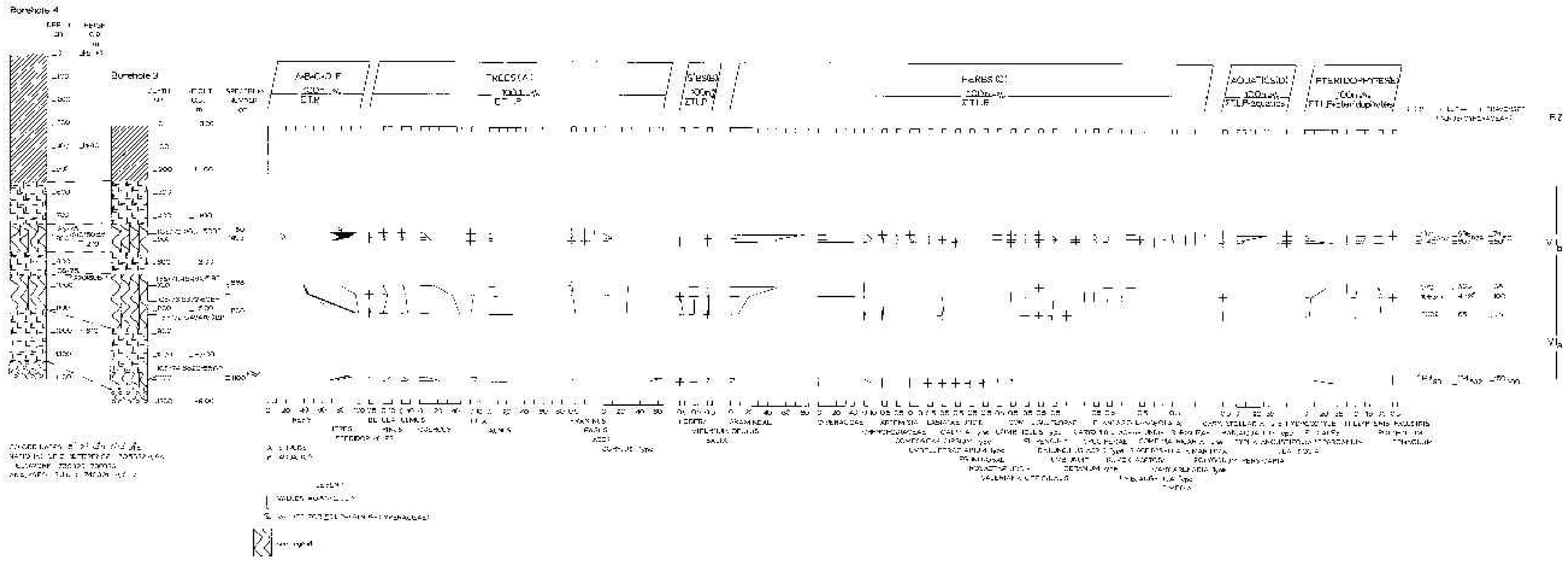


Figure 20. Pollen diagram from Littlebrook Power Station EB 3 and 4. The sediment symbol represents a well humified red-brown, homogeneous peat with a high monocot fraction and a significant gyttja content.

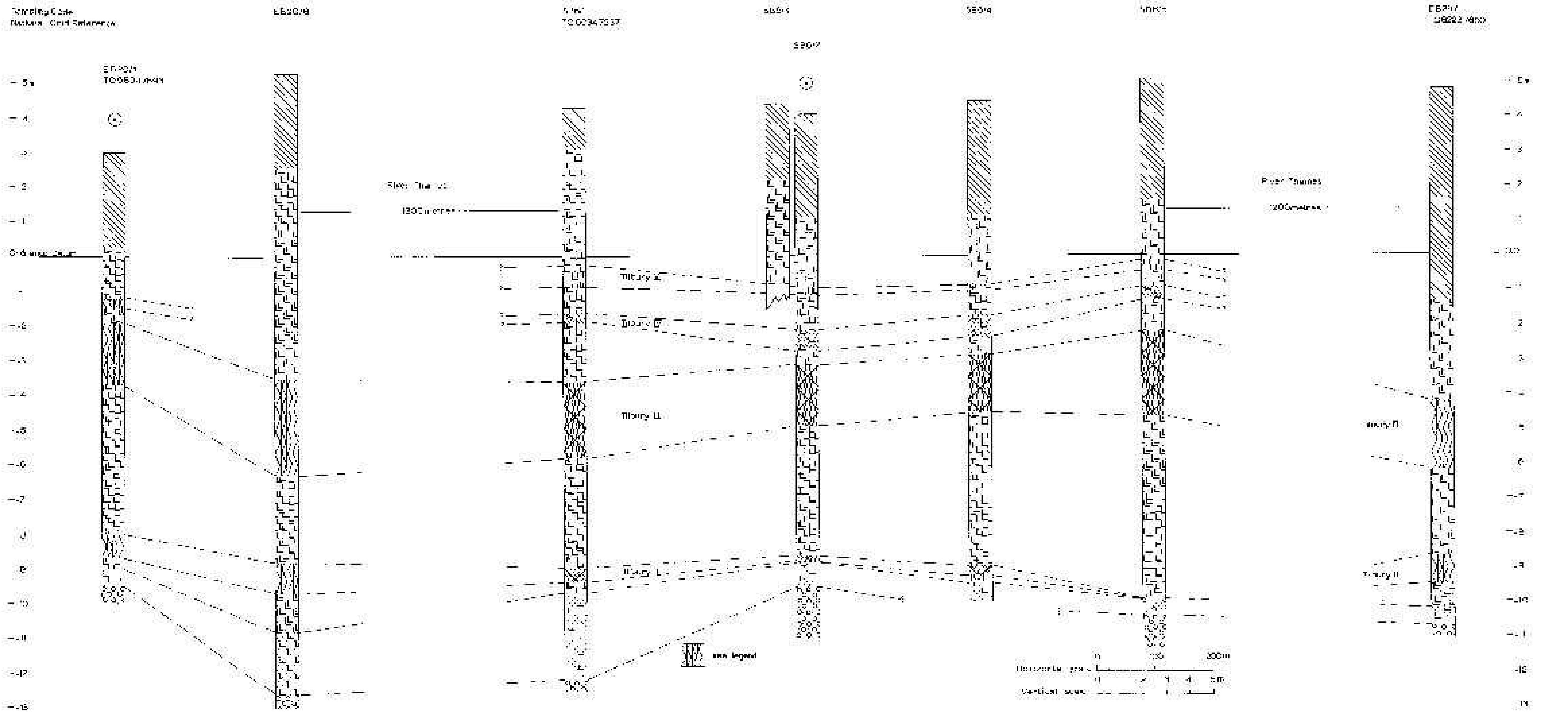


Figure 21. Stratigraphic diagram from West Thurrock and Broadness marshes, based upon borehole data supplied by Binnie and Partners Ltd, C.E.G.B., A.G. Weeks & Co. Ltd and the author. The sediment symbol represents a medium brown fen peat, well humified, with a significant gyttja content. Branches and twigs are common. ⊙, sample borehole.

FIGURE 22. Pollen diagram from Broadness Marsh, S.B.2.

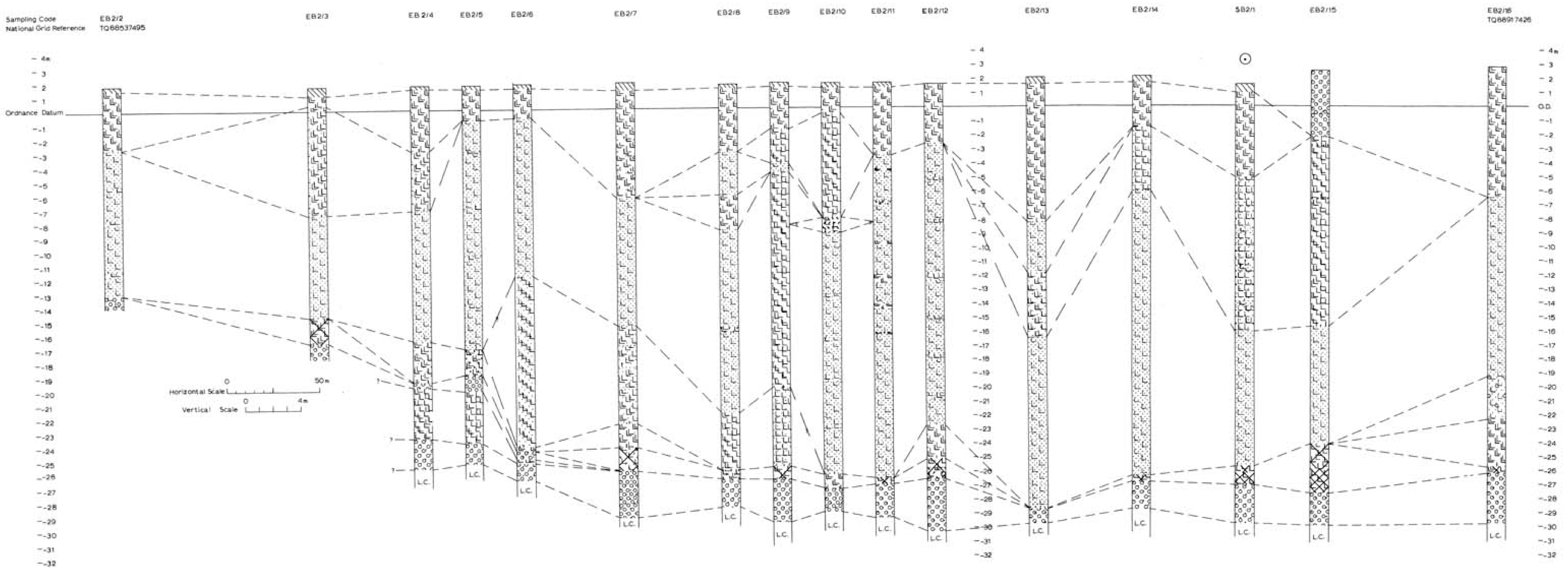


FIGURE 24. Stratigraphic diagram from Cockleshell Hard, Isle of Grain, based upon borehole data from G. Wimpey & Co. Ltd, and the Building Research Establishment, Watford. L.C., London Clay, a very stiff and tenacious, fissured brown silty clay; ⊙, sampled borehole.

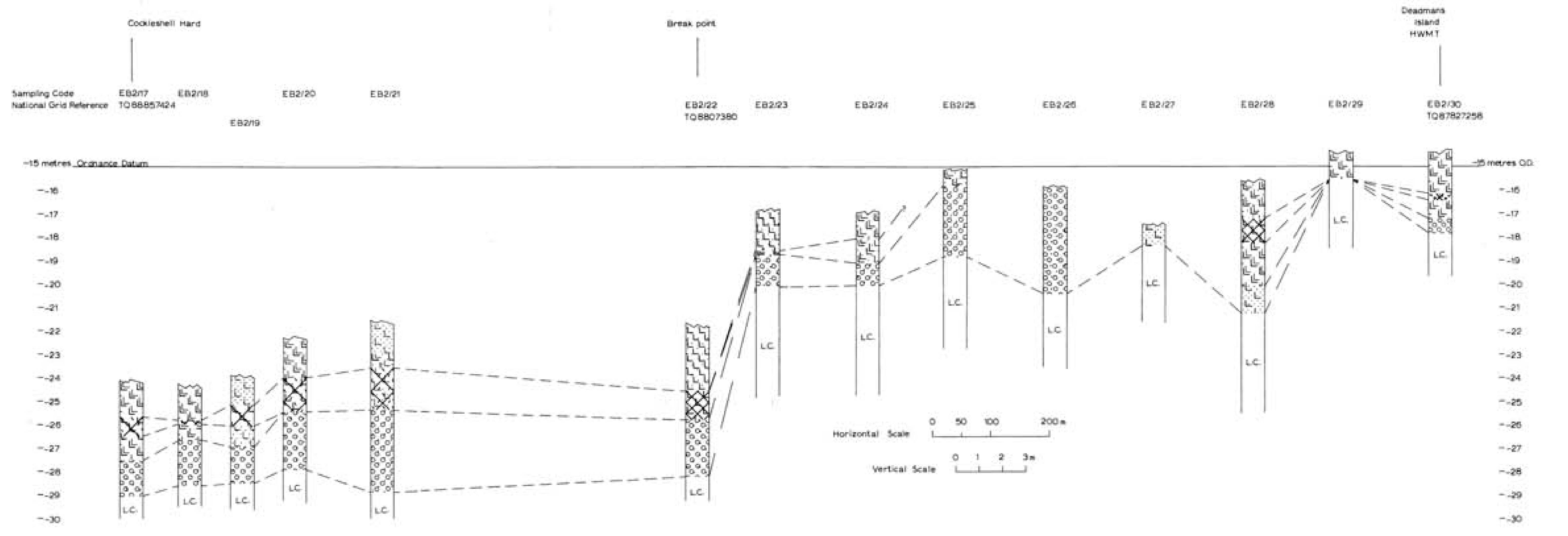


FIGURE 25. Cross section of the River Medway, showing the London Clay surface and basal buried channel sediments, based upon borehole data supplied by G. Wimpey & Co. Ltd. L.C., London Clay – a stiff and tenacious, fissured brown silty clay.

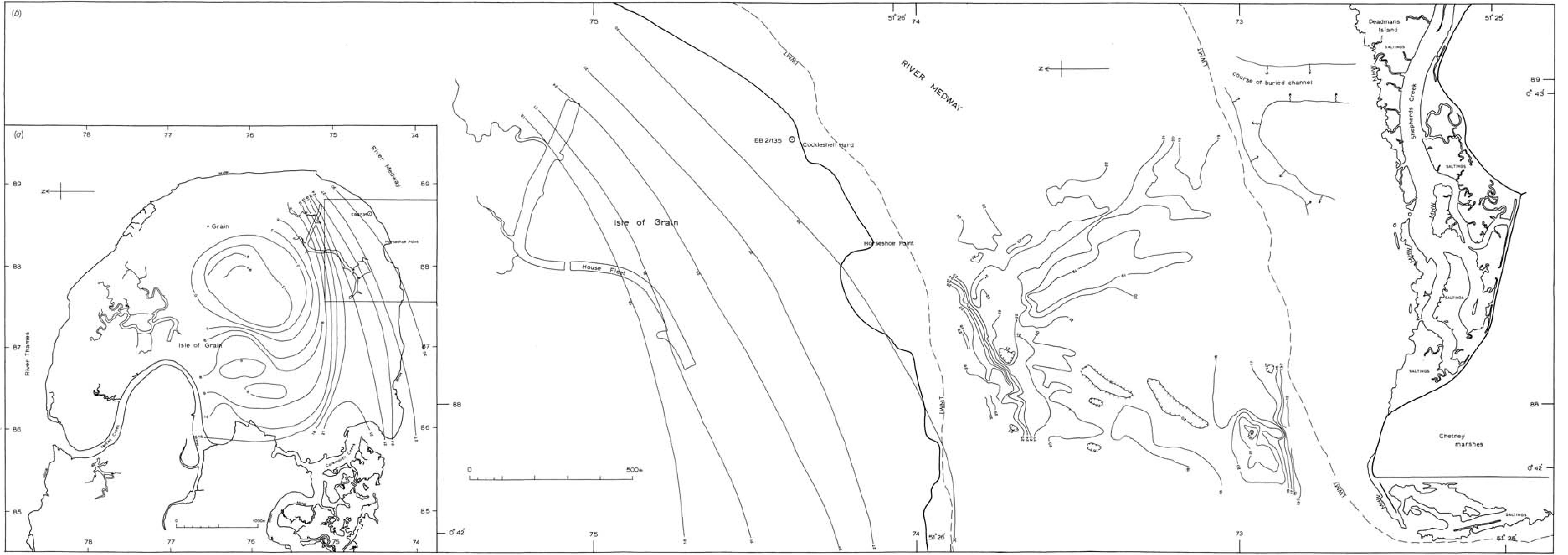


FIGURE 26. Maps of the London Clay surface. (a) Isle of Grain; (b) The Isle of Grain and the Medway channel. Contours are plotted in metres below O.D. (Newlyn), from borehole and geophysical data supplied to the C.E.G.B. by G. Wimpey & Co. Ltd (1966–72), and to British Petroleum by Soil Mechanics Ltd. ⤳, Direction of slope; —, embankment.

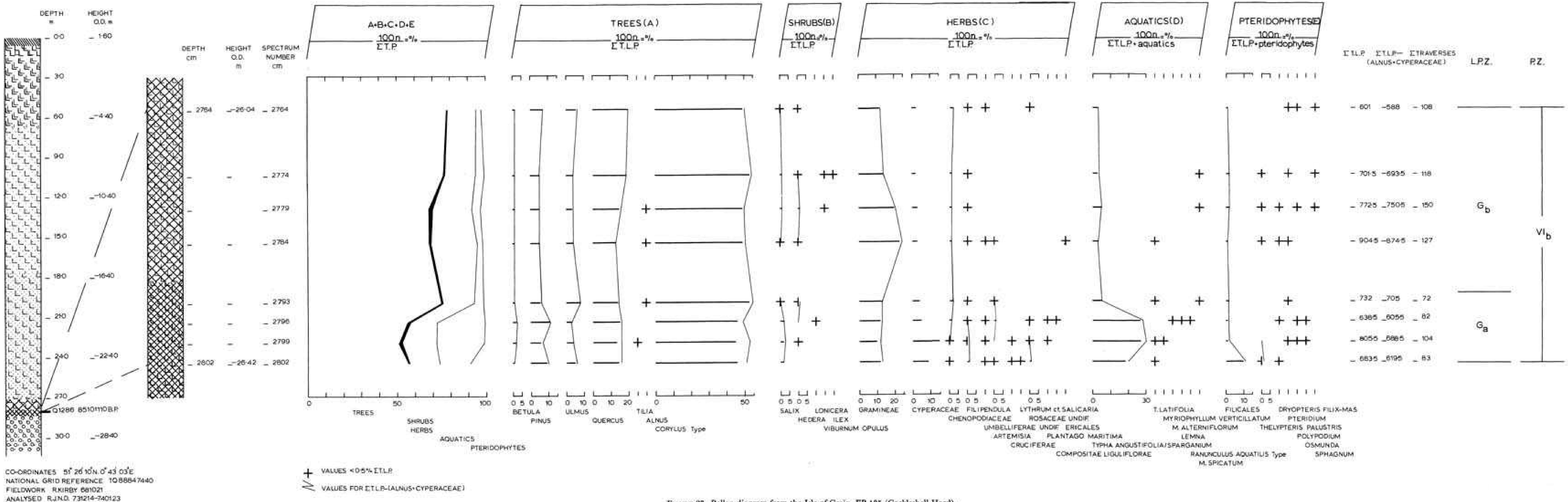


Figure 27. Pollen diagram from the Isle of Grain, EB 135 (Cockleshell Hard).

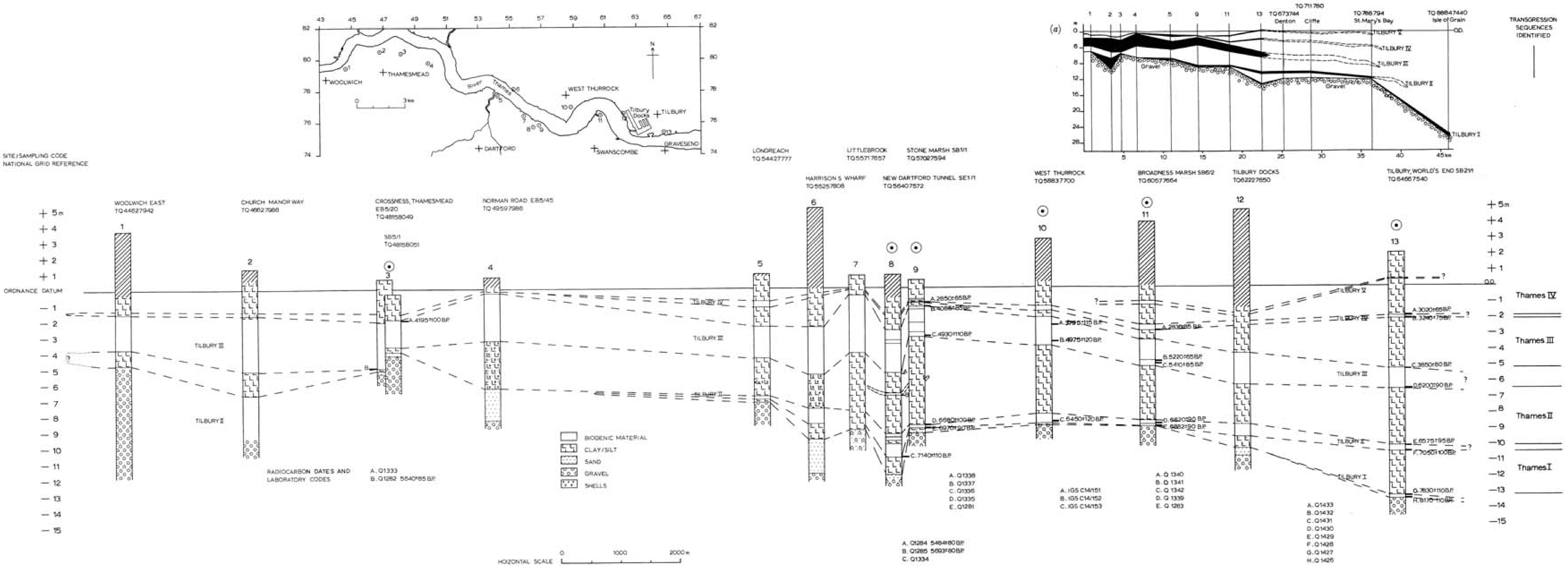


FIGURE 28. Flandrian transgression sequences in the Thames Estuary. Figure 28*a* gives a generalized section of the lower Thames Estuary, showing the distribution of biogenic and inorganic sediments and the relation of the Isle of Grain sequence to the Tilbury sequence. ⊙, Sampled borehole.