Flandrian sea-level changes in the fenland

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FLANDRIAN SEA-LEVEL CHANGES
IN THE FENLAND

by

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ABSTRACT

Flandrian sea-level changes in the Fenland

Micropalaeontological, stratigraphic, radiocarbon, and published data have been assessed to elucidate sea-level changes in the Fenland during the Flandrian Stage. Up to 8 periods characterised by positive tendencies in sea-level movement have been identified, Wash I - VIII, separated by up to 7 periods, Fenland I - VII, dominated by negative tendencies in sea-level movement. 102 ^{14}C dates form the chronological framework on which this scheme is based. Negative tendencies cannot yet be confirmed as absolute falls in sea-level due to the errors involved in the assessment of sea-level indicators. These errors relating to age and altitude have been quantified wherever possible. The variation in stratigraphic surfaces has been briefly assessed and the statistical limitations of pollen analyses have been shown by the application of confidence limits to the pollen diagrams. A computer program, NEWPLOT, has been developed to draw the pollen diagrams, including pollen concentration, from 6 sites at Bourne Fen, Cowbit Wash and Adventurers' Land. Models have been suggested to assess the stratigraphic and micropalaeontological changes at the salt marsh-freshwater fen transition and to identify tendencies of sea-level movement.

Problems relating to the existing methodology of sea-level studies have been noted from the difficulty in objectively correlating the data and results of various authors. The errors identified in the collection, interpretation and correlation of sea-level data have repercussions for the planning of sea-defences and land-use in low-lying coastal areas.

DECLARATION

This thesis is the result of my own work and includes nothing which is the outcome of work done in collaboration. Data from other authors which are referred to in the thesis are credited to the author in question at the appropriate point in the text.

STATEMENT OF COPYRIGHT

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CHAPTER ONE

Introduction

The study of relative sea-level change in the Fenland is of more than local importance since it contributes to the understanding of world-wide phenomena; including glacio-eustasy, climatic change, and neo-tectonics. The Fenland is the low-lying area surrounding the Wash and for a long time the rich stratigraphic evidence for sea-level change has been recorded (eg. Skertchly 1877). The time limit of the study is nominally the Flandrian Stage but effectively the age of the earliest post-glacial marine or organic onshore deposits to be recognized within the Fenland is c.8600 BP.

The approach used for this research is set out within this chapter in the following parts -

1.1 : Methodology.
1.2 : Operational definitions.
1.3 : Scope of the study.
1.4 : Selection of the sampling areas.
1.5 : Data collection and statistical testing.
1.6 : Objectives.

Part 1.1 : Methodology

Studies of sea-level change lack any accepted formal methodology and therefore scientific laws and theories. The treatment of data is inductive : information is converted into a numerical form and then by the process of definition, measurement, and classification the data are placed into groups and categories that impose some degree of seemingly rational order upon the data. Two examples of this approach can be given.

> "The... aim is through the analysis of data to provide a rational and internally consistent series of arguments that can be used to reconstruct the post-glacial uplift, emergence and crustal deformation of areas that vary in size from local, through regional, to continental. The treatment is principally inductive and statistical rather than deductive." (Andrews 1970 p.1).

> "The argument is inductive,and stress is laid on the nature and quality of the field and laboratory observations and descriptions, as a basis for strong empirical models." (Tooley 1978a p.2).

The development of explanation via inductive models is the normal route followed by a science during the period of data collection. Problems arise when a common language is required for classification. Without adequately rigid operational definitions, and strict adherence to them, even statistically significant features are not capable of comparison. Furthermore problems involving circular arguments easily arise. These are described in parts 1.2 and 1.3.

Part 1.2 : Operational definitions

Without strict definition of terms comparability between different research projects become increasingly difficult. Most of the necessary definitions, eg. those used in the pollen analyses, are given when they first occur in the succeeding chapters, but the following, widely-used terms are defined here:-

Altitude and depth : the altitude of a sample is it's level related to Ordnance Datum, Newlyn by levelling and is given in metres, whereas the depth of a sample to the local datum, usually ground level for a borehole, is given in centimetres.

Radiocarbon age : these data, abbreviated to ^{14}C, are given as uncorrected ages, as shown in Radiocarbon, with a half life of 5570 ± 30 years, and quoting the error to one standard deviation. All dates are given as BP.

Flandrian, Holocene, post-glacial : the term used to describe the last 10000 years is usually one of these. The term Flandrian is used here for the following reasons:-

- the term "Post-glacial" can be misleading and is only used in the form "post-glacial" as a genetic facies term indicating sediments deposited outside the influence of the receding ice (Mörner 1973a).
- both Flandrian and Holocene cover the last 10000 years. Flandrian is used here as the formal stage name for the present interglacial stage following the recommendation of the Quaternary Era Sub-Committee (Michell et al. 1973) and the arguments expressed by Hyvärinen (1978 cf. Paepe et al. 1976, Mangerud and Berglund 1978).

Sea-level and tide-levels : following Jardine (1975a) mean sea-level and mean tide-level are considered to be the same within the constraints of present research techniques. Tide-levels are abbreviated and defined from Admiralty Tide Tables (1980).

Eustatic factor, isostatic factor : Mörner (1976a) explains that the relative sea-level, or shoreline displacement, for any given point and age is a function of the water-based and the land-based variables. The former consist of the following components : glacial-eustasy, tectono-eustasy, geoidal-eustasy, meteorological local effects, hydrological local effects and oceanographic local effects. These are collectively defined as the eustatic factor. Similarly the land-based variables are crustal movement and local compaction, which together represent the isostatic factor.

Transgression and Regression : these terms are widely used in sea-level studies but are seldom explicitly defined with the result that meaningful correlation becomes difficult.

Mörner (1976b) uses transgression to indicate a positive vertical movement in sea-level, regression a fall in sea-level. In correlating between his type area, the Kattegatt region, and Böborg Sö, Denmark, he clearly distinguishes between shorelines, transgressions, and fjord stages.

However in different sedimentary environments, where the record is represented by intercalated organic and clastic horizons, the definition of terms is not so clear. This contributes to the conflicting interpretation of similar sequences (eg. Kidson and Heyworth 1973, 1979, Tooley 1979). These papers illustrate the dispute over the form of the sea-level curve during the Flandrian Stage. The interpretation of "peat-above-clay" and "clay-above-peat" contacts determines the form of the relative sea-level curve produced. These two contacts have been described as the regressive and transgressive overlaps respectively (eg. Streif 1979a) and the problem arises when they have been applied in relation to lithologic changes, sea-level movement and chronological schemes.

The interpretation of intercalated organic and clastic horizons as fluctuations in sea-level has been clearly stated by Donner (1970) and Tooley (1974). Tooley explains that (1974 p.38):-

> "The oscillating, relative sea-level curve from north-west England shows periods of very rapid rise in sea-level followed by periods of apparent stillstand or fall. Each oscillation comprehends a marine transgression; from the initiation of the transgression, a rise in sea-level is inferred, whereas the culminating stages of the transgression indicate a relative fall in sea-level."

Tooley's use of the term transgression becomes unclear with his introduction of "regression" (1976 p.144):-

> "The oscillations recorded on the sea-level curve are closely associated with periods of marine transgression and regression in West Lancashire."

His listing of the transgressions, Lytham I to X, presumably implies that the intervening stages are regressions, represented by peat layers. However the terminology, explanation of rise and fall of sea-level, and the diagrammatic representation are not consistent (Tooley 1974 fig.10, 1976 fig. 2).

Firstly the transgressions Lytham II and III show an inconsistency with the interpretation of intercalated horizons outlined by Donner (1970). No period of falling sea-level is shown on the curve (Tooley 1974 fig.10) even though there is an intervening, intercalated dated peat layer, at NB-10 and NB-2 (Tooley 1974 fig.6). Furthermore comparison of the stratigraphy, Lytham Hall Park-8, the ^{14}C data (Tooley 1976 table 1), inferred sea-level movement (1976 pl.43) and the oscillating sea-level curve (1976 fig.2) indicates a period of transgression to represent a rise and then fall of sea-level and a regression a fall followed by a rise. This confusion has developed from the use of transgression to define a facies unit, ie. marine sediments, at a type locality and then the use of this lithostratigraphic unit as the equivalent to a period of rise or fall in sea-level.

A simple stratigraphic model (fig.1.1) shows the different meanings of transgression and regression following the examples of Mörner and Tooley outlined above. Using limited evidence, ie. dating the lithologic boundaries in boreholes A, B, C, the resulting chronologies of periods of transgression and regression differ quite considerably. Therefore the sequences designated Lytham I to X should not be used in a chronostratigraphic scheme to correlate with the chronology of transgressions and regressions proposed by Mörner (1976b) since the time boundaries refer to different events (cf. Devoy 1979, Mörner 1976b, Tooley 1978a).

Devoy (1977a,b, 1979) recorded 5 organic, regression sequences and 4 clastic, transgression, sequences in the lower Thames estuary. However there are slight discrepancies between the time limits given for the "Flandrian transgression sequences" (Devoy 1977b table 1) and the movement of sea-level as shown on the time-depth graph (Devoy 1977b fig.2). This is despite a clear definition of the terms transgression and regression contact. Devoy (1977a) asserts that a peat-over-clay contact is interpreted as showing a net negative or downward movement of sea-level and not simply the exclusion of marine or open water conditions due to the local changes in coastal morphology, and this vertical movement is termed a regression.

This is quite different from Jelgersma (1961, p.87)

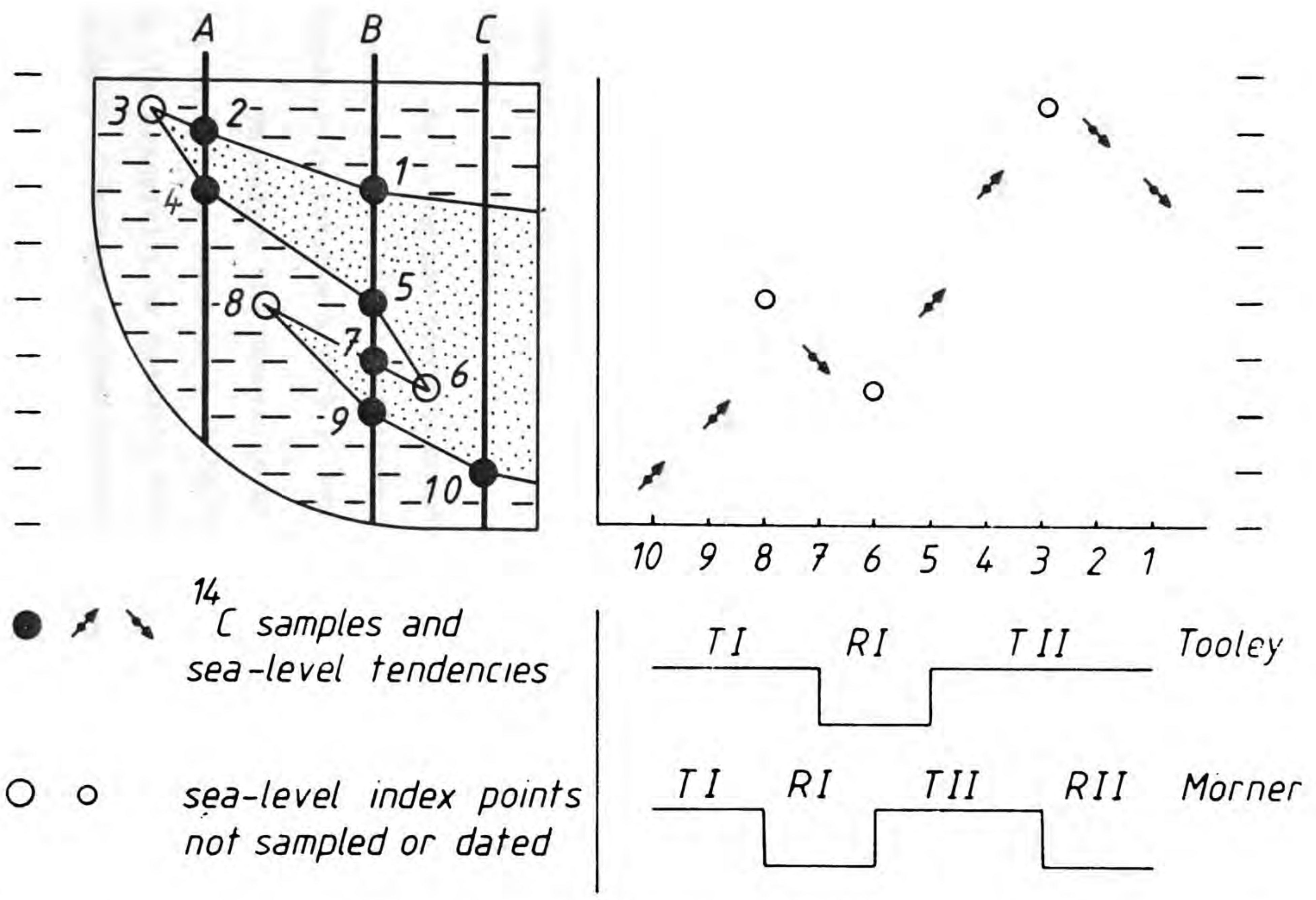


Figure 1.1 : Definition of transgression and regression sequences. The model stratigraphic section is sampled by 3 boreholes, A.B.C, from which 7 radiocarbon assays are taken. The sea-level tendencies and the transgression/regression sequences as defined by Tooley and Mörner (see text) appear to the right.

who states:-

> "the expressions 'transgression' and 'regression' phase should not be interpreted as a rise and fall of sea level. Major fluctuations of sea-level are not indicated on our curve, the word transgression only expresses that land was covered by the sea, regression a withdrawal of the sea."

However it should be noted that Jelgersma (1979) accepts a peat layer on top of the marsh clay in the Eem valley as the start of the fall of sea-level during the Eemian.

Jardine (1975b) indicated the problems associating "transgression" and "regression" with lithology, chronology, and movements in sea-level by referring the terms to periods of landward and seaward migration, either by horizontal or by vertical movement or by combined horizontal and vertical movement, of the line of intersection of the land and the surface of the sea.

By using the terms transgressive and regressive overlap Streif (1979a) indicates that the latter need not necessarily involve a fall in sea-level at the open coast.

Therefore the consensus of opinion appears to favour the use of the terms in a lithostratigraphic sense, referring to the transition or tendency for change from semi-terrestrial to marine/brackish sedimentation and vice versa. This leads to confusion where the terms are applied to a chronostratigraphic correlation scheme intrinsically linked to movements in relative sea-level (eg. Devoy 1979 fig.31) since the definition of the terms is not suitable. Indeed the relationship between lithologic changes in the tidal flat and lagoonal zone and sea-level changes at the open coast is a major question yet to be adequately answered. Due to historical misuse and over-use of the terms transgression and regression it would appear unwise to use them in studies of the tidal flat and lagoonal zone in any other sense than aiding stratigraphic description, such as transgressive and regressive overlap/contact. Therefore transgression and regression are used with no explicit relationship to vertical change in sea-level, or formally in the development of chronostratigraphic schemes, except when they have been used in existing schemes to which direct reference is made.

Part 1.3 : Scope of the study

The spatial and temporal scales over which sea-level changes are studied varies considerably since their origin and causality are applicable in many geomorphological models, ranging, for example, from earth history to salt marsh development. The components of the eustatic and isostatic factors, given in part 1.2, only indicate the main groups of variables but the distinction of cause and effect among geomorphic variables varies with the extent of the landscape and time. The more specific the study the shorter the time span dealt with and the smaller the space considered. Similarly if the variables are not considered with respect to the time span involved it is difficult to determine which variables are independent (Schumm and Lichty 1965). Thus the resolution of the eustatic factor required in a study of sea-level response to ice-volume fluctuations throughout the Quaternary Era is quite different to the requirements for planning present coastal defences and the status of the variables changes.

The approach adopted here follows the guidelines given by Tooley (1978b p.204) -

> "The first criterion is that variates should come from a small homogeneous area, so that the effects of tidal inequalities, earth movements and variations in geoid configuration would be minimised."

This criterion is widely accepted in theory but no figure is indicated to what constitutes a small homogeneous area. Relative sea-level curves, due to their implicit space dependence, should be published only with the areal measurements over which they are applicable. Furthermore, the assessment of the status of the variables is most important. The clearest examples of this difficulty are the status of palaeo-tidal range and geoidal changes. They may be invoked to hinder the comparison of sea-level curves from different localities, ignored altogether, or measured by the difference in altitude of sea-level curves from different localities.

The problem of circular arguments is often difficult to avoid. For example an earth viscosity model and a sea-level curve can be used to verify a glacial history model; a glacial history model and sea-level curve to verify earth viscosity models ; an earth viscosity model and glacial history model to predict sea-level curves, with geoidal models sometimes added as a further refinement (eg. Andrews 1974, Chappel 1974, Clark and Bloom 1979, Clark and Lingle 1977, Farrell and Clark 1976, Walcott 1972).

Therefore, the scope of the present study is sea-level changes in the Fenland during the Flandrian Stage. Within this time it is hypothesized that such an area has acted uniformly to changes in all of the components of the eustatic factor. This uniformity is defined by the limits of the presently measurable variation of sea-level index points. Thus, the approach is one of gathering local information, its quantification, and the development of locally valid inductive models which can then be tested further locally and regionally.

Part 1.4 : Selection of the sampling areas

The Fenland includes all of the low-lying land, generally less than +10 m.OD, south of a line between Chapel Point and Hunstanton (fig.1.2). The morphology and sediments of the Fenland are primarily the result of processes under the direct or indirect influence of sea-levels during the Flandrian Stage.

The suitability of the Fenland as an area for study is shown by its long history of investigation (eg. Godwin 1978, Skertchly 1877) but now requiring re-investigation using refined techniques. Furthermore the area has a recent history of instability between the sea and the reclaimed marshes, for example the 1953 and 1978 floods, and has been deemed a possible site of nationally important development schemes, eg. water storage, nuclear power generation. Together these factors warrant the scientific investigation of sea-level changes affecting the area during the Flandrian.

The location of individual sites for data collection was decided at two levels of selection. Firstly the general location was decided by reference to earlier investigations, particularly those of Skertchly (1877) and Godwin (1940a), which revealed both areas with little or no detailed

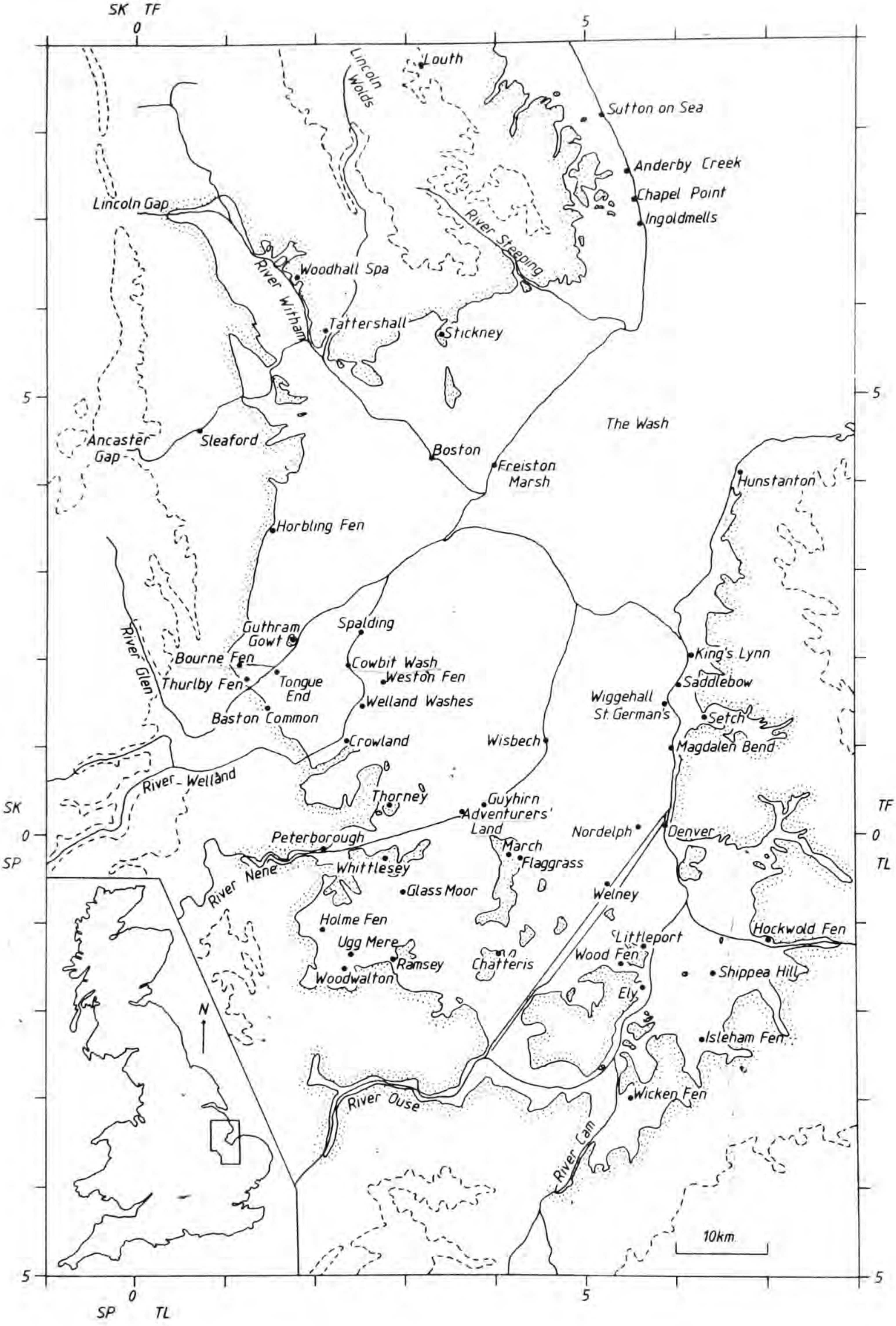


Figure 1.2 : The Fenland, showing the location of the major sites mentioned in the text.

investigation and sites of particular interest requiring re-investigation. The exact location of the line of boreholes was heavily dependent on ground conditions, particularly local farming practices and access.

Part 1.5 : Data collection and statistical testing

The collection of samples was constrained by the type of boring equipment available at different times during the period of research. Samples taken were supplemented by published data recording ^{14}C, pollen, stratigraphic and archaeological analyses. The location of the sites mentioned in the text is shown in fig. 1.2.

The collection of data for the resolution of a relative sea-level curve for the Fenland attempts to follow the guidelines for the IGCP Project 61 (van de Plassche and Preuss 1978) and the ^{14}C data additionally conform to criteria outlined by Tooley (1978b) that the dated samples should come from similar palaeoenvironments whenever possible and that they should be capable of independent age corroboration.

Statistical testing of data is not widely used in sea-level studies. This is probably due to the difficulty of obtaining sufficient data but may also reflect an unwillingness to test the statistical weakness of the data. In the present research statistical techniques have been applied wherever possible to indicate within-sample variation, thus giving an indication of the resolution that can be expected from this kind of study. Confidence limits and significance tests have been applied to the pollen data (chapter 5). However it has not been possible to use extensive statistical correlation techniques for inter-regional comparison.

Part 1.6 : Objectives

The objective of this research is to study the relative sea-level changes and sediment accumulation in the Fenland during the Flandrian. This is achieved in the following stages:-

- description of sites from the tidal flat and lagoonal zone.
- analysis of the data.
- interpretation of the data.
- establishment of a transgression/regression tendency chronology.
- construction of a sea-level curve.
- correlation with UK. and European schemes to indicate events of regional significance.

Within this program present methodologies, techniques of data collection, presentation, classification and interpretation are assessed to evaluate the resolution and limitations of the research conclusions which can then be used in other scientific programs.

CHAPTER TWO

Geological history up to the Flandrian Stage

This chapter is divided into 3 parts in order to cover the development of the regional geological environment which preceded the deposition of the unconsolidated Flandrian sediments. The 3 parts are:

2.1 : The pre-Quaternary geology of the Lincolnshire Marshes, Fenland and the North Sea.

2.2 : Environmental changes during the Quaternary Period up to 10,000 BP.

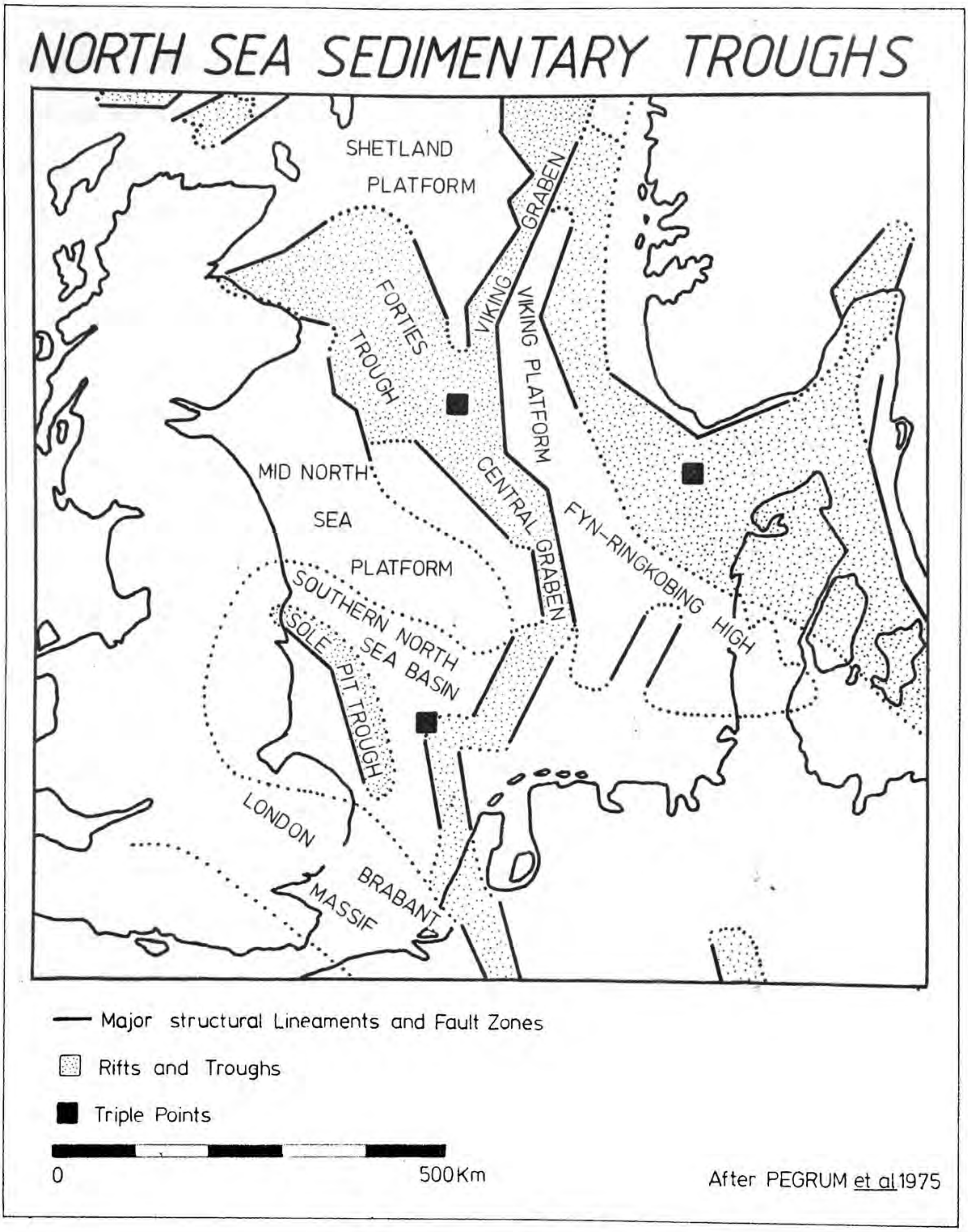
2.3 : The pre-Flandrian landscape of the northern Fenland.

Part 2.1 : The pre-Quaternary geology of the Lincolnshire Marshes, Fenland, and the North Sea

Since at least the Jurassic Period, when the oldest outcropping rocks of the area were formed, the Lincolnshire Marshes and Fenland have been an area of change between terrestrial and marine environments. There have been absolute vertical movements of both land and sea-levels. The limestones and clays of the Lincolnshire Edge and Huntingdonshire were deposited in a Jurassic sea of varying water-quality and depth. Similarly, the sandstone, ironstone, clay and extensive chalk deposits of Cretaceous age, which are 330 m. thick in Norfolk and 100 m. in Lincolnshire, are of marine and estuarine origin. However, between these two periods of marine deposition was a long period of relative land uplift with extensive land denudation (Chatwin 1961, Swinnerton & Kent 1976).

It will be appreciated that these relative sea-level changes are due to changes of both land and oceanic variables. However, the relative importance of these variables changes when a different time scale is used. In geological time, measured in 10 Ma, the changes of ocean basin shapes and volumes are very important; indeed the scale of the relative land-and sea-level changes increases as the timescale on which the movement can be identified becomes greater. Ancient tectonic movements are recognizable in the geological record but it has been argued (Mörner 1979) that a tectonic component to uplift, in addition to isostatic recovery, has been identified as a feature solely of Fennoscandinavia and is not found in the records from the United Kingdom, Iceland, and Baffin Island.

Regional folding and faulting during the Upper Carboniferous Period replaced a north-westerly tilting by an easterly tilting and marked the establishment of the North Sea Basin (Pegrum et al. 1975). This basin, part of the seismically inactive Eastern Atlantic continental margin (Bott 1975) is characterized by substantial vertical movements. Basin subsidence is explained, by Bott, as the result of crustal creep in response to the stress system at a margin, resulting in both regional and local subsidence with normal faulting in the brittle uppermost crust. However, the linear, sediment filled troughs, where crustal extension was expreseed simultaneously along three converging spreading axis, or triple points, (fig. 2.1), have also been explained by a stretching motion in a rift valley stage of development (Pegrum et al. 1975). Furthermore, Collette



After PEGRUM *et al* 1975

Figure 2.1 : North Sea sedimentary troughs.

(1968,1971) has attributed the subsidence to crustal thinning by transformation of gabbroic material to ecologite in response to thermal changes in the underlying mantle rather than proximity to a margin (Bott 1975). The resulting structure is that the mid-and northern North Sea have a central graben and fault block system, originating in Permian times, with major subsidence during the Jurassic and Lower Cretaceous, concealed beneath an essentially unfaulted deep basin of Upper Cretaceous and Tertiary rocks (Kent 1975). The geology of the southern North Sea Troughs is however further complicated by salt dome intrusion and the development of inversion troughs (Pegrum _et al_. 1975).

Jurassic and Cretaceous rocks are the sole solid outcropping rocks in Lincolnshire and around the Fenland basin but the subsidence of the North Sea Basin during the Tertiary and the associated erosion of the land surface are probably the most important geological events in explaining the present structure. Away from the Central Graben, erosion was widespread at the end of the Cretaceous period (63 MA ago), the inversion troughs of the southern North Sea reached their maximum uplift (Pegrum _et al_. 1975 fig. 15), and the soft chalk was eroded, as were the cores of older sediments. The combined results of the easterly tilting and erosion was that the clays were more easily denuded than the limestones and chalk and therefore the clay vales were separated by ranges of hills with westward facing scarps and more gently dipping eastward slopes. Kellaway and Taylor (1953) have shown that in the basins of the rivers Welland and Nene the present "erosion cycle" commenced as a surface gently sloping towards the North Sea. Similarly, Posnansky (1960) argued that the pre-glacial Trent flowed into the Wash Basin through the Ancaster Gap, to be diverted during the Quaternary to the Lincoln Gap and finally to the Humber estuary. The combination of the Lincolnshire rivers, the Trent, and others from the south were responsible for the wide gap in the Jurassic clays and Cretaceous chalk sequence which now forms the Fenland Basin and the Wash.

However, over much of the North Sea Basin, away from the inversion troughs, uplift was only gentle, with much of the chalk not being removed. The basin was once again surrounded by emergent land masses providing clastic sediments, giving rise to the Tertiary clays, shales and sandstones. The Tertiary sedimentary basin was never much greater in extent than the present day North Sea, - the London Basin, East Anglia, Holland and northern Germany then lying beneath the sea. Where subsidence was continuous in the central and northern North Sea the Tertiary sediments locally attained thicknesses in excess of 3500 metres (Pegrum *et al*. 1975).

The depth contours on the base of the Tertiary show it to be elongated over the Central Graben and a general conformity with the present coastline, except for the areas noted above. A remarkable feature however, is that such major ancient structures as the Mid-North Sea and Fyn-Ringköbing Platforms apparently had little or no control on Tertiary sedimentation. Subsidence in the northern region appears to have been continuous for seventy million years, but this was not the case for the whole basin. Thickness variations in the Central and southern North Sea Tertiary sequences show the continued plastic deformation of the underlying Zechstein salt bearing strata. In the Netherlands the Tertiary sequence is over 1700 metres thick and testifies to the changes in the marine environment at the edges of the basin with the interdigitation of marine and non -marine conditions. Intervals of more rapid relative subsidence alternated with still stands or possible periods of uplift and erosion around the margins. The identification of peneplanation surfaces, benches and graded river systems and their correlation with such still stands, however, still appears difficult to prove unequivocally (Straw 1961, Swinnerton and Kent 1976).

The Alpine epeirogenic movements, 25 Ma ago, made the Paris-Hampshire Basin supra-tidal, and the Scottish Massif was probably further uplifted relative to the North Sea Basin (Pegrum et al. 1975). However, with the Tertiary Era approaching its end the North Sea Basin was more uniform in its response to land-and sea-level changes than previously it had ever been. Apart from halokinetic disturbances the ancient structures now exerted little control but during the following Quaternary Period the North Sea area underwent extreme changes in land-and sea-levels and environmental conditions. Their causes, effects, and spatial variability can be studied at much smaller spatial-and time-scales, and in more detail than the earlier changes. Therefore the recognizable variables change in importance as the precision and resolution of the time-scale is reduced from millions of years to considerably less than 10,000 years in the Late-Quaternary.

Part 2.2 : Environmental changes during the Quaternary Period up to 10000 BP

The Pleistocene Epoch of the Quaternary Period (Mangerud et al. 1974) covers the period 2 Ma ago to 10,000 BP during which time sea-level is known to have risen above and fallen below the present shoreline as the result of the interaction of the extreme changes of climate, isostasy, tectonic movements, the volume of water in the oceans, ice volumes and the configuration of the geoid associated with the glacial and interglacial stages. West (1972) has presented evidence to suggest a fluctuation of sea-level with an amptitude of 218 m. during the Pleistocene in south-east England.

The Pliocene/Pleistocene boundary (Tertiary/Quaternary Period boundary) in Britain is within the crag sequence of the East Anglian basin; the Coralline Crag is of Pliocene age and the Red Crag Pleistocene (Miller et al. 1979). West (1972) and Mitchell et al. (1973) have outlined the stages of the British Pleistocene Epoch and the former has synthesized the evidence for changes in land-and sea-levels within the period. There are many difficulties, acknowledged by West, due both to the paucity of data relating the sediments to their contemporaneous tide-level and the difficulties of dating relative and absolute events. Indeed, there is still controversy over the age and extent of the glacial deposits of Lincolnshire and the Fenlands as noted by Turner (1973) and Catt (1977). Devensian tills occur only in North Lincolnshire, while the "chalky boulder clay" to the west of the Fenland basin has been ascribed both Wolstonian and Anglian ages (Shotton 1973, Turner 1973).

The Pleistocene sequence reaches a thickness in excess of 600 m. in the Netherlands and up to 70 m. near to Great Yarmouth in East Anglia. These sequences provide some information on land and sea-level changes in the southern North Sea area. The combination of differential land movements and a regression of sea-level to 183 m. between Lenham and south-east Suffolk for the upper Pliocene, and between Netley Heath and south-east Suffolk for the lower Pleistocene, is necessary to explain present differences in height of the Crag deposits (West 1972). Other estimates of net downwarping have been made for interglacial deposits in East Anglia (West 1972 fig.7) but it is difficult to interpret regional rates due to the limited distribution of outcrops.

There is some direct evidence of Pleistocene movements of relative sea-level within the Fenlands and Lincolnshire. The pre-Devensian shoreline, inland of the present coast of Lincolnshire, consisted of bold chalk cliffs up to 75 m. high running north from Louth. The lower part of these cliffs is buried beneath Devensian Till. This shoreline is also exposed north of the Humber Estuary at Sewerby. It age has been given as Ipswichian (Straw 1961), but it was undoubtedly formed earlier, for at Sewerby pre-Ipswichian deposits rest on the platform and they themselves were planed by the Ipswichian sea (Catt 1977).

At Tattershall a peat bed of supra-tidal origin lies below present mean sea-level. The pollen assemblage places the deposit in Ipswichian zone IIb (Catt 1977). This interpretation of a low relative sea-level in Ipswichian IIb correlates favourably with the sites at Langham, Austerfield and Sewerby described by Gaunt et al. (1974) where there is evidence of a rise in relative sea-level from -14 m. to +1 m OD between the end of Ipswichian I to the middle of Ipswichian III.

Horton et al. (1974) report a sequence of interglacial raised estuarine and lacustrine beds to the west of Peterborough. The Woodston Beds are up to 7 m. thick and their surface is approximately +15 m OD. The interglacial age inferred from the pollen assemblage is not refuted by the radiocarbon assay; > 40000 (IGS-C14/125). The pollen spectra indicate a transition from salt marsh and estuarine environments to fluviatile and possible lacustrine sequences. It is not stated with which interglacial period the beds are associated.

Pleistocene gravels outcrop around the Fenland Basin. Skertchly (1877) suggested that the gravels are all of marine origin except for those off the Lincolnshire Wolds, but it is probable that some of those along the western Fen edge are of fluviatile or fluvio-glacial origin. However of proven marine origin are the March Gravels. These occur above the fen surface to a height of +10—12 m. OD at March (Baden-Powell 1934). They contain a rich fossil marine fauna and have been correlated with the third terrace (Ipswichian) of the River Cam (Turner 1973, West 1977).

The First and Second Terraces of the River Cam are of Devensian age and a similar sequence of terraces is reported for the River Nene (Shotton 1973).

However at Stutton, Suffolk, brackish water deposits from Ipswichian III are found at +1 m. OD and on this basis West (1972) suggested a tilting of about 9 m. between the western and eastern part of East Anglia since that time.

Jelgersma (1979) has summarised the evidence for the Ipswichian (Eemian) sea-level maximum around the southern North Sea. The highest level reported is +15 m. at Aveley in the Lower Thames valley. On the continent and in the adjacent North Sea Basin Eemian deposits trace the rise of sea-level from about 40 m. below the present level to a maximum 8 m. below in the Eem valley, Netherlands, 9 m. below in Lower Saxony, 6.5 m. below on the Isle of Juist and 5 m. below in Schleswig-Holstein. Near Brugge, Belgium, marine Eemian deposits appear close to the present sea-level (Jelgersma 1979). A late Eemian fall in sea-level is indicated by a peat layer on top of salt marsh clays in the Eem valley and in Friesland. Jelgersma concludes that the differences in elevation of the Eemian sea-level maximum might be caused by differences in tectonic downwarping in and around the southern North Sea basin.

Eden *et al*. (1978) have discussed the Quaternary deposits of the Central Graben of the North Sea. They note that the greatest average rate of Tertiary subsidence in the North Sea is of the order of 5 mm/100 years, whereas the average subsidence for the whole of the Quaternary in the area north of the Forties Field is c. 30 mm/100 years, assuming the deposits to be shallow water facies. For the Forties, Auk, and Josephine Fields the average subsidence rates since the Late Devensian glacial maximum are reported as 360,290 and 360 mm/100 years respectively. The conclusion is that the Devensian, in particular, comprises a disproportionate amount of the sediments deposited since the opening of the Tertiary Period. The authors argue that the average subsidence rates for the late Pleistocene are too high to be accounted for by tectonic subsidence alone, and that isostatic movements, at times of glaciation positive in the Central Graben and negative during deglaciation, must be a major factor (Eden et al. 1978). They argue that this is in accord with Bott's hypothesis (Bott 1971) of mantle flow resulting in preferential isostatic subsidence in the Northern North Sea. Their results are also compared with the conceptual models of Cathles (Cathles 1975) which involve a peripheral bulge followed by possible subsidence during a glacial-deglacial cycle. Eden et al. (1978) argue that the field data support, but do not prove, this type of explanation (c.f. Jelgersma 1979). They conclude (Eden et al. 1978 p.15) "that if peripheral bulge during glaciation and subsidence following glaciation has involved mantle flow, regional geological considerations lend support to a hypothesis that vertical movement may have been greater under the North Sea Graben than is predicted by assuming laterally homogenous crust and mantle structure" (c.f. Kent 1975). They add that the relationship between the sequence of events in the area north of 56°N and that described farther south, particularly in the Dutch area, where lower parts of the Quaternary sequence appear to be better represented, remain to be investigated. As these southern areas are more remote from the main centres of ice accumulation, however, it may be expected that isostatic effects would be less pronounced. Jelgersma (1961) noted that tectonic subsidence even since Eemian (Ipswichian) times was unlikely to have been a continuous process and that the Pleistocene is characterized by increased tectonic activity in the Netherlands. However, while accepting the peripheral bulge hypothesis of geophysicists (e.g. Walcott 1972), Jelgersma (1979) is of the opinion that in the area of the sedimentary basins of the North Sea region the amount of isostatic downwarping is questionable and highly speculative.

Therefore it would appear that until more data are available from Quaternary sequences it is not possible to quantify subsidence rates around the North Sea. Differential downwarping is evident but it is not yet possible to differentiate between long-term subsidence of sedimentary basins, e.g. movements initiated in Tertiary times, and isostatic adjustment consequent upon the advance and retreat of ice sheets. A further complication is the allowance to be made for hydro-isostatic effects. Considerable research remains to be done in this field.

Finally, the Pleistocene Epoch was one of marked changes in the drainage pattern of the Fenland rivers. It appears that during the Tertiary period the river systems were initiated on a land surface sloping gently towards the southern North Sea basin. However, the till of two glaciations filled many of the pre-glacial east draining valleys, and along with the damming of valleys by glacier ice and with glacial overflow channels, the present drainage pattern was initiated. The pre-glacial valleys of the Trent, Witham, Glen and Braceborough were established upon the easterly sloping erosion surface but their present courses now cut across these at right angles due to the till, sands and gravels of the "chalky boulder clay" glaciation, of Wolstonian or Anglian age (Rice 1965, Wyatt 1971).

Part 2.3 : The Pre-Flandrian landscape of the northern Fenland

The pattern, extent and thickness of Flandrian coastal sequences and associated environmental changes is aided by a knowledge of the sub-surface topography of the glacial and late-glacial sediments and landforms. This generally buried surface upon which Flandrian peats, silts and clays have accumulated will be referred to as the pre-Flandrian topography or landscape even though, strictly, it will have been modified during the Flandrian Stage prior to the accumulation of the lowest peat or clay.

The cover of deposits of Quaternary age on the Jurassic of the Fenland basin is not uniform and in places it is absent. The thickness of Flandrian deposits varies within the basin, attenuating against "islands" of both pre-Quaternary and Quaternary sediments. Oxford clay rises to the surface at Ramsey, Whittlesey and Thorney, while Chatteris, Littleport and Ely (fig. 1.2) are situated above the fen on outcrops of Kimmeridge Clay (Chatwin 1961).

Quaternary sediments form islands at March(over Kimmeridge Clay) Guthram Gowt and Stickney (Baden-Powell 1934, Skertchly 1877). The pre-Flandrian landscape would control the location and pattern of deposition of early Flandrian sediments and therefore influence the course of early transgressions, and possibly reveal the areas in which peat formation may have been initiated without the influence of a rising sea-level (c.f. Jelgersma 1961, 1979).

The data required for such an investigation are borehole records. The density of data points controls the detail of variation in relief which can be expected. For example, 650 borehole logs were used for an area 11 x 11 km. at Emden, West Germany, and it was possible to follow ancient channels in the glacial sands which had subsequently been filled with Flandrian (Holocene) sediments (Barckhausen and Streif 1978). However it was during the stage of data collection for the Fenland region, particularly the northern part, that the investigation revealed its own limitations. Data of the required quality were not available in sufficient quantity. Most of the early records (Edmunds and Spires 1945, Jukes-Browne 1887, Skertchly 1877, Ussher et al. 1888) were not levelled to Ordnance Datum (Liverpool) and only in a few cases was it even possible to estimate their location and ground height to an accuracy of ±1.0 m. from the 1:25000 Ordnance Survey Series.

However, with the limited data available an attempt to portray the topography has been made since it reveals a series of methods that could be employed when, at a suitable time in the future, sufficient information becomes available.

It will also reveal the limitations in both the data and the techniques, and how to recognize the limitations.

190 borehole records were used for an area bounded to the north and south by the limits of the TF 100 km. grid square, and landward by the +15 m. contour. Of these only 33% were accurate to ±1.0 m. The figures produced in this preliminary analysis utilize the SYMAP and SYMVU packages developed at the Laboratory for Computer Graphics and Spatial Analysis, Harvard University.

The location of the boreholes used is shown in fig. 2.2 and with a shaded contour map, with hand drawn contours below O.D. added (fig. 2.3), together reveal the effect of clustering in the data, the complexity of the pre-Flandrian topography increasing with the density of boreholes. The CONFORMANT MAP elective in the SYMAP package, which divides the map into nearest neighbour zones, shows how large areas are covered by single data points in the coastal sites, while the variation in the landward areas is much greater (fig. 2.4). The problems associated with using the SYMAP package for data sets without a suitable quantity of more or less evenly spaced data points possessing a high degree of autocorrelation have been discussed by Liebenberg (1976). With these limitations in mind the SYMVU diagram, figure 2.5, should be viewed cautiously, and only illustrative of general trends and how such data can be presented. Again the contrast between the coastal zones, showing large flat areas, and the apparently more complex landward zones reflect the limitations of the data. A larger data set should

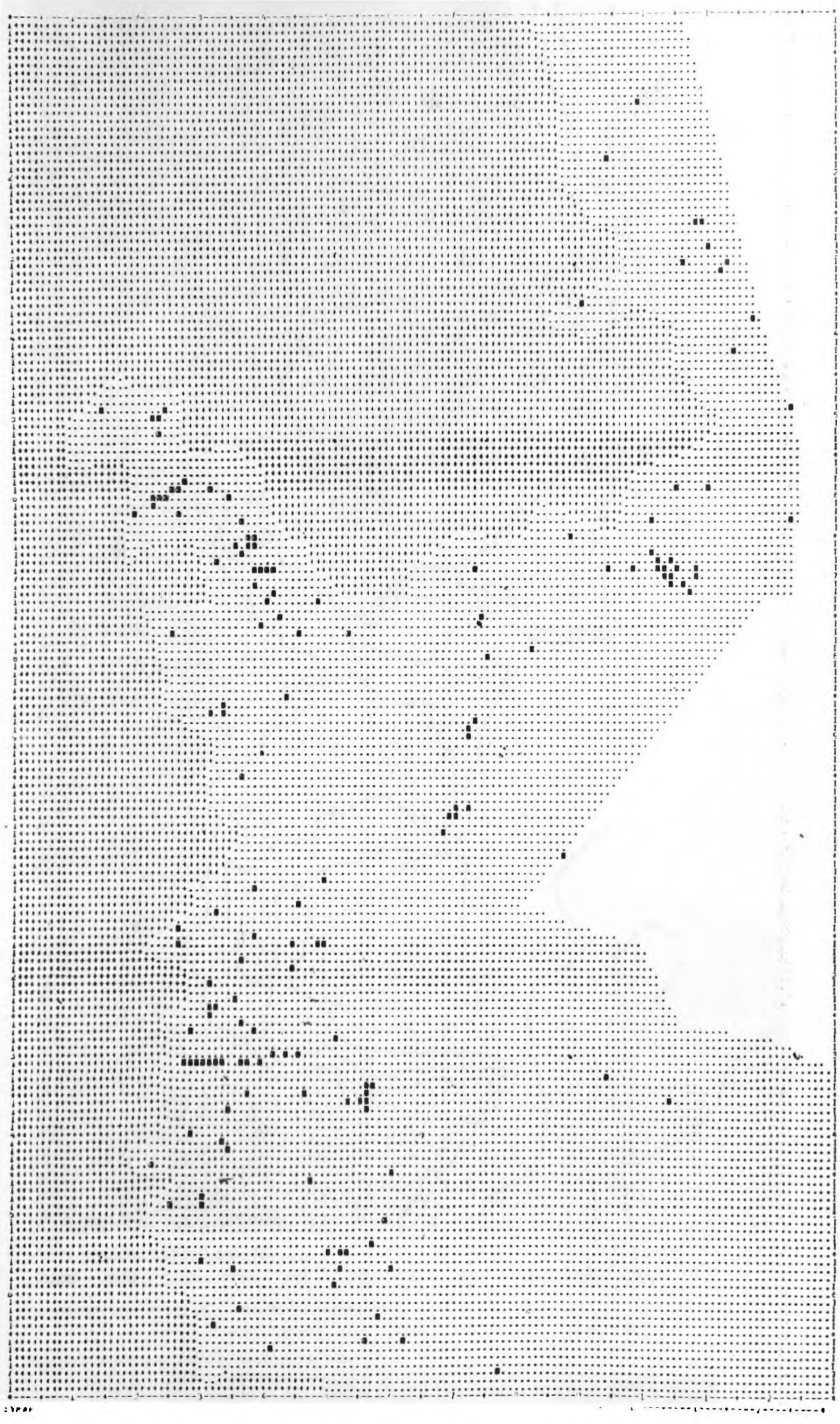


Figure 2.2: SYMAP : Lincolnshire Fenland, location of boreholes.

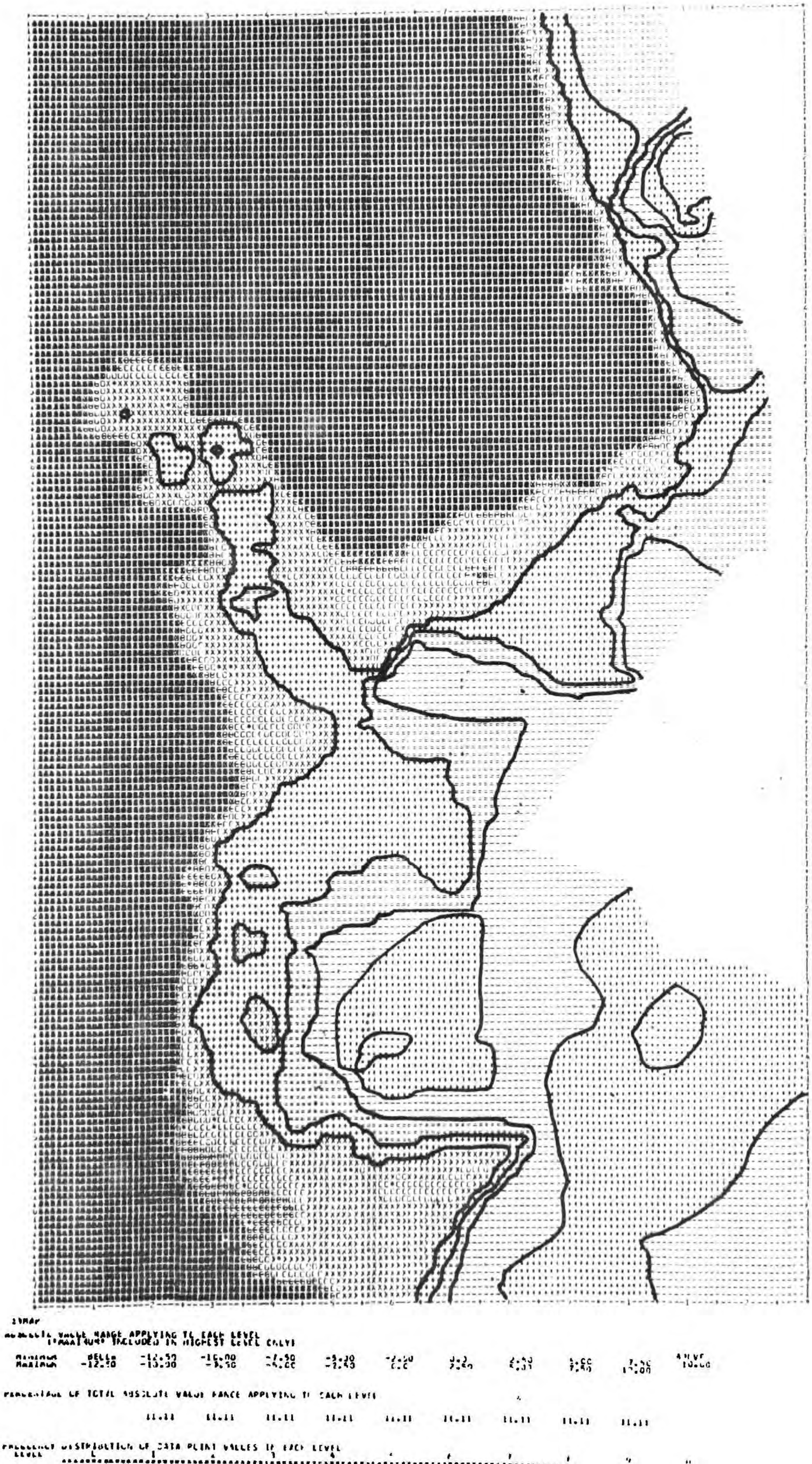


Figure 2.3 : SYMAP : Pre-Flandrian relief of the Lincolnshire Fenland below +10 m.OD Contours below O.D.inserted by hand

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SYMAP
ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
      ('MAXIMUM' INCLUDED IN HIGHEST LEVEL ONLY)

MINIMUM    BELOW    -12.50   -10.00   -7.50   -5.00   -2.50    0.0    2.50    5.00    7.50    ABOVE
MAXIMUM   -12.50    -10.00    -7.50   -5.00   -2.50    0.0    2.50    5.00    7.50   10.00    10.00

PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL

                     11.11    11.11    11.11   11.11   11.11   11.11   11.11   11.11   11.11

FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL
LEVEL        L        1        2        3       4       5       6       7       8       9       H

SYMBOLS

FREQ.        1        9       13       15      17      51      46      13      12       5     115
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Figure 2.4: SYMAP : "nearest-neighbour"effect on figure 2.3

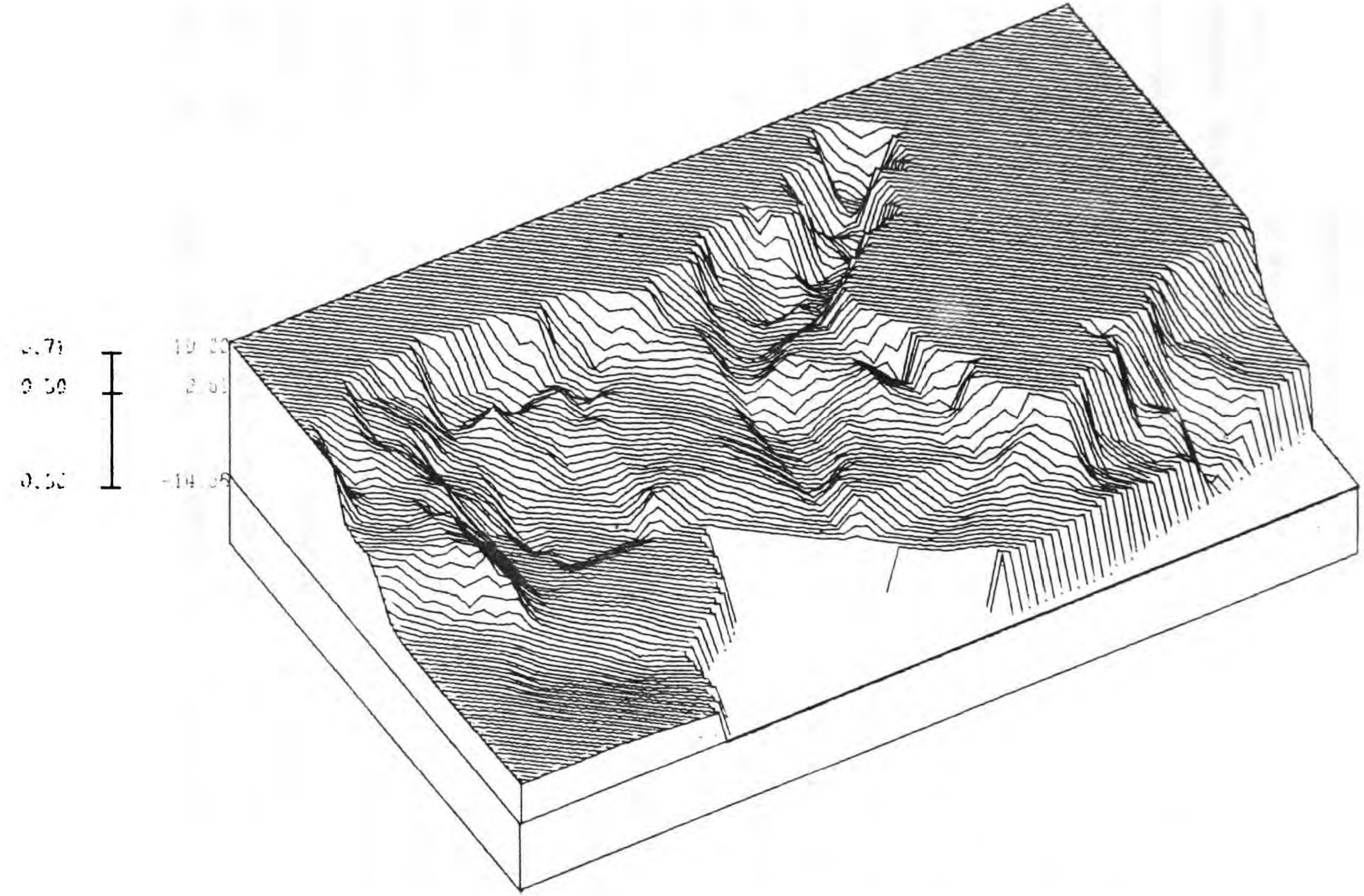


Figure 2.5 SYMVU : Pre-Flandrian relief of the Lincolnshire Fenland below +10m.OD.

only be considered reliable and suitable for more detailed topographic analysis if such areas do not exist.

The relative complexity of the Lincolnshire fen edge region led to further analysis of an area 20 x 10 km. between Spalding and Bourne, using 70, accurate to ±0.05 m., recorded borehole logs. However the same problems of data clustering were encountered.

Therefore, the conclusion is that borehole analysis using the SYMAP and SYMVU packages can provide potentially basic information on palaeogeographical sequences. Other methods of computer storage and analysis of borehole data have been put to practical use by Barckhausen and Streif (1978). The density of borehole data required for different scales of study will need careful investigation. The method of using the SYMAP and SYMVU packages is capable of revealing the limitations of the data (fig. 2.4), while a reasonable visual model can result (c.f. fig. 2.5). However, the analysis of borehole data from the northern Fenland has unfortunately been unable to reveal any reliable major variations in relief, such as river valleys, likely to have affected greatly the early Flandrian development of the area. Analysis of isolated sites and sections still appears to provide the most suitable evidence for environmental reconstructions.

CHAPTER THREE

Investigations of Fenland Flandrian Sequences

Chapter Three summarizes the published results of research relevant to Flandrian sea-level changes in the Fenland and Lincolnshire Marshes. The chapter is divided into 4 parts :

3.1 : Pre-1900 publications.
3.2 : Publications after 1900.
3.3 : Fenland terminology.
3.4 : Fenland sea-level index points.

Part 3.1 : Pre-1900 publications

At the close of the Devensian (Weichselian) Stage the Fenland was a gently undulating plain between the chalk and limestone uplands of eastern England. This land surface of glacial, fluviatile and aeolian deposits, ranging from gravels to clays, bore the expanding Flandrian forest only to be flooded firstly by fresh-water and then the rise in sea-level consequent upon the melting of the ice sheets. The gentle slope of the plain towards the North Sea basin made it a sensitive area to register the course of the Flandrian transgressions. Sedimentary cycles representing marine and terrestrial stages have been recorded by workers from numerous disciplines for over 100 years. During the early and middle 19th century there was a number of literary, rather than specifically scientific, accounts of the Fenland, mainly contrasting the landscape before and after the major drainage schemes had been carried out.

Wheeler (1868 p.120) described the fens around the outfall of the River Welland at the beginning of the 16th century prior to drainage : "Higher up that same river lies Spalding, surrounded on all sides with rivulets and canals, an handsomer town than one would expect in this tract among stagnated water", while following drainage of Deeping Fen; "... the Fen, which, before the drainage, was little better than a morass, growing a course herbage and affording a scanty pasturage during the summer months, became rich arable and grass lands... This result was not obtained without several serious riots caused by the Fen men, ... The enclosure was regarded by the men as an infringement of rights and privileges which they had long enjoyed." (Wheeler 1868 p.102).

However, the major advance in the scientific enquiry of the Fenland deposits was in 1877 with the publication of The Geology of the Fenland by S.B.J. Skertchly. This was the first publication to synthesize a large amount of information from boreholes, cuttings and wells to present a thesis of the development of the Fenland from the close of the glacial period. Whereas previous authors had just described the topography (Wheeler 1868) Skertchly attempted to correlate sequences and inferred processes: "The Fenland has been, and is still, the battleground of salt and freshwater. Sometimes the sea has pushed it's lines into the country of freshwater for a time, sometimes the rivers have invaded the district of the sea ... whenever freshwater stagnated peat grew. And as the sea was continually damming itself back, by piling up its silts, the peat followed its retreating footsteps until the changing climate had so altered as to have become unfavourable to its growth" (Skertchly 1877 p.129).

Many of the interpretations made by Skertchly have been reinforced during the 20th century but the continuity of the Flandrian sequences has been shown to be greater than he had argued. This point had first been raised by Jukes-Browne (1887). The comprehensive volume, The Fenland, Past and Present by Miller and Skertchly (1878) was a broader account of Fenland history and provided valuable information on the flora, fauna, and peat cutting. However, many of the archaeological ideas enunciated by Miller have stood the test of further inquiry less favourably than the geological interpretations of his co-author (Godwin 1978).

Lincolnshire was well documented by Geological Survey of England and Wales in the late 19th century by, in addition to Skertchly's monograph , The Geology of part of East Lincolnshire by A.J. Jukes-Browne in 1887, followed the next year by The Geology of the Country around Lincoln by W.A.E. Ussher, A.J. Jukes-Browne and A. Strahan.

Thus by 1888 the whole of the northern Fenland and Lincolnshire Marshes was documented by scientific publications. These works are still a valuable reference source of the locations of the different Flandrian sequences and it was another 40 years before further advances were made in the problems of Fenland stratigraphy and chronology.

Part 3.2 : Publications after 1900

The first major publication in the 20th century dealing with Fenland stratigraphy was The Post-Glacial deposits of the Lincolnshire Coast by H.H. Swinnerton (1931) which was a thorough investigation of an important sequence still fundamental to the analysis of sea-level changes along the east coast of England (Akeroyd 1972, Gaunt and Tooley 1974, Smith 1970, Tooley 1978a). Following Swinnerton's description of the coastal sequences Godwin and Godwin (1934) and Smith (1958) have analysed the pollen content of the sediments, Godwin and Willis (1964) have dated peat and shells from the site, Baker (1959) has investigated the Iron Age saltern sites associated with the sequences, and Alvey (1969) has described the floral and faunal macrofossils from other exposures along the Lincolnshire coast near to Chapel Point.

Just as Swinnerton's detailed stratigraphic work along the Lincolnshire coast has stimulated others into research in the area, which continues at present, so the work of Professor Sir Harry Godwin, mainly in the southern Fenland, stimulated much of the post-war research into both the post-glacial history of British vegetation and the environmental changes in the Fenland during the Flandrian Stage. With his many scientific papers from the early 1930's onwards Godwin was the major authority in developing scientific enquiry into the Fenland sequences. However, the work of his associates must not be overlooked, and the combined efforts of the Fenland Research Committee and other workers is now admirably recorded in Godwin's recent publication, Fenland : Its Ancient Past and Uncertain Future. (1978).

The main breakthrough of the 1930's in the southern Fenlands was the stimulus to fresh advance in research coming from the development of ecological ideas, particularly those of vegetation succession, the new technique of pollen analysis developed by O.G.E.Erdtman and L.von Post, and indeed the whole concept of Quaternary research based on a stratigraphic approach (Godwin 1978).

In 1933, the first paper of the analysis of pollen preserved in the Fenland peats was published (Godwin and Godwin 1933) and of the foraminifera of the marine clays at Wiggenhall St. Germans (Macfadyen 1933). The latter showed that the "Buttery Clay" contained mainly brackish water forms indicative of quiet water sedimentation not wholly cut off from the sea. Old water courses, including silt roddens, had been traced in the Cambridgeshire fens (Fowler 1934) and the shrinkage of the peat consequent to drainage was already studied (Fowler 1933).

The majority of site descriptions, pollen analyses and ecological interpretations of Fenland sites are within Godwin's early papers (Godwin 1940a, Godwin & Clifford 1938) but the accuracy of chronological correlations had to await the ^{14}C-dating method, by which time the majority of Godwin's research had been concluded. However, many of the sites were revisited and resampled to provide material for radiocarbon assays. Most of Godwin's work was restricted to the southern parts of the Fenlands and a reliable lithostratigraphic and chronological correlation with the deposits of the rest of the Fenland and Lincolnshire coast is still needed (Churchill 1970, Tooley 1978a).

Further discussion of publications relating to Fenland sequences is not included here in order to avoid repetition when the environmental development of the area is discussed in light of the new work presented in this thesis (see Ch. 6-7).

Part 3.3 : Fenland Terminology

Local terminology for deposits and sequences is a common feature of geological investigation, indeed it is required, following certain formal rules, by the International Subcommission on Stratigraphic Classification (Hedberg 1976), but the Fenland Flandrian deposits have only been classified with an informal nomenclature. Godwin and Clifford (1938) presented a schematic model to illustrate the sequences from different locations within the Fenland and made a broad comparison with the sequences found in Belgium, the Netherlands and West Germany. However, the correlation of sequences at the seaward sites in the Fenland is still very difficult (Smith 1970, Churchill 1970) and the development of litho-and chronostratigraphic systems comparable with those developed in West Germany and the Netherlands still remains an aim for the future. Lessons can be taken from the continental workers with reference to the problems of terminology and classification especially if both lithostratigraphic and chronostratigraphic correlations are envisaged.

Godwin developed the basic four-fold classification of the Fenland Flandrian sequence of Lower Peat, Fen Clay, Upper Peat and Upper Silt (note upper case letters, fig. 3.1). The Upper Silt has also been referred to as the Marine Silt and Romano-British Silt and the Fen Clay as the "Buttery Clay". This sequence, figure 3.1, equates well with Hageman's (1969) scheme of perimarine zone and tidal flat and lagoonal zone.

Hageman's terminology is very useful as an aid to explaining processes and coastal development but it is not a scheme for classifying sediments for any mapping or stratigraphic project.

Gallois (1979) has discussed briefly the Flandrian deposits of the eastern Fenland near to King's Lynn. The different units have been named after local sites at which they are represented but otherwise the scheme is similar to Godwin's classification. 'Lower Peat' is still retained and an age range of 5000 to 6000 BP is suggested. The Fen Clay of Godwin is named the Barroway Drove Beds within which predominantly silty-clays, tidal creeks of coarser sediments and occasional thin peat beds are noted. Gallois recognizes the complexity of the Flandrian sequences and makes no attempt at further correlation or clarification. The Upper Peat, sensu Godwin, is named the Nordelph Peat, with approximate age limits of 4000 to 2000 BP, and the Upper Silt becomes the Terrington Beds, approximately dated between 3250 and 2250BP.Otherwise the explanation of environmental changes offers nothing additional to the work of Godwin.

A number of problems have arisen within the traditional four-fold classification for the Fenland since the terms have attained genetic and chronological connotations as well as being lithostratigraphic units. The problems have often been increased by a combination of the lack of detailed borehole evidence and the attempt to correlate isolated locations within the traditional framework (c.f. Smith 1970). As a simplified example, in figure 3.1, correlation between boreholes A and C would give misleading data about the periods of peat growth without knowledge of B even though A and C would together show the 'typical' Fenland sequence. The four-fold division can be found in many areas but it is difficult to apply in seaward sites where up to five separate peat layers have been recorded, such as at Guyhirn, Wiggenhall St. German's, and Spalding (Godwin and Clifford 1938, Smith 1970). A section from Churchill (1970) is illustrative of the difficulties of applying the traditional term to sequences which do not easily fit into the desired model "... extensive borings... show the top of 'The Fen Clay' from -6 to -3 ft. O.D.N. overlain by the 'Upper Peat' which extends to the surface at about ±2 ft. O.D.N. Further north at Shippea Hill and at Welney, the top of the Fen Clay lies at about -3 to -4 ft. and is overlain by the Upper Peat..." (Churchill 1970 p.134). Furthermore the highest peat bed at Saddlebow has been referred to as "the upper peat bed" (Godwin and Willis 1961), "the so-called Upper peat bed" (Godwin <u>et al</u>. 1965), and "the Upper Peat" (Churchill 1970). It would appear that use of capital letters is dependent on the certainty of the correlation with the sequence found in the southern Fenland.

The same terminology has also been applied to the sequences along the Lincolnshire coast and around the Humber Estuary (Smith 1958) leading to difficulties when attempting to apply it to a chronostratigraphic and lithostratigraphic scheme.

Therefore it would be an advantage if sequences could be recorded in the field or from archive material without preconceived ideas of the Lower Peat, Fen Clay, Upper Peat and Upper Silt. Furthermore it is suggested that these terms should be avoided whenever possible and only used with capital letters, e.g. Upper Peat, in a direct reference to the sequence in the southern Fenland. The use of upper peat etc., with lower case letters, therefore refers to the higher of two peat beds at a particular site and as such upper and lower peat cannot be used if the site has more than two peat layers.

An attempt has been made to utilise a newly developed system for the lithological classification of Flandrian (Holocene) coastal sedimentary sequences (Barckhausen et al. 1977). It is an hierarchic system based on the vertical succession and the lateral interfingering of clastic sediments and peat (Appendix I). Three hierarchic levels and corresponding profile types are distinguished :

-Complexes, with 3 profile types : X, Y, Z.

X : a clastic complex without intercalated peat layers

Y : an interfingering complex in which clastic sediments are intercalated by peat layers

Z : a peat complex with only thin layers of clastic sediments

-Sequences, with 12 subordinate profile types : X1, X2, X3, X4, Y1... etc. (Barckhausen et al. 1977)

-Facies Units, with a variable number of special profile types dependent on the specific objectives and prevailing conditions

The hierarchic levels can be used for mapping at different scales and for different purposes, since the facies units can be represented in an unlimited number of special profile types based on petrographic, genetic, structural and other criteria. The hierarchic level employed for mapping will depend on the scale of the map required, its purpose, and the amount of data available. For example, the first sheet produced using this method, Emden West, was at 1:25000 scale, employed data from about 650 boreholes for an area approximately 11 km. square and utilized 27 special profile types (Barckhausen and Streif 1978).

Fenland sequences can conveniently be classified and recorded with this system which is suitable for computer storage and display. Any borehole in the coastal zone can be immediately ascribed to one of the 3 main profile types (complex) and one of the 12 subordinate profile types (sequence) while in the field or during an evaluation of published borehole data. The compilation of facies units has to await further analyses of the data. By recording the borehole data in computer compatible form as outlined by Barckhausen _et al_. (1977) then, in the future, mapping of Fenland sequences will offer the possibilities of classifying and representing the coastal deposits in numerous ways well-suited for different technical and scientific purposes, including correlation.

The system has been applied to the schematic section, fig. 3.1, showing the complex types and sequence types. The definition of facies units would be dependent on the specific objects of the project and the prevailing local conditions. By applying the hierarchic system terminological problems would be avoided since sequences are only referable to a particular borehole or section until all of the data

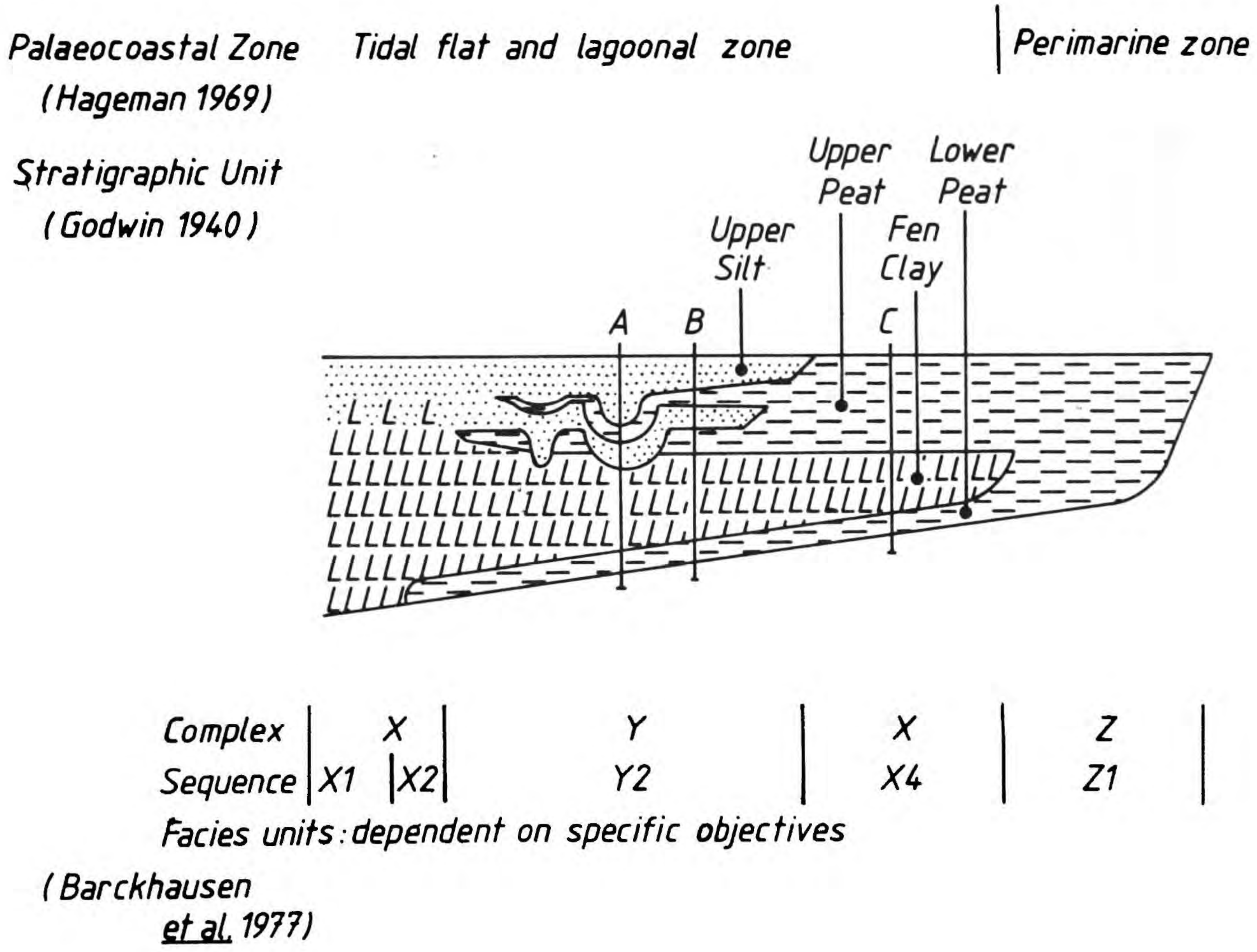


Figure 3.1 : Schematic Fenland section and terminology.

are analysed. The lithological system can then be linked with a chronostratigraphic system with ^{14}C dated samples, but the two systems must be regarded as two independent methods of subdividing the Flandrian Stage for the Fenland region. This latter point was confused when lithological and chronological interpretations became inherent in the use of such terms as Fen Clay and Upper Peat. However, the palaeogeographic reconstruction of the area can be done only with a combination of both the lithostratigraphic and chronostratigraphic systems.

Part 3.4 : Fenland sea-level index points

Unfortunately the amount of fieldwork and research devoted to the Fenlands from 1960 onward appears to be less than for the previous decades with the result that no lithostratigraphic system or chronology for the whole area is available. Radiocarbon assays from numerous sites are now recorded and collectively form a working hypothesis on the evolution of the Fenland.

The earliest assays which can be related to the Flandrian stage are from peat and gyttja samples now submerged beneath the North Sea. A moorlog from the Leman and Ower Banks gave an age of 8422 ± 170 BP (Q-105) (Godwin and Willis 1959) which is approximately 200 years after the separation of eastern England to the continent (Jelgersma 1961). Recently Kolp (1976) has obtained a date on a peaty-gyttja, 9933 ± 100 BP (no lab. code) from the Austern Ground south-east of the Dogger Bank, at a depth of -42.75 m. below present sea-level.

However, the earliest peat growth within the present Fenland basin was confined to deep channels and hollows in the undulating glacial landscape. The lowest dated horizon at Shippea Hill, recorded at approximately -4.3 m O.D., yielded an age of 8620 ± 160 BP (Q-588). With the coastline at that time north of the Dogger Bank the relationship of this assay to a rising sea-level is unlikely. As a working hypothesis, however, it can be assumed that from approximately 8600 BP the effects of the Flandrian sea-level rise were beginning to be recorded in the Fenland.

The data available recording the changes of relative land-and sea-levels have been divided into 4 sections:-

3.4.1 : stratigraphic analysis, supported by pollen, diatom and foraminiferal analyses, no radiocarbon dates.

3.4.2 : historical and archaeological data relating to relative movements of sea-level.

3.4.3 : radiocarbon dated index points. The reliability of such index points is very variable, ranging from isolated dated samples not originally dated with the evaluation of sea-level movements in mind, to dated samples from a systematic sequence of dates specifically taken to relate to sea-level changes and supported by pollen, diatom and other laboratory analysis.

3.4.4 : the twentieth century, tide gauge measurements, tidal and surge phenomena.

Section 3.4.1 : Stratigraphic Analysis

The majority of the early work in the Fenland relating to sea-level movements falls within this category and formed the basis on which the ^{14}C programme was founded in the 1960s. Godwin (1940a) presented the regional environmental changes and a relative sea-level curve based on the stratigraphic analysis of many sections and the pollen and archaeological chronology. The sea-level curve appears to have been only slightly amended with the ^{14}C analysis of critical sites (Godwin 1978). It is unnecessary to reiterate the details of the early stratigraphic studies (Godwin and Clifford 1938, Godwin 1940a, 1978) although a few important conclusions should be noted. Godwin clearly illustrated that the Fen Clay of the southern Fenlands was a much better marker horizon than had been previously thought (Skertchly 1877). Notwithstanding the effects of consolidation and the rises which evidence old channels in the Fen Clay the long sections studied within the southern Fenlands, such as the Woodwalton, Green Dyke and Trundle Mere sections, showed that the top of the Fen Clay was in general -1.0 m. to -1.5 m. O.D., rising to 0.0 m O.D. over channel deposits (Godwin and Clifford 1938). The uniformity and origin of the Fen Clay in areas away from the south level of the Fenland has since been questioned (Godwin and Vishnu-Mittre 1975) and it is not always clear whether O.D. refers to the Liverpool or Newlyn Datum. Godwin (1940a, 1978) gave the altitude of peat bed C at St. Germans as <u>C</u>. -5.25 m. O.D., while Churchill (1970) corrected the level to -5.7 m. O.D.

Newlyn. The three main sites used for the early analysis of sea-level movements were Shippea Hill, Chapel Point and Wiggenhall St. Germans all of which have since been ^{14}C dated, (See section 3.4.3).

Section 3.4.2 : Archaeological and historical data

From the Mesolithic onward there is an assemblage of data which can be used to interpret sea-level movements. Two major archaeological sites, Shippea Hill, with Mesolithic and Neolithic occupation layers, and Chapel Point, Iron Age and Romano-British salt making sites, have also been studied from other approaches and are corroborated by ^{14}C analyses. However, where suitable deposits are not available archaeological investigations have given invaluable evidence for changes in the coastline. The majority of the published material comes from the Lincolnshire silt fens since the peat areas were inundated by freshwater. Of the coastal silt fens in south Lincolnshire Hallam wrote "We must envisage the earliest Wash settlers occupying a wide belt of mature coastal marshes, choosing sites where deposition had been highest and most silty alongside tidal creeks, with before them the wide pastures of the marsh for their sheep and behind them freshwater fens providing summer pasture and winter fodder for cattle; peat, silty clay and clay for wall construction; reed for thatch, peat and brushwood for fuel; fish and fowl." (Hallam 1970 p.44).

Fascinating evidence from the edge of the Lincolnshire silt fens between Bourne and Sleaford shows that Iron Age salterns, dated approximately at 200 B.C., occur at +4.6 m. O.D. or more, but not less. Similarly, those of the Roman period are on, or near, the 3 m. contour (Simmons 1978). Simmons also reports that careful study of the surface pottery from 120 new Roman sites suggests no occupation of the fens earlier than the second quarter of the second century, although A.D. 50 has also been suggested (Salway 1970). Hallam (1970) offers evidence of a sharp increase in the number of households on the coastal silts taking place during the 2nd century A.D. Hallam suggests a fall in relative sea-level to such an extent that areas where freshwater had been held back to cause peat growth and /or preservation were now dry enough to allow the removal of peat down to the underlying clay layers. During the late 3rd and the 4th century A.D. former arable land was returned to pasture and once prosperous fen settlements languished (Hallam 1970, Churchill 1970). However, Hallam (1970) argues that any transgression must have been during the 5th-7th centuries A.D.

Settlement studies (Hallam 1965) and further research into the salt making industry (Healey 1978) provide details of later movements of the coastline. "... between about 800 and the close of the eleventh century the east coast of England was emerging from the North Sea, but that in the twelfth century a new marine transgression began, that it became very much worse from 1236 onwabds and that it continued into the later Middle Ages and even beyond." (Hallam 1965, p.132).

Finally Fowler has discussed briefly the more recent rise of relative sea-level as deduced from the altitude of successively seaward and younger sea-banks and concludes a relative rise of approximately 2.5 m. in 900 years (in Godwin 1940a).

Section 3.4.3 : Radiocarbon dated index points

There are 81 ^{14}C dates (Table 3.1) which can be related to the Flandrian development of the Fenland. Unfortunately many of the samples dated are not reported as levelled to O.D. These are widespread throughout the southern Fenland and often represent the resampling of sites that had been studied in the 1930s and 1940s. The majority of the ^{14}C data that can be related to sea-level events are of poor quality when set alongside the evaluation for sea-level points in the IGCP Project No. 61 (van de Plassche 1977).

Willis (1961) discussed Flandrian sea-level changes in the Fenlands using the stratigraphic evidence of Godwin and the early series of ^{14}C dates from the southern Fenlands. The ^{14}C data he used are discussed in the following sections for each site. Considering that Willis' analysis was at the outset of the period of radiocarbon dating of Fenland sequences it is not unexpected that the chronology he presented can now be questioned. He had advocated two periods of marine transgression, the first from around 4950 BP to 4150/3950 BP, and the second of Romano-British Age.

The dates from the floor of the North Sea have been discussed and the series of dates for the Fenland, working from Chapel Point around to the Nar Valley, are now described.

Table 3.1 : Published ^{14}C dates from the Fenland

No.	Code	Date (BP)	height m.OD	Material	Layer	Tendency	Site	Reference
1	Q823	1212±154	c.+0.40	Phrag.*	qhA	+	Welney 14	1
2	Q713	1464±154	c.+2.43	wood			Hockwold	1
3	IGS78	1615±100	c.-3.0 to -3.4	shells	?qhK		Spalding A16.4	11
4	IGS124	1875±100	c.+0.90	Phrag.+	qhK		Spalding 4	12
5	IGS126	1875±100	c.0.0	peat	qhA	+	Setch NV-1	12
6	Q549	1875±100	c.0.0 to -0.02	peat	qhA	+	Saddlebow	3
7	IGS77	1915±100	c.-3.0 to -3.4	shells	?qhK		Spalding A16.14	11
8	Q820	1940±130	+0.40 to +0.38	peat	qhA	+	Welney 14	1
9	Q819	1970±100	+0.20 to +0.18	peat	qhA	+	Welney 8	1
10	Q550	2070±110	c.-0.02 to -0.04	peat	qhA		Saddlebow	3
11	Q829	2227±90	c.+0.40	peat**	qhA	+	Welney 14	1
12	Q806	2275±100	c.-0.12 to -0.15	peat	qhA		Saddlebow	6
13	Q807	2377±100	c.-0.23 to -0.25	peat	qhA		Saddlebow	6
14	Q81	2455±110	c.0.0	wood	qhA	+	Ingoldmells	3
15	Q805	2495±110	c.0.0 to -0.02	peat	qhA	+	Saddlebow	6
16	Q687	2630±110	c.+0.40	shells	qhK		Chapel Point	5
17	Q688	2630±110	c.-2.74	shells	qhK		Chapel Point	5
18	Q844	2815±100	c.+0.12	peat	qhA	+	Chapel Point	1
19	HAR1749	3010±80	c.+0.52	peat	qhOB	?+	Horbling Fen	
20	Q531	3065±110	+0.28	peat	qhOB	?+	Flaggrass	3
21	IGS127	3215±100	c.-1.0	peat	qhA	-	Setch NV-1	12
22	Q546	3260±110	c.-1.25	peat	qhOD	?-	Ugg Mere	3
23	Q547	3305±120		peat	qhA	?+	Magdalene Bend	3
24	Q686	3340±110	c.0.0	peat	qhA	-	Chapel Point	5
25	Q403	3400±120	c.-2.45	Calluna	qhO		Holme Fen	2
26	Q404	3415±120	c.-2.50	Calluna	qhO		Holme Fen	2
27	Q545	3415±110		peat	qhO		Woodwalton	3
28	IGS58	3475±100		peat	?qhA		Peterborough	10

Table 3.1 (Continued)

No.	Code	Date (BP)	height m.OD	Material	Layer	Tendency	Site	Reference
29	IGS117	3570±100	-1.95 to -2.10	Phrag.+	qhKO		Spalding 1	12
30	HAR149	3621±130	c.0.0	peat	qhOB		Woodhall Spa 1.2	7
31	HAR1750	3750±70	c.+0.05	palaeosol			Horbling Fen	
32	HAR148	3770±130	c.1.25	peat	qhOB	+	Woodhall Spa TB	7
33	Q489	3905±120	c.-0.71 to 0.73	peat	qhA	-	Saddlebow	3
34	Q490	3915±120	c.-0.69 to -0.71	peat	qhA	-	Saddlebow	3
35	Q685	3943±100	-1.82	peat	qhOB	+	Chapel Point	1
36	IGS109	3945±100	c.1.45	peat	qhOB	+	Woodhall Spa 5.4	12
37	HAR189	3950±120	c.-1.25	peat	qhOB	+	Woodhall Spa TB	7
38	IGS111	3980±100	c.-0.90	peat	qhOB	+	Woodhall Spa 4	12
39	Q532	4055±110	-0.45	peat	qhOB		Flaggrass	3
40	HAR147	4080±130	c.-0.90	peat	qhOB	+	Woodhall Spa 3.3	7
41	Q264	4085±110	c.-150	peat	qhA	-	Denver	3
42	HAR151	4116±130	c.-0.90	peat	qhOB	+	Woodhall Spa 3.3	7
43	IGS112	4130±100	c.-1.25	replicate of No.32			Woodhall Spa TB	12
44	IGS110	4155±100	c.-1.70	peat	qhOB	+	Woodhall Spa 5.4	12
45	HAR150	4162±130	c.-1.45	replicate of No.36			Woodhall Spa 5.4	7
46	Q405	4190±130	c.-3.15	wood	qhO		Holme Fen	2
47	Q544	4195±110	c.-1.50	peat	qhO	?-	Wood Fen	3
48	Birm12	4201±60		wood	qhO		Isleham	8
49	HAR192	4205±100	c.-1.70	replicate of No.44			Woodhall Spa 5.4	7
50	Q474	4345±110		cones	qhOB	?+	Glass Moor	3
51	Q129	4380±140		wood	qhO		Wicken Fen	3
52	Q263	4390±120	c.-1.50	wood	qhA	-	Denver	3
53	IGS118	4445±100	-2.52 to -2.55	peat	qhA	+	Spalding 1	12
54	IGS57	4460±105		peat	?qhA		Peterborough	10
55	Q589	4495±120		wood	qhO		Ely	3
56	Q130	4605±110		wood	qhO		Wicken Fen	3
57	Q31	4690±120	c.-5.70	wood	qhA	+	Wiggenhall	3
58	Q499	4695±120	c.-3.20	wood	qhOB	?+	Shippea Hill	3

(Table 3.1 (Continued)

No.	Code	Date (BP)	Height m.OD	Material	Layer	Tendency	Site	Reference
59	Q580	4800±120	*c.*-3.04 to -3.05	peat	qhOB	+	Shippea Hill	3
60	Q525/6	4870±120	c.-3.5 to -3.7	charcoal	qhOB		Shippea Hill	3
61	IGS119	4890±100	-5.09 to -5.14	peat	?qhOB	+	Spalding 1	12
62	IGS64	4950±100	*c.*-3.7 to -4.1	peat	?qhA	?+	Spalding 0	10
63	Q527/8	4950±120	*c.*-3.5 to -3.7	charcoal	qhOB		Shippea Hill	3
64	Q406	4958±130	*c.*-3.85	wood	qhO		Holme Fen	2
65	Q581	5130±120	*c.*-3.05 to -3.06	peat	qhOB	?+	Shippea Hill	3
66	IGS121	5175±100	-5.83 to -5.88	peat	qhA	+	Spalding 2	12
67	Q583	5295±120	*c.*-3.50	peat	qhOB		Shippea Hill	3
68	Q582	5310±120	*c.*-3.35	peat	qhOB		Shippea Hill	3
69	Q585	5330±120	*c.*-3.70	peat	qhOB		Shippea Hill	3
70	IGS128	5440±100	*c.*-3.60	peat	qhOB	?+	Setch NV-1	12
71	Q584	5465±120	*c.*-3.65	peat	qhOB		Shippea Hill	3
72	IGS122	5600±100	-6.23 to -6.26	peat	qhA	-	Spalding 2	12
73	IGS120	5665±100	-5.60 to -5.65	peat	?qhOB		Spalding 1	12
74	IGS123	5905±100	-6.49 to -6.51	peat	?qhOB	+	Spalding 2	12
75	IGS76	6220±120	*c.*-7.06	peat	?qhOB	?+	Spalding A16.11	12
76	IGS75	6240±120	*c.*-8.46 to -8.91	peat	?qhOB	?+	Spalding A16.8	12
77	Q1296	6600±120	*c.*-5.00	wood	qhO		Holme Fen	9
78	Q586	6695±150	*c.*-3.90	peat	qhOB		Shippea Hill	4
79	Q1297	6794±120	*c.*-5.00	peat	qhO		Holme Fen	9
80	Q587	7610±150	*c.*-4.00	peat	qhOB		Shippea Hill	4
81	Q588	8620±160	*c.*-4.30	peat	qhOB		Shippea Hill	4

N.B. Full laboratory code for IGS dates is IGS-C14/78etc.

* washed rhizomes of *Phragmites* from peat.

** peat matrix with *Phragmites* rhizomes removed.

\+ *Phragmites* rhizomes in clastic sediments.

Reference Key 1 = Godwin & Switsur 1966, 2 = Godwin & Willis 1960, 3 = Godwin & Willis 1961, 4 = Godwin & Willis 1962, 5 = Godwin & Willis 1964, 6 = Godwin *et al.* 1965, 7 = Otlet & Slade 1974, 8 = Shotton *et al.* 1968, 9 = Switsur & West 1975, 10 = Welin *et al.* 1972. 11 = Welin *et al.* 1973, 12 = Welin *et al.* 1974.

1 : CHAPEL POINT Series (14, 16, 17, 18, 24, 35 Table 3.1)

The amount of research devoted to the coastal deposits along the section of coast between Sutton-on-Sea and Ingoldmells, from now on referred to collectively as Chapel Point, is quite considerable (Alvey 1969, Baker 1959, 1975, Godwin 1940a, Godwin and Clifford 1938, Godwin and Godwin 1934, Godwin and Switsur 1966, Godwin and Willis 1961, 1964, Smith 1958, Swinnerton 1931).

An extensive discussion will be presented for this site since it has often been quoted in sea-level studies (Gaunt and Tooley 1974, Tooley 1978a) and has also yielded abundant plant macrofossils to corroborate the salt marsh to coastal swamp changes inferred from the pollen and stratigraphic analyses. It is in this respect that the peat/clay/peat/clay sequence at Chapel Point is instructive in the interpretation of other Fenland sites.

Swinnerton (1931) described the two transgression sequences at Chapel Point. The undulating boulder clay surface is overlain by a woody detrital peat of varying thickness, up to 0.6 m., containing broken branches of *Alnus*, *Betula*, *Quercus*, *Prunus* and *Taxus*, in addition to numerous stumps rooted in the boulder clay. Alvey (1969) recorded the following macrofossils from the upper contact of the equivalent peat bed at Anderby Creek : seeds of *Atriplex* spp., 13 nuts of *Corylus avellana* L., fruitstones of *Crataegus monogyna* Jacq., *Prunus spinosa* L., and *Rubus fruticosus* L.agg., a seed of *Iris pseudacorus* L. and 11 specimens of *Hydrobia ulvae* (Pennant).

The woody detrital peat, showing a clear freshwater fen origin, is conformably overlain, though intersected by erosion channels in places, by a transitional deposit to a salt marsh clay containing macrofossils of Triglochin maritima, Phragmites communis, Juncus maritima, Limonium and Armeria (Swinnerton 1931). The maximum date for the onset of highest salt marsh conditions is given by a date on the upper contact of the peat bed of 3943 ± 100 BP (Q-685) at -1.83 m. O.D.

Only the lower layers of the clastic horizon contains the abundant macrofossils and passes into the barren middle layers characterized by vertical black streaks within the purple clay suggestive of Salicornia (Swinnerton 1931). Above this the flora is characterized in sequence by an assemblage of Triglochin and Juncus, then Limonium and Armeria before Phragmites communis becomes dominant. This Phragmites gyttja clearly represents a reduction in marine influence.

Alvey (1969) has analysed two samples of this "freshwater clay", one from a site south of Chapel St. Leonards and one at Anderby Creek. Collectively they contained macrofossil remains of Atriplex spp., Carex spicata Hudson, Ranunculus batrachium (L.), Schoenoplectus lacustris (L.), Centaurea nigra and Cirsium spp. Freshwater mollusca are also recorded but the close proximity of a marine environment is shown by the presence of several foraminifera.

The Phragmites clay is overlain by a thin peat bed from 0.0 m. O.D. to +0.15 m. O.D. This layer is almost totally composed of horizontally bedded *Phragmites* rhizones in an organic matrix, except near to Ingoldmells where leaves and twigs of *Salix* and *Taxus* have been recorded (Swinnerton 1931). Smith (1958) has also recorded the seeds and fruits of the following species in an exposure at Ingoldmells: *Potamogeton pusillus* (L.) Dandy & Taylor, *Potamogeton natans* L., *Ranunculus scleratus* L., *R.lingua* L., *Sparganium angustifolium* Michx., *Hydrocotyle vulgaris* L., *Carex spp.*, *Alnus glutinosa* (L.) Gaertn, and *Betula* cf. *verrucosa* Ehrh.

A further characteristic of this upper peat bed is the overlap between Quaternary ecology/geology and archaeology which has arisen in the study of the fragments of salt making industrial materials which have been found *in situ* on the upper surface of the peat and within the clastic deposits immediately above it (Swinnerton 1931, Baker 1959). Swinnerton assigned a post-La Tène, probably Halstatt, age to the salt-making debris, inferring a Late Bronze Age/Early Iron Age for the peat. However Smith (1958) argued for a Romano-British age for the same peat bed. This latter dating appeared to be corroborated by Baker (1959) but a reappraisal of the pottery suggested the 4th century B.C. for the commencement of the salt industry (Baker 1975).

It is worthwhile to delay reference to the ^{14}C analysis of the *Phragmites* peat bed and follow the stratigraphic/archaeological arguments as they developed. This peat bed is overlain by a soft purple clay, conformably at some sites but at others in channels cut through the whole post-glacial sequence into the weathered glacial till. The lowest layers of this purple clay contains shells of

Cardium edule Linné, Scrobicularia plana (Da Costa) and Hydrobia ulvae Pennant in situ, and was named the Scrobicularia clay by Swinnerton (1931). From these data Swinnerton postulated a sea-level approximately -8.0 m. O.D. at the time of the formation of the basal peat, -3.0 m. O.D. for the higher peat and a spring tide level 3.0 metres above the level of the Scrobicularia and Cardium horizon. On the basis of a Roman occupation layer only 1.3 m. above the Scrobicularia Clay Swinnerton suggested that "the [relative land] subsidence which was followed by the deposition of the Scrobicularia clays took place after the Roman occupation." (Swinnerton 1931, p.370).

Baker (1959) accepted Swinnerton's evidence for the post-Roman age for the clay horizon but the evidence is not unequivocal. There is no intermixture of Iron Age and Roman pottery and Swinnerton cites no location where the Roman occupation level is covered by clastic deposits containing shells of Scrobicularia and Cardium. This point was raised in the discussion of Swinnerton's paper by Warren (Swinnerton 1931, p. 374) "... he had never found Roman remains on or over the thin peat in the middle of the series, or in or under the Scrobicularia clay overlying it : that was the Hallstatt horizon. He found it difficult to place the horizon of the Roman remains anywhere but over the Scrobicularia clay, and consequently in his view, the submergence which that deposit represented would fall between the Hallstatt and Roman periods." Godwin also noted difficulty in equating Swinnerton's chronology with the stratigraphy and suggested that either the Ingoldmells Roman site lay behind protective sea walls, although Swinnerton found no trace of them, or that the bulk of the clastic deposit "had been deposited before the Romano-British colonisation of the first century, that during the first to third centuries there was temporary marine regression, and that at the end of this time marine transgression, though not extensive, again became apparent." (Godwin 1940a p.293).

The conclusions relating to a pre-Roman transgression resulting in the deposition of the Scrobicularia bearing clay appears to be confirmed by ^{14}C analysis. Saltmarsh peat, with macrofossils of Suaeda maritima and Salicornia, at the contact with the Phragmites gyttja at 0.0 m. O.D. yielded a date of 3340 ± 100 BP (Q-686). Wood, in situ, at Ingoldmells gave 2455 ± 110 BP (Q-81), but an older date for the top of the upper peat bed, from the same monolith as Q-686 at Chapel Point, is 2815 ± 100 BP (Q-844). Two assays on shells of Scrobicularia plana from the base of the Scrobicularia clay both gave 2630 ± 100 (Q-687, Q-688). The former was on shells in situ from a narrow channel deposit through the upper peat bed at +0.40 O.D. while the latter was on shells from the bottom of an erosion channel cut down to the chalky glacial till at -3.0 m. O.D. All of these dates agree with a pre-Roman date for the Scrobicularia clay transgression.

However, a few comments are necessary concerning the sequences exposed along the Lincolnshire coast. It had been hoped to resample the sediments to study further the pollen, diatom and particle size distributions within the sediments, but even after six separate visits with trial boring equipment no consistent picture emerged. The basal peat layer was always well exposed during low tide of the spring tidal cycle. It was seen to be crossed by many erosion channels and was also limited by the undulations of the glacial till. Unfortunately no satisfactory samples of the basal peat/salt marsh clay transition could be found.

Exposures of the upper peat and adjacent sequences were more difficult to find since they were often covered by beach sand. On the occasions they were exposed a very confusing picture emerged. The whole length of the intertidal zone between Sutton-on-Sea and Chapel Point was examined in early summer 1978 and at no location did a boring through the upper peat reach the basal peat, it appeared that the basal peat was limited to depressions in the glacial till or that it had been eroded by the pre-Iron Age transgression. Similarly the upper peat was never found to be as extensive as Swinnerton had recorded, probably due to modern wave action, and the only exposures were immediately south of Anderby Creek and approximately 400 metres north of Chapel Point. Both of these sections showed the upper peat deposit to be restricted to a narrow zone, varying between 0.30 to 2.0 m. wide, and following a meandering course along the intertidal zone (Plate I). The peat at Anderby was intersected by a straight channel filled with an organic silty clay approximately 30 cm. wide (Plate II). Meanwhile, at Chapel Point rectangular areas of differing clastic deposits, surface area approximately 2 x 4 metres, were exposed on one occasion.

Plate I : Meandering remnant of the intertidal peat bed south of Anderby Creek

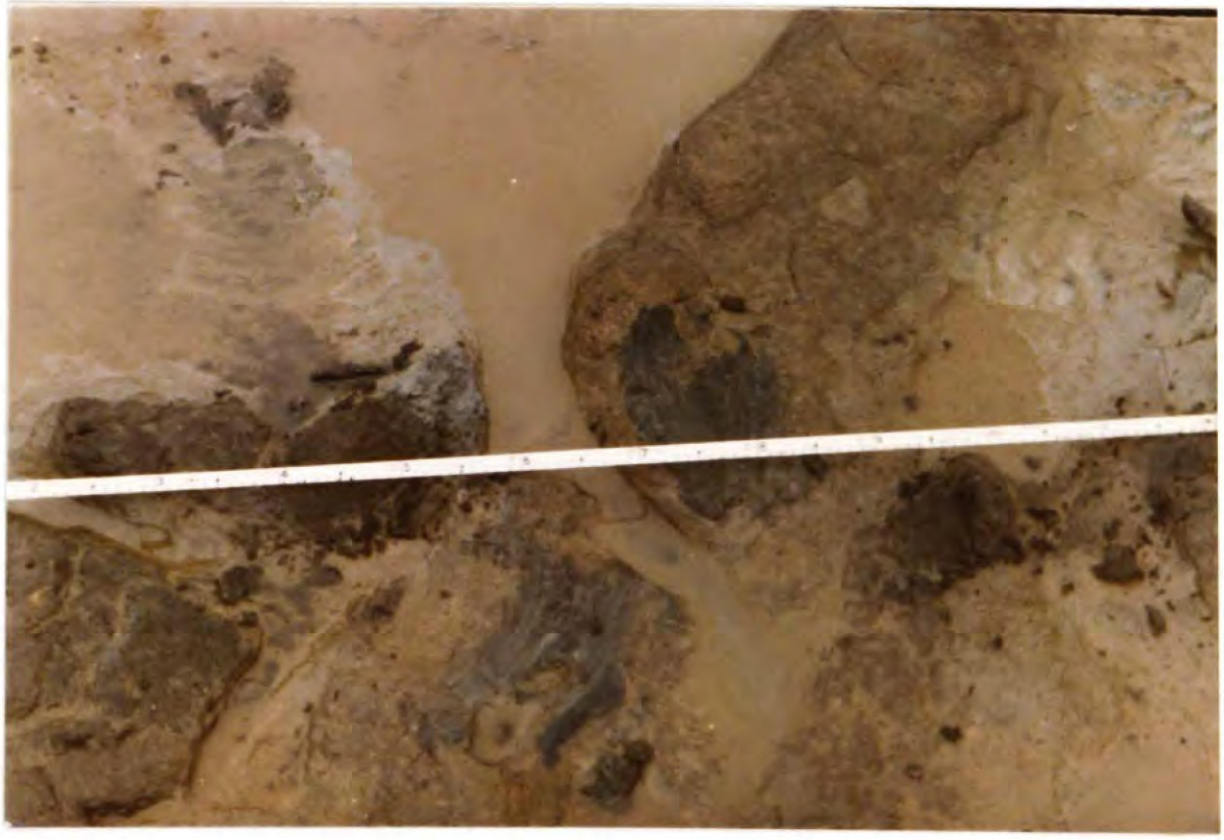


Plate II : Close-up view of the organic clay cutting through the remnant of the peat bed

Therefore it must be concluded that in the light of recent exploratory stratigraphic analysis the schematic section presented by Swinnerton (1931) must be considered questionable with regard to the continuity of the beds. The sequence has never been recorded in a transect of boreholes and the remaining deposits appear extremely localised in extent. Nevertheless these coastal sequences warrant a full interdisciplinary study to elucidate some of the problems identified by the exploration analysis.

2 : WOODHALL SPA Series (30,32, 36, 37, 38, 40, 42, 43, 44, 45, 49, Table 3.1)

11 radiocarbon assays are recorded in this series (Otlet and Slade 1974, Valentine and Dalrymple 1973, Welin et al. 1974). All relate to a basal peat bed, overlain by blue grey clay and directly above a humic grey soil developed in coarse sands and clays. The peat is assumed to be the basal layer of the Flandrian sequence with the underlying inorganic horizons being of glacial origin. None of the sections has their absolute levels recorded but approximate heights can be estimated from Valentine and Dalrymple (1973, fig. 2 and Table 2). The base of the peat bed, immediately overlying the sands, has been dated at 5 sites with altitudes ranging from c.-1.7 m. O.D. at section 5, Kirkstead Bridge, to approximately O.D. at section 1, Thorpe Tilney Dales, and dates from 4205 ± 100 BP (HA 192) to 3620 ± 130 (HA 149). There are two assays on the transition to the overlying clay at Kirkstead Bridge. This contact is at approximately -1.45 m. O.D. and is dated,

by replicate samples, 3945 ± 100 BP (IGS -C14/109) and 4162 ± 130 BP (HA 150). A similar discrepancy for the two laboratories is also evident from the dating of equivalent samples from Tattershall Bridge. At this location the basal layer of the peat, at c.-1.25 OD, is dated 4130 ± 100 BP (IGS -C14/112), while two replicate samples from the same horizon gave 3770 ± 130 BP (HAR 148) and 3950 ± 120 BP (HAR 189). This scatter for the Harwell dates may indicate the presence of a non-contemporary contaminant (Otlet and Slade 1974); but the dates are not significantly different.

3 : HORBLING FEN (19, 30 Table 3.1)

Two dates are available (B.B. Simmons pers.comm) from a section over 1 km. long to the east of Horbling which was exposed during drainage work by the Anglian Water Authority (AWA). The samples are from the east end of the section where a palaeosol had developed on the boulder clay surface. Peat directly overlies the buried soil and is overlain by clastic deposits of upper tidal marsh origin (Simmons pers.comm.). The assay from the palaeosol at C. +0.05 m. OD gave a date of 3750 ± 70BP (HAR 1750) while a sample from the middle of the peat bed, C. +0.52 m. OD, yielded 3010 ± 80 BP (HAR 1749). The pollen analysis showed a post- Ulmus decline age, with high Alnus percentages, high Gramineae, Cyperaceae, very high Chenopodiaceae frequencies, and other marine indicators : Plantago maritima, Artemisia, Armeria maritima and Triglochin (Simmons pers. comm.). Therefore at a time, represented by approximately 0.25 m. of peat, after 3010 ± 80 BP Horbling Fen was transgressed by high salt marsh conditions at an altitude of approximately +0.72 m. OD.

4 : SPALDING Series (3, 4, 7, 29, 53, 61, 62, 66, 72, 73, 74, 75, 76 Table 3.1)

At Spalding there is a series of 13 radiocarbon dates taken from 7 locations by the Institute of Geological Sciences (IGS). The Spalding area had been studied previously by Jennings and the results published by Smith (1970), when the difficulties of correlating the levels of biogenic deposits over large distances had been clearly illustrated. Some of the difficulties may have arisen from Smith's use of engineering borehole logs which are not as reliable as hand cored samples.

Only two of the boreholes, Spalding-1 and Spalding-2, have been accurately levelled, the other ground levels being estimated. At Spalding-2 a sample of peat between clastic sediments at -6.49 m. to -6.51 m. OD has been dated at 5905 ± 100 BP (IGS-C14/123). A peat layer above this, from -6.26 m. to -5.83 m. OD gave a date of 5600 ± 100 BP(IGS-C14/122) for its regressive contact and 5175 ± 100 BP (IGS-C14/121) for its transgressive contact. This peat horizon may be tentatively correlated with one sampled in Spalding-1 from -5.65 to -5.09 m. OD. The regressive and transgressive contacts gave 5665 ± 100 BP (IGS-C14/120) and 4890 ± 100 BP (IGS -C14/119). A higher organic layer in Spalding-1, at -2.55 m. to -2.52 m. OD, gave a date 4445 ± 100 (IGS-C14/118) and reed rootlets <u>in situ</u> within clastic sediments at -1.95 m. to -2.10 m. OD were dated at 3570 ± 100 BP (IGS-C14/117).

The oldest biogenic phase recorded at Spalding was in borehole A16.8, dated 6240 ± 120 BP(IGS-C14/75) at approximately -8.46 m. to -9.91 m. OD, assuming a ground level of +3.0 m.OD. With the same assumption, the youngest assay is from *Phragmites* roots within clastic sediments at *c*.+0.9 m. OD in Spalding-4; 1875 ± 100 BP (IGS-C14/124). The remaining 4 dates are given in table 3.1 and discussed further in chapter 7.

5 : PETERBOROUGH (28, 54 Table 3.1)

Two samples, of uncertain relationship to marine processes, from the alluvial clay sequence of the River Nene have been dated. 4460 ± 105 BP (IGS-C14/57) and 3475 ± 100 BP (IGS-C14/58) are assays relating to the early stages of alluvium accumulation.

6 : HOLME FEN - WHITTLESEY MERE (25, 26, 46, 64, 77, 79 Table 3.1)

6 assays are reported from Holme Fen. The oldest is on unoxidised detritus peat, 6794 ± 120 (Q-1297), which is immediately below an oak trunk 12 m long x 0.6 m. diameter lying horizontally in peat over reworked boulder clay. The outer rings of the oak are dated to 6600 ± 120 (Q-1296) and the boulder clay surface is at approximately -5.5 m. OD (Godwin and Vishnu-Mittre 1975).

The *Ulmus* - decline in the pollen diagram is dated to 4958 ± 130 BP (Q-406) by an assay on wood, *in situ*, in *Cladium* fen peat. The altitude, in 1957, of this horizon was *c*-4.7 m. OD, but this has been affected by the drainage of Whittlesey Mere in 1851. Holme Fen itself is a perimarine site at which *Sphagnum* bog developed and limited the extension of the clastic deposits, the equivalent of the Fen Clay. The peat was 7.3 m. thick in 1848 but less than 3.3 m. in 1957 due to shrinkage and wastage after drainage. Two thin clay bands, once thought to be the marginal extension of the Fen Clay (Godwin and Willis 1960), but now shown to be the result of freshwater flooding and upland soil erosion at about the same time as the maximum of marine transgression, were formed at approximately OD yet are now at -3.3 m. OD and -3.4 m. OD (Godwin and Vishnu-Mittre 1975 p.601, cf. Godwin 1978 fig. 36).

The chronology available is that of the transition from fen peat to Sphagnum peat at C.-4.0 m. OD which is dated at 4190 ± 130 (Q-405) and statigraphically pre-dates the arrival of marine conditions locally. The two clay bands are dated by assays on twigs of Calluna vulgaris and rhizomes of Eriophorum vaginatum within them, 3400 ± 120 BP and 3415 ± 120 BP (Q-403, Q-404), and immediately post-date the clastic deposition immediately seaward.

7 : GLASS MOOR, Ramsey (50 Table 3.1)

Cones of Pinus sylvestris, in a woody peat including Pinus stumps, beneath a thin layer of brackish water clay yielded a date of 4345 ± 100 BP (Q-474). However this may not be a reliable index for the onset of marine conditions at the site since there were shells of Cardium edule growing upon the peat surface and pine stumps suggesting that the peat-clay boundary is erosional (Godwin and Willis 1961).

8 : FLAGGRASS, March (20,39 Table 3.1)

This site on the eastern margin of the gravel 'island' of March, at Flaggrass, was effected by one period of marine transgression, represented by tidal channel deposits bearing a Roman gravel causeway (Godwin 1978). The lowest peat formation, dated 4055 ± 110 (Q-532) at -0.45 m. OD, may be related to general waterlogging as a consequence of an earlier marine (Fen Clay) incursion (Godwin and Willis 1961). The contact between the peat and the tidal silts is dated 3065 ± 110 BP (Q-531) but the abrupt transition suggests an erosive contact (Godwin and Willis 1961).

9 : UGG MERE (22 Table 3.1)

Along the Green Dyke section and at Ugg Mere the upper surface of the Fen Clay is generally between -1.0 m. and -1.5 m. OD (Newlyn or Liverpool ?) away from channel sequences (Godwin and Clifford 1938). Thereafter Sphagnum peat developed prior to a freshwater marl and droppings of elk within in this peat layer have been dated 3260 ± 110 (Q-546).

10 : WOODWALTON (27 Table 3.1)

The initiation of ombrogenous peat growth at this perimarine site is dated by an assay on peat characterised by Dryopteris thelypteris of 3415 ± 110 (Q-545) and is held to post-date the extensive marine incursion since it overlies a Phragmites peat (Godwin and Clifford 1938).

11 : WICKEN, Adventurers' Fen (51, 56 Table 3.1)

Two dates on Quercus wood/roots relating to the forest destroyed during waterlogging of the area are recorded; 4380 ± 140 BP (Q-129) and 4605 ± 110 BP (Q-130).

12 : ISLEHAM (48 Table 3.1)

An oak within peat, dated 4201 ± 60 BP (Birm-12), outside the limit of any clastic deposition.

13 : ELY, Queen Adelaide Bridge (55 Table 3.1)

An assay on Quercus wood from the basal forest of the Fenland, 4495 ± 120 BP (Q-589)

14 : WOOD FEN, Ely (47 Table 3.1)

Collected in 1934 and dated in 1960 a sample of woody peat, from the perimarine zone, yielded a date of 4195 ± 110 BP (Q-544). It has been argued that the pine layer from which the sample came immediately post-dates the Fen Clay (Godwin and Willis 1961) and was compared with Q-405 (4190 ± 130 BP) at Holme Fen, incorrectly assigned to a post Fen Clay age (Godwin and Willis 1961 cf. Godwin and Vishnu-Mittre 1975).

15 : SHIPPEA HILL, Peacock's Farm (58, 59, 60, 63, 65 67, 68, 69, 71, 78, 80, 81 Table 3.1)

The excavations through the Flandrian sequence at Shippea Hill have given much valuable information on Fenland Mesolithic and Neolithic communities and vegetation history as well as changes in sea-level. Once more it is not clear whether Newlyn or Liverpool is the reference datum. The base of the Fen Clay at Peacock's Farm is given as -3.0 m. OD for the monolith taken for ^{14}C samples (Clark and Godwin 1962) and occupies a channel eroded to a maximum depth of -7.0 m. OD (Godwin 1940a), but given as -8.5 m. OD in 1978 (Godwin 1978).

There are 12 dated samples from Peacock's Farm, all from the lower peat bed. The lowest dated level is from 1.3 m. below the clay and gave 8620 ± 160 BP (Q-588) while the youngest date in the series is 4695 ± 120 BP (Q-499) on wood, in situ, from just below the clay. However there are also two dates on the clayey Phragmites peat below the clay to date the onset of marine conditions, 4800 ± 120 BP (Q-580) and 5130 ± 120 BP (Q-581). The date on the wood is younger than those from the Phragmites peat, contrary to what may be expected for such samples from the same horizon (Churchill 1970, Streif 1972). Also the assays on charcoal samples give values at least 400 years younger relative to their stratigraphic position (Godwin and Willis 1961, Godwin 1978).

16 : HOCKWOLD (3 Table 3.1)

An assay on wood, 1464 ± 154 BP (Q-713), is related to an episode of freshwater flooding at +2.44 m. OD.

17 : WELNEY (1, 8, 9, 11 Table 3.1)

This site is the southernmost in a series along the eastern Fenlands which havegiven a lot of difficulty in their interpretation, in this case due to the younging of ^{14}C dates. In 1964 pits were dug to obtain samples from the top of a peat bed between two clastic layers. An age of 1970 ± 100 BP (Q-819) was for a peat at C. +0.2 m. OD directly below a Phragmites clay that is overlain by estuarine silts of a rodden sequence. Q-820, 1940 ± 130 BP, at C. +0.4 m. OD in a different pit below the grey estuarine clay, appeared to give a consistent age for the upper content of the peat layer. However "contamination of the peat by younger fossil Phragmites rhizomes was apparent, although there was no indication where these had penetrated the overlying clay" (Churchill 1970 p.138). Therefore Churchill separated the Phragmites rhizomes and the matrix, the latter then being treated with NaOH to remove the soluble humic acid fraction. The washed Phragmites rhizomes gave 1212 ± 154 (Q-823) (Godwin and Switsur 1966), reported as 680 AD ± 154 (1270 ± 154 BP) by Churchill (1970). The reprecipitated residue gave 2227 ± 90 BP (Q-829), although Churchill again reported a different date:-

	Godwin & Switsur (1966)	Churchill (1970)
Q-819	1970 ± 100 BP	2010 ± 100 BP
Q-820	1940 ± 130 BP	1980 ± 130 BP
Q-823	1212 ± 154 BP	1270 ± 154 BP
Q-829	2227 ± 90 BP	2267 ± 90 BP

Churchill argued that Q-819 and Q-820 should be rejected due to contamination by Phragmites, the same argument as developed by Streif (1972), although the origin of the rhizomes could not be explained since there was no trace of them in the overlying clay. Furthermore Churchill argued that the humic acid fraction could still contain alkali soluble material derived from the Phragmites and therefore the true radiocarbon age of the peat could be up to 300 years older.

Therefore this critical site remains problematical, The difference between Q-823 and Q-829 is 1000 years yet the origin of the Phragmites is not evident.

18 : DENVER (41, 52 Table 3.1)

Two assays on wood from a peat bed between the "Fen Clay" and "Romano-British Silt" (Godwin and Willis 1961) gave 4390 ± 120 (Q-263) and 4085 ± 100 (Q-264). The wood is not stated as being in situ.

19 : MAGDALENE BEND (23 Table 3.1)

The top of a peat bed in contact with sandy silt yielded a date of 3305 ± 120 (Q-547). However there were shells, Cardium edule, in situ on the upper surface of the peat which could represent erosion of peat during the transgression.

20 : WIGGENHALL ST. GERMAN'S (57 Table 3.1)

Within peat bed C of the well-recorded section, an in situ oak stump gave a date of 4690 ± 120 (Q-31). Godwin (1940, 1978) gave the altitude for peat bed C at c. -5.25 m. OD (?), however Churchill 'corrected' this to the Newlyn datum, -5.7 m. OD (Churchill 1970).

21 : SADDLEBOW (6, 10, 12, 13, 15, 33, 34 Table 3.1)

The difficulties encountered in dating the Saddlebow sequence is illustrative of the problem of ^{14}C analysis of the youngest organic layers within the Fenland deposits. The peat layer at Saddlebow was designated equivalent to the upper peat of the southern Fenland by Churchill (1970) with altitudinal limits of 0.0 m. ± 0.3 m. OD to 0.73 m. ± 0.3 m. OD. The monolith was sampled for radiocarbon analyses in 1961 and 1965 (Godwin and Willis 1961, Godwin et al. 1965)

Depth (cm)		1961		1965
0 - 2	Q-549	1875 ± 110	Q-805	2495 ± 110
2 - 4	Q-550	2070 ± 110		
12 - 15			Q-806	2275 ± 100
23 - 25			Q-807	2377 ± 100
c. 70	Q-490	3915 ± 120		
c. 73	Q-489	3905 ± 120		

Both Godwin et al. (1965) and Churchill (1970) have criticised the first series of dates, firstly for the interval of 2000 years for 0.73 m. of peat, and secondly, for the young age for the upper samples compared to other dates from the same stratigraphic horizon. They both quote Q-547 (3305 ± 120 BP) at Magdalene Bend and Churchill also refers to the Flaggrass date, 3065 ± 110 BP (Q 531). However both of these could represent erosion channels.

The problems represented by the dates for both the contacts of this peat bed cannot be solved satisfactorily without new assays. There is no age gradient for the second series of dates and 600 years for the replicate samples Q-549 and Q-805 is disturbing, for although the monolith was penetrated by Phragmites roots and "great care was taken in the radiocarbon age determinations", "no attempt was made to remove the younger material from the peat" (Churchill, 1970, p.135).

22 : SETCH, Nar Valley (5, 21, 70 Table 3.1)

A Y2 complex, the typical 4 fold division for the southern Fenland, was dated in 1974 (Welin et al. 1974). A sample from the base of the lower peat, 7.3 m. below the surface yielded 5440 ± 100 BP (IGS-C14/128). Above this 0.69 m. peat bed clay deposits come to within 4.7 m. of the surface. The base of the upper peat bed was dated at 3215 ± 100 BP (IGS-C14/127) and an assay near to the top of the peat bed, 3.7 m. below the surface, gave 1875 ± 100 BP (IGS-C14/126).

In addition to these 81 ^{14}C dates there are 12 radiocarbon assays from the Humber Estuary which can be related to sea-level changes. With the series of assays taken for the present research project, over 100 radiocarbon dates will form the basis of the chronology of environmental changes discussed in chapters 6-7.

Section 3.4.4 : The Twentieth Century

As many miles of the coastline become heavily utilized by man for various commercial uses the effect of marine flooding is of great economic interest. The floods of 1953 are probably the most famous, but marine flooding of low lying coastal areas is really quite frequent. The Fenlands are particularly dependant on modern coastal defences to prevent extensive inundation during each tidal cycle. The most recent sequence of marine flooding along the east coast started on the 11th January 1978 and highlighted many salient features of the present policy on coastal protection.

The South Holland Internal Drainage Board (Price 1978) reported that on 5 occasions since 1953 sections of the coastline under their jurisdiction have recorded tide levels above those recorded in 1953. "Following the 1953 tidal surge, analysis of the incidence of high tides at Sheerness led to the conclusion that this was a 1 in 200 year event. If this was correct in 1953, land silt and the melting of the polar ice cap would now reduce the frequency of the 1953 surge level to 1 in 100 years. The occurrence of the 1953 type levels during the last 25 years and the surge of the 11th January 1978 have cast doubt on the accuracy of the post-1953 reports or perhaps on their relevance to the Welland and Nene frontage. Because of this doubt, it has been decided that local records are the only reliable basis for our design standards. A statistical analysis of annual maximum levels over the last 25 years, using records at Lawyer's Sluice [R. Welland outfall] , gives much more credible figures for return periods and which are much more in accordance with local opinion. The return period of the 1953 level [+5.39 m. OD] is shown to be 1 in 10 years, while the January 1978 level [+5.79 m.OD] is a 1 in 75 year event." (Price 1978).

The need for studies on both long term and short term changes is clear and is recognized by the relevant authorities. There is a reasonable data base for both long term and short term studies but these require local accuracy, rather than regional generalisation, whenever possible. However as Price (1978) points out, the Ministry of Agriculture insists on a measurement of cost to benefit gained when schemes are put to it for a grant.

In conclusion it is apparent that palaeoecological, archaeological, historical and present day studies together provide the background of environmental change over the last 8600 years. However many sites need careful interpretation, or even further analysis, before reliable correlations can be made. The data presented in this chapter will be discussed in chapters 5-7.

CHAPTER FOUR

Techniques employed for establishing sea-level index points

Chapter Four is divided into 7 parts, each relating to a technique used in assessing the environmental conditions in the Fenland during the Flandrian Stage and the collection and analysis of samples to be used as sea-level index points. The objective is to produce reliable high quality data following the principles outlined for IGCP Project 61 : Sea-level movements during the last deglacial hemicycle (about 15000 years), (van de Plassche 1977):

4.1 Field sampling methods.
4.2 Levelling.
4.3 Stratigraphic analysis.
4.4 Pollen analysis.
4.5 Diatom analysis.
4.6 Particle size analysis.
4.7 ^{14}C analysis.

Part 4.1 : Field sampling methods

Two main methods have been adopted : coring, and free-face exposures.

Coring has been the most frequently used sampling technique; for rapid reconnaissance investigations, detailed stratigraphic analysis, and to provide samples for further laboratory analysis. The coring techniques employed to obtain samples varied greatly depending on the nature of the sediments and the depth to the base of the Flandrian sequence.

In all cases of sites visited the initial borings were carried out with a Duits' gouge sampler due to its easy and rapid use. This provided small diameter cores suitable for stratigraphic analysis except in cores through alternating tenacious clastic sediments and thin peat layers where gaps in the core were revealed on extraction. However it was not possible to use any other sampling method in thick clastic deposits until 1979. At landward sites, where peat and soft clastic deposits dominated, X4 profiles with the peat layers thicker than the clay/silt, there were no problems with the Duits' gouge sampler.

The most reliable hand coring device used, before 1979, was a Russian-type peat sampler. However, due to the intractable nature of the clastic sediments its use has been restricted to the areas dominated by soft sediments, typically X4 and Z1 profile types. This sampler was used to provide samples for stratigraphic and pollen analysis from Bourne Fen, and for diatom and particle size analysis at Freiston Marsh. The sampler was cleaned between taking each 50 cm. core and the sediment was transferred, undisturbed, into 50 cm. lengths of plastic guttering, sealed in polythene and stored.

In an attempt to collect samples large enough in diameter to provide material for ^{14}C analysis from the site at Adventurers' Land, Guyhirn, which had been sampled for pollen analysis by Dr. M.J. Tooley, a U-4 boring was commissioned in 1976. Unfortunately the 8.5 m. core was of disappointing quality and only the bottom 0.5 m. resting on the glacial sands were suitable for further analysis.

In 1979 a modified Livingstone piston corer and percussion drill (Merkt and Streif 1970) became available and was used to provide undisturbed 48 mm. diameter samples, in 1 m. lengths, from Cowbit Wash and Adventurers' Land.

In order to collect samples for ^{14}C analysis from the Bourne Fen sites 2 pits were dug. The dimensions were approximately 2 m. x 1 m. x 1.5 m. depth. These pits provided a great amount of very useful stratigraphic information as well as ample sediment for further analysis. After the pits had been excavated one long face and one end section were carefully prepared for stratigraphic analysis. Overlapping monolith samples for the vertical extent of the clastic sequence and the upper and lower transitions to fen peat were collected. The monolith samples were cut away from the face, sealed in polythene, and stored at 0°C.

Part 4.2 : Levelling

All of the sites have been related to O.D. Newlyn using a Kern level. Benchmark data were taken from the Ordnance Survey Bench Mark Lists. In general it has not been possible to use two benchmarks for each site, but the distance to a site, or the end of a section, has usually been less than 500 m. The levelling was always completed as a loop, except at Freiston Marsh, and the maximum closing error was 2 cm. This value was for the Bourne Fen section where the distance from the nearest benchmark to a temporary benchmark set up by the author at the middle of the section was c. 1.3 km. The AWA carried out work on the Bourne Eau in 1978 and their independent levelling confirmed the accuracy to 1 cm. Therefore, since the Bourne Fen levelling involved the longest closed transect it would appear reasonable to assume that all of the surface levels are accurate to ± 2 cm.

Part 4.3 : Stratigraphic Analysis

Stratigraphic analysis was carried out in the field except where the modified Livingstone corer was used. The sediments were described according to the scheme of Troels-Smith (1955).

With the samples from the hand-coring equipment the surface of the sediment was cleaned with a spatula, dissected to reveal any internal mixing during sampling, and then divided into layers according to changes in the physical properties. Each layer was then recorded according to Troels-Smith.

The two pit sections in Bourne Fen allowed much greater stratigraphic detail to be recorded, especially since one of the faces cut the side of a channel eroded into the lower peat bed and subsequently filled with clastic sediments. Once the pit had been dug one face and end section were planed to the vertical and carefully cleaned with a trowel and spatula. 25 cm. sections of the face were then treated individually and the boundaries between layers marked by inserting matchsticks. This was done for each 25 cm. section and therefore the boundaries could be followed along the whole face.

A datum line was set up at or near to the ground surface, carefully adjusted until horizontal, and then levelled to OD. A sketch could now be made of faces onto graph paper showing the changes in level of the boundaries by recording their down and across coordinates. Any other major stratigraphic features such as large pieces of wood or involutions of clay and peat could be noted by sketching on the graph paper and recording their coordinates. Having recorded the horizontal and vertical extent of each layer its properties were described according to Troels-Smith.

The Troels-Smith scheme is well documented (1955) and its application to Flandrian coastal sediments proven (Tooley 1978a). However a few points need to be noted.

The volume of sediment provided by the Duits' gouge sampler is quite small, making the physical properties stratificatio and elasticitas difficult to assess for thin layers. This however only applied to the Cowbit Wash series of cores.

The main difficulty in using the scheme is the description given to the microscopic particles of mud-like material which form the matrix of a humified peat, e.g. a "Fen peat". Troels-Smith (1955) noted the difficulties of differentiating between Limus detrituosus, L. humosus, Substantia humosa and highly humified Turfa. A fen peat could typically consist of fragmented pieces of wood (Detritus lignosus), leaves and stems of herbaceous plants (Detritus herbosus and Turfa herbacea), macroscopic remains of the roots and rhizomes of Phragmites (Turfa herbacea (Phragmites)) and a matrix of an organic mudlike substance. The difficulty is assigning a classification to this matrix. Substantia humosa could be used since the origin of the organic substance cannot be stated with certainty. It cannot be said that it is the product of in situ decomposition of the Turfa, though neither need it be entirely a humous substance sedimented in water, notably of undefined depth (Troels-Smith 1955). Troels-Smith outlined the different properties of colour and elasticity that can be given to Limus detrituosus +/- L. humosus (Troels-Smith 1955 pp. 62-64). This latter characterization has therefore been used to describe the organic matrix of the peat/gyttja deposits, while Turfa and Detritus only describe the visible plant remains. Therefore Limus is taken to describe deposition in water-logged conditions, with water depths from a few centimetres upwards. Furthermore, the symbolisation developed by Troels-Smith has been adapted to provide a more logical diagram. The number of symbols per unit area are directly proportional to the component's contribution, by volume, to the deposit. This is not the case with Troels-Smith's original scheme where, for example, the density of the symbol for Turfa lignosa (Troels-Smith 1955, Table V), for proportions 1:2:3:4 are 13:18:25:53 per unit area. The stratigraphic sections drawn by computer (Part 4.4 below) exhibit the extreme adaption of the 4 part division (see fig. 5.9 for example).

Part 4.4 : Pollen analysis

Pollen analysis was carried out on all of the sites, apart from Freiston Marsh, with samples taken from the cores transported back to the laboratory. This has the advantage over collecting the samples in glass vials in the field in that, firstly, fieldwork is quicker, and, second, extra levels can be counted for detail at critical points where necessary.

The actual chemical preparation of samples followed well-established techniques (Appendix II). Counting was carried out on a Zeiss photomicroscope with magnification up to 12.5 x 2 x 63 (eye-piece x ocular x objective). A pollen key (Faegri and Iversen 1964), type-slide collection, and pollen reference books and photomicrographs were used (Erdtman *et al*. 1961-3, Moore and Webb 1978, Nilsson *et al*. 1977).

Corylus and *Myrica* pollen were counted together as Coryloid. *Phragmites* pollen is included in the Gramineae. *Sparganium* pollen was counted as *Typha angustifolia*-type.

For percentage diagrams 150 tree pollen, including *Alnus*, excluding Coryloid, were generally counted, although this was not possible at a few levels where pollen was either scarce or poorly preserved.

The pollen concentration technique using *Lycopodium* tablets (Stockmarr 1971) was also employed, with between 200 to 400 *Lycopodium* spores counted, where possible, and depending on the concentration of the other pollen grains.

The difficulties and importance involved in the choice of the pollen sum and the method used to calculate the percentage frequency of each taxa have been discussed by Moore and Webb (1978). A specific pollen sum is chosen to enable the separation of the immediately local elements in the pollen assemblage from the regional elements. Local elements can be excluded from the pollen sum although the interpretation of the percentages for taxa outside the pollen sum (denominator) used can be difficult since the upper values are greatly inflated by their inverse relationship to the pollen sum. Additionally it is possible to compare directly the true proportions of each taxon contributing to the pollen sum between levels, whereas counts outside the sum are suited to the study of level to level variation in ratios of true proportions, the denominator always being the true proportion of marker grains, the pollen sum (Mosimann 1965). In order to reduce these problems it is preferable to express pollen frequencies as either a percentage of a total pollen sum or as a percentage of the local + arboreal pollen sum (Wright and Patten 1963).

Two methods of representing the pollen data have been employed. The expression of taxa frequencies as a percentage of the arboreal sum + one of 4 local ecological groups, (%AP + Group) : shrubs, herbs, aquatics, and spores of Bryophyte and Pteridophyte taxa; follows Tooley (1978a), while the use of a pollen sum consisting of total land pollen (%TLP), with aquatics and spores outside the main sum, has been used by Devoy (1979). Aquatics and spores can either be calculated outside the sum or with the addition of the group to the pollen sum (%TLP + Group), see Devoy (1979). It is felt that these two methods (%AP + Group, %TLP), in addition to pollen concentration data allow the important local and regional effects to be separated.

Mosimann (1965) published equations for calculating the confidence bands of the calculated pollen frequency. The use of confidence bands is widespread for pollen concentration and pollen influx studies but has found little favour in general percentage analyses. This may be due to the calculations involved but this problem is easily solved by the use of a computer. Therefore a program, called NEWPLOT, has been written in FORTRAN IV, to calculate the pollen data using different pollen sums and to present the results in summary tables and as a series of diagrams.

The equations used in NEWPLOT to calculate the 95% confidence bands of the percentage estimates are taken from Mosimann (1965) and the standard error for the pollen concentration is after Stockmarr (1971).

The 95% confidence limits of the estimated true proportion, calculated within the sum are given by:-

$$\frac{\hat{p} + [1.96^2/2n] \pm [1.96]\sqrt{[\hat{p}(1-\hat{p})/n] + [1.96^2/4n^2]}}{1 + [1.96^2/n]}$$

while the estimated ratio of a pollen type to the pollen sum has 95% confidence limits given by:-

$$\frac{\hat{u} + [1.96^2/2n] \pm [1.96]\sqrt{[\hat{u}(1+\hat{u})/n] + [1.96^2/4n^2]}}{1 - [1.96^2/n]}$$

The standard error for the estimate of the pollen concentration is given by:-

$$\hat{N} \pm \hat{N}\sqrt{[S/t.L.\sqrt{t}]^2 + 1/x + 1/L'}$$

where x = number of grains counted of the taxon

n = number of grains in the pollen sum

L' = number of *Lycopodium* spores counted

t = number of *Lycopodium* tablets used

L = mean number of *Lycopodium* spores in each tablet

s = standard deviation of the mean 'L'

$\hat{p}$ = x/n, where x is within the pollen sum

$\hat{u}$ = x/n, where x is outside the pollen sum

$\hat{N}$ = $L.t.x/L'$, the estimate of pollen concentration

Program NEWPLOT (Appendix III) calculated pollen concentration, where applicable, and taxa as:

- % Arboreal Pollen (%AP)
- % AP + Group
- % Total Pollen

Options within the program allowed the definition of the constituents of the AP sum, each ecological group, and the total pollen sum to be defined. Aquatics and Spores were generally excluded from the total pollen sum, to represent total land pollen (%TLP). Similarly it was quite easy to re-run the program to consider the effect of the inclusion and exclusion of *Alnus* and Coryloid pollen in the $\sum$AP. It was decided to include *Alnus* in the $\sum$AP for each of the sites since it was a component of both the local fenwood and the regional forest, and also would have made the analysis exceedingly time-consuming if it had been excluded. Coryloid pollen was excluded from the $\sum$AP since *Myrica* pollen was not distinguished from *Corylus* pollen.

The use of confidence bands for percentage pollen diagrams has been limited, but with widespread use of computers this is unjustified. Confidence limits reveal limitations in the data otherwise not readily apparent and the effect of a lower than normal $\sum$AP can be clearly seen. Moore and Webb (1978) have summarized the advantages of using confidence bands and write "In this way one can easily differentiate between random fluctuations in pollen curves and changes due to real alterations in the composition of the pollen assemblage. These real changes can then be used as the basis for constructing a zonation system for the diagram" (Moore and Webb 1978 p. 89). Furthermore, Evans (1974 p.168) states that "confidence bands permit a rough test for the differences between two samples. If the bands do not overlap, then the samples are significantly different at a higher level of confidence. If they do overlap, there is some chance that the samples differ at the level of the confidence band, though this chance is less the more the bands overlap". Evans shows that the probability that two distributions with non-overlapping 95% confidence bands are truly different exceeds 99%.

Therefore the point where the 95% confidence bands of certain taxa do not overlap for two levels can be used as the basis for constructing the boundaries of a Local Pollen Assemblage Zone (LPAZ). There are no set rules for the construction of LPAZs boundaries and the use of confidence bands seems more uniformally applicable than the opinion of individual authors, yet is a long way from the statistical analysis reported by Gordon and Birks (1972, 1974). Godwin (1940a, b) constructed pollen zonation schemes for both the Fenland and the whole of southern Britain. The Fenland scheme was not a purely biostratigraphic zonation since Fenland Zone VIIc was related to the deposition of the Fen Clay (*sensu* Godwin). The scheme for southern Britain became associated intricately with climatic changes and therefore the pollen zones came to be regarded as a period of time. The dating by radiocarbon assay of the pollen zone boundaries at type sites, e.g. Red Moss (Hibbert *et al.* 1971) gave rise to the use of chronozones for the Flandrian Stage. A chronozone can be defined as a zonal unit embracing all rocks formed anywhere during the time range of some geologic feature or specific interval of rock strata (Hedberg 1976). The basis for the time span of a chronozone may be the time range of a biostratigraphic zone such as a pollen assemblage zone and therefore is defined from a type site where boundaries, of regional significance, have been ^{14}C dated. Thus, for sites where ^{14}C analyses have not been carried out, local pollen assemblage zones are correlated biostratigraphically with Regional Pollen Assemblage Zones (RPAZ) and ultimately with the chronozone system (e.g. West 1977, table 2.10). This method of correlation will give a coarse approximation to the age of the deposit. However for deposits younger than *c*.5000 BP, post *Ulmus*-decline, pollen assemblages cannot provide a finer age estimate than "younger than 5000 BP". The use of the chronozone and pollen zonation scheme is much more useful for the period 10000 to 5000 BP.

The chronostratigraphic use of pollen zones has been criticised by Smith and Pilcher (1973) and Moore and Webb (1978). The latter two authors argue that when dealing with environmental changes during the last 5000 years the regional pollen zonation system should be abandoned in favour of local zonation schemes which are valid only within the area of study. The traditional pollen zonation for southern Britain (Godwin 1940b) generally follows the concepts of a biostratigraphic range - or acme-zonation scheme (Hedberg 1976) where the zone is defined by the maximum development of certain, generally arboreal, taxa. Regional pollen assemblage zones can be correlated with the scheme in a broad sense since the assemblage-zones defined by the arboreal taxa generally coincide with the original acme-zones. However the assemblage zone is particularly significant as an indicator of environment; it is also a general indicator of geologic age, and is of high value in local correlation (Hedberg 1976). Therefore Moore and Webb (1978) suggest that a zonation of the pollen diagram should incorporate the locally derived pollen as well as that from more regionally significant taxa when concerned with elucidating local successional or retrogressive developments in vegetation. However if one is interested in regional changes, and correlation, the local pollen types may be ignored in zonation. Definition of local and regional pollen types is of utmost importance.

The great variation in water-table levels in the Fenland during the Flandrian Stage caused great environmental changes quite different to those at the sites where regional pollen assemblage zones (and at some, chronozones) have been defined, e.g. Hockham Mere, Red Moss (Godwin 1975, Hibbert et al. 1971). Therefore there are advantages in defining pollen assemblage zones of local significance to facilitate the description of Fenland pollen diagrams, to elucidate vegetation development, and for local correlation. The system adopted is therefore to study the whole pollen spectra and to define the Local Pollen Assemblage Zones by changes in numerous taxa, not limited to the tree species. Therefore the LPAZs described in Chapter 5 are of local significance and are only numbered and not named after significant taxa (Birks 1970, Hedberg 1976, Moore and Webb 1978). The LPAZ boundaries may not coincide with Regional Pollen Assemblage Zones defined by mainly arboreal taxa, indeed Godwin & Clifford (1938) noted the absence of a clear Ulmus-decline in many Fenland diagrams due to local effects, but where possible the arboreal assemblages from each site are compared to the chronozone system for southern Britain as an aid to corroborate ^{14}C data.

The presentation of the low and sporadic occurrence of pollen of some shrubs, herbs, and aquatics is a variable feature of pollen diagrams. It is preferable to show all of the pollen types recorded. However this may make the diagram an unmanageable size, either requiring large fold-outs (Devoy 1979), gutter-bridging which is not very satisfactory (Tooley 1978a), or having to divide the diagram into up to 3 separate figures (Moore and Webb 1978, figs. 6.8-6.10). A possible solution, used here, is not to plot individually taxa occurring in low frequencies. These are grouped together into separate classes dependent on their broad ecological habitats. Where the pollen type covers a wide range of species with different ecological habitats a definite classification is not possible and therefore the 4 classes of herbs are kept broad. The same classes are retained for each pollen diagram and are defined as follows:-

Class 1 :	pollen of herbs not usually associated with fens or with a coastal preference.
Class 2 :	pollen of herbs usually growing in wet, waterlogged or fen habitats.
Class 3 :	pollen of herb families characteristic of disturbed habitats including some taxa exhibiting coastal affinities.
Class 4 :	pollen of herbs with definite coastal preference.

Therefore pollen taxa which occur intermittently and at low frequencies are represented collectively in the pollen diagrams. Prior to the description of the Local Pollen Assemblage Zones for each site the individual taxa in each group are listed, along with the total number of levels in which each occurs and its maximum percentage frequency (%AP + Group). To complete the hierarchy of data presentation the pollen counts of all taxa identified for all sites are given in Appendix IV.

Further justification for this grouping of taxa is found when the 95% confidence bands are considered.

An example is given using the data in Table 4.1 taken from BF10 (see Chapter 5).

TABLE 4.1 : Sample Pollen data from BF10

Counts

	Trees(AP)	Shrubs	*Filipendula*	*Succisa*	Other herbs
245 cm	150	39	3	3	255
250 cm	150	33	10	1	250

Percentages: lower 95% confidence limit-mean-upper 95% confidence limit

	%AP	%AP + Herbs	%TLP
Filipendula			
245 cm	0.6 - 2.0 - 5.8	0.2 - 0.6 - 1.7	0.2 - 0.5 -1.6
250 cm	3.4 - 6.7 -12.1	1.1 - 2.0 - 3.6	1.0 - 1.8 - 3.4
Succisa			
245 cm	0.6 - 2.0 - 5.8	0.2 - 0.6 - 1.7	0.2 - 0.5 - 1.6
250 cm	0.1 - 0.7 - 3.7	0.0 - 0.2 - 1.1	0.0 - 0.2 - 1.1

Table 4.1 reveals that for *Succisa*, whichever method of calculating the percentage estimate is used, the upper 95% confidence limit for 250 cm, 1 grain, is greater than the mean for 245 cm, 3 grains. Even for *Filipendula*, 3 and 10 grains, there is still considerable overlap of the confidence bands. This should be taken into account when comparing, say, the decrease from 7 to 2%AP. Similarly the different methods of calculating the percentage can be viewed in clearer perspective when these statistics are considered. It is clear that %AP shows larger apparent changes than the other methods if the mean is considered by itself with no reference to confidence bands. Therefore the use of confidence bands reveals the limitations in the

interpretation of between level variation of taxa recording low frequencies.

The importance of these taxa is their presence or absence and the collective quantitative changes of ecologically similar types rather than the between-level change in the estimates given by the mean without reference to confidence limits.

Part 4.5 : Diatom analysis

The method for the preparation of fossil diatom slides is given in Appendix II. Diatom identification and counting were on the same microscope as for pollen counting. Initial instruction was given by Dr. Maj-Britt Florin, Department of Quaternary Geology, University of Uppsala, and the main references used were Cleve-Euler (1951-3), Hustedt (1927-62), Hendey (1964) and van der Werff and Huls (1958-74). Diatom nomenclature is from the latter reference unless stated otherwise.

Wherever possible, 200 diatom values were counted for each slide. The presentation of diatom data is discussed in Chapter 5.

Part 4.6 : Particle size analysis

Particle size analysis of the clastic sediments followed the pipette method, BS 1377 : 1967 (British Standards Institution 1967).

Part 4.7 : ^{14}C Analysis

Radiocarbon assays were made in collaboration with Dr. M.J. Tooley by Dr. M.A. Geyh at Niedersächsisches Landesamt für Bodenforschung, Hannover and by N.E.R.C. at East Kilbride.

Before each sample was submitted all the macroscopic remains, generally the rhizomes of Phragmites, were removed from the well-humified organic samples. Macroscopic remains were not removed from samples where Turfa herbacea was a major constituent. The removal of penetrating Phragmites rhizomes was an attempt to reduce the younging effect described by Churchill (1970) and Streif (1972). The samples were heat sealed in polythene before being sent to the laboratories at Hannover or East Kilbride. No further pre-treatment was carried out in Durham. The dates from each site are given in Chapter 5.

CHAPTER FIVE

Sites investigated : presentation of data

The chapter is divided into 4 parts, each describing the data collected from the series of boreholes and excavations. Discussion and correlation are reserved for chapter 6, except for some discussion of the results from Freiston Marsh which have influenced the method of data presentation for the other sites. The 4 parts are : 5.1 : Freiston Marsh; 5.2 : Bourne Fen; 5.3 : Cowbit Wash; and 5.4 : Adventurers' Land.

Part 5.1 : Freiston Marsh

Freiston Marsh is an intertidal area of saltmarsh, mud-and sand-flats in the south-west corner of the Wash, north of the river Witham outfall, incorporating Freiston Low and Butterwick Low (figs. 1.2 and 5.1). In November 1978, 12 boreholes, 3 transects of 4 boreholes each, and one free-face excavation were made between TF 409435 and TF 422429. Each site was levelled to O.D. Newlyn and samples were collected for particle-size and diatom analyses. 91 samples were analysed for their particle-size distribution according to BS 1377:1967 and 7 samples were prepared for diatom analysis. The proportions of fine sand, coarse silt, medium silt, fine silt and clay (British Standards Institution 1967) are shown on a linear percentage scale with each profile related to Ordnance Datum (fig.5.1). In none of the 91 analyses was any significant fraction (>0.5%) coarser than 0.21 mm. (fine

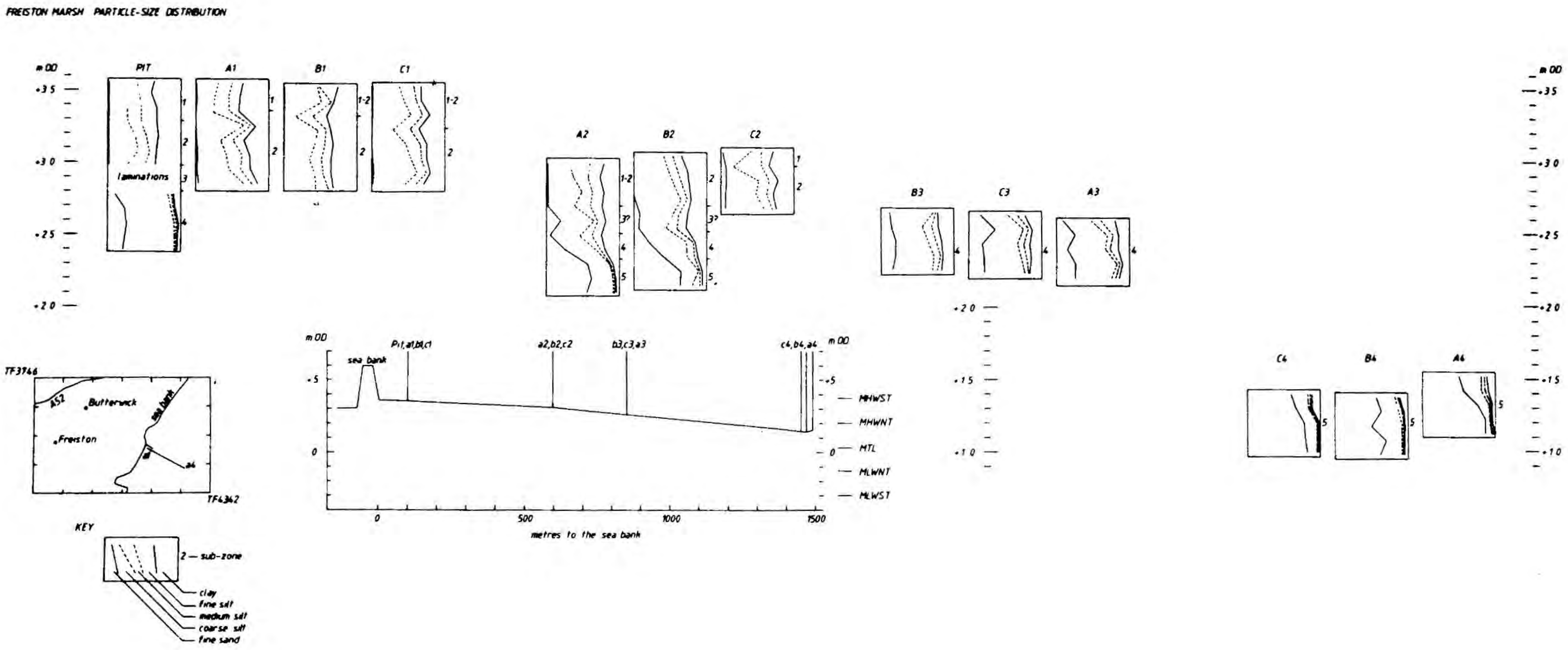


Figure 5.1 : Freiston Marsh particle-size distribution.

sand) recorded. The horizontal distances are measured from the sea bank.

The pit and boreholes A1, B1, C1 and A2, B2, C2 were located in the area of saltmarsh vegetation. The higher sites, between +3.55 and +3.58 OD, just below MHWST (+3.7 m.OD), were located in a vegetation community dominated by *Puccinellia maritima*(Huds.) with some *Salicornia* spp. and *Halimione portulacoides* L. and traces of *Armeria maritima* L., *Artemisia maritima* L., *Aster tripolium* L., *Limonium vulgare* Mill., *Plantago maritima* L. and *Triglochin maritima* L. The second series of sites, +3.04 m. to +3.11 m.OD had vegetation mainly of *Puccinellia*, *Halimione* and *Aster* with some *Salicornia* and *Suaeda maritima* L.

Sites A3, B3 and C3, +2.62 m. to +2.67 m.OD., at approximately mean high tide level, were close to a major creek and at the beginning of incomplete vegetation cover, dominated by *Salicornia* and algal mats with only occasional *Aster*, *Spartina anglica* E.Hubbard and *Halimione*. The lowest sites, +1.43 m. to +1.55 m. OD. were below MHWNT and beyond the limit of herbaceous vegetation. In reference to the zonation of Evans (1965) sites 1-3 were in the saltmarsh zone, site 3 almost at the seaward limit, and site 4 represented the higher mud flat - *Arenicola* sand flat transition.

Section 5.1.1 : Particle size analysis (fig.5.1)

In general the samples reveal a coarsening with decreasing altitude, depicted both in a seaward direction and down each core.

The highest site, cores A1, B1, C1 and the pit section, are characterized by a low fine sand fraction, generally below 2%. Clay values are 20-40% with a maximum of 43%, and there are a few sharp changes, e.g. in A1 where there is a sharp increase in the coarse silt fraction. Only A1 shows any general decrease in the clay fraction down the core. The coarse silt fraction reveals a change with depth. Within the surface 35 cm., below which root penetration is very little in evidence, coarse silt often accounts for less than 50% of the total silt fraction, while below that depth, +3.20 m.OD at these sites, it is always greater than 50% of the total silt proportion.

The pit section revealed much greater detail than the cores taken with the Russian corers. Between 60-80 cm. depth there was a series of coarse-fine laminations which made particle size analysis in that depth range meaningless and marked the transition to the coarser sediments below. These laminations were not noted in the Russian cores and no doubt the transition to sandy sediments provided the increased friction which prevented further penetration. Below the laminations the proportion of fine sand rises from 10% to 23% within 10 cm., clay values fall to below 10% and then to 5%, and coarse silt totally dominates the silt fraction. The pit section also revealed the transitions of the laminated zone to finer and coarser sediments above and below to be virtually horizontal. However, this consistent picture does not preclude the possibility of coarser gully deposits cutting through these high salt marsh deposits.

The second series, A2, B2 and C2, still above MHT, revealed a continuation of the sequence from the first. C2 revealed up to 8% fine sand, while A2 and B2 contained less than 2% until about 35 cm. depth (c. + 2.7 m. OD). Only two samples recorded coarse silt less than 50% of total silt and these coincided with the organic staining near the surface. Below 30-35 cm. depth the deposits were much browner compared to those above which were predominately grey with black organic particles. The only iron staining in these upper levels was around roots. Although not seen prior to analysis the cores from A2 and B2 presumably penetrated the laminated zone since the proportion of fine sand increases to over 60% by +2.30 m.OD.

The third series of boreholes, with a surface height c. + 2.70 m. representing mean high tide level, shows fine sand at 10-30% and may be comparable to the transitional zone, possibly with laminations to the bottom layers of A2 and B2 with over 50% fine sand. The altitudes would agree with this correlation. Coarse silt is constantly greater than 50% of total silt and the clay fraction is between 10-20% of the total weight after pre-treatment.

The final series of boreholes, below MHWNT, show fine sand proportions between 50-80% with coarse silt dominating the rest of the matrix.

These analyses confirm Evans' (1965) zonation for the surface sediment of the salt marsh to the higher mud flat/Arenicola sand flat transition. 5 sub-zones can be proposed from the present analysis. The salt-marsh zone is most readily defined by the surface vegetation while vertically grading to the higher mud flat. No sharp changes in particle size proportions are apparent. The 5 sub-zones recognized are:-

Sub-zone 1: Salt marsh. Generally grey deposit. Fine sand <2%, clay 20-40%, decreasing in a seaward direction. Coarse silt occasionally >50% total silt fraction. Present altitude varies from +3.60 m. to +3.20 m. OD at site 1 to +3.20 m. to +2.70 m OD at site 2.

Sub-zone 2: Lower salt marsh. Fine sand <2%, clay 20-40%, coarse silt always accounts for more than 50% of the total silt fraction. Generally a brown/orange colour. The altitude of the base of this sub-zone presently varies between +3.00 m. to +2.7 m. OD. Sub-zone 2 is not always clearly differentiated from sub-zone 1. Perhaps organic content would be a better criterion for differentiation.

Sub-zone 3: Laminated zone. This zone was only noted in the pit section although it is thought to have been sampled in A2 and B2.

Sub-zone 4: Higher mud flats. Fine sand 20-40%, clay generally < 20%. Coarse silt dominates the silt fraction. This zone is revealed in the base of the pit, below the laminations, in the middle/lower part of A2, B2, and by A3, B3, C3. This represents the surface transition from the salt marsh - higher mud flat of Evans (1965).

Sub-zone 5: Sand flat/higher mud flat transition. Fine sand 50-85%, clay falls from 11-2%, coarse silt >50% total silt. Revealed in the base of A2, B2 and by A4, B4, C4.

These zones appear to fit in well with Evans' zonation but disagree in the position of the laminations when compared to Amos' (1974 fig. 8.9) interpretations. Since the laminations were only seen with certainty in the pit section perhaps more reliability should be placed on the other 4 sub-zones. Therefore sub-zone 4 would correlate with the higher mud flat (Evans 1965) as revealed at A3, B3, C3, but is revealed below the laminations in the pit section.

There is tentative evidence of a seaward decrease in altitude of the sub-zone boundaries. If the laminations are represented in A2, B2, at c.+2.60 m.OD, compared to +2.90 m.OD in the pit, and the sub-zone 5 sand dominated deposits in A2, B2 are at +2.3 m.OD, below +2.2 m.OD in A3, and occur on the surface, +1.4 m.OD at A4, B4, C4, then a slope in a seaward direction in the order of 1:1000 is revealed. This supports Amos (1974).

To summarize : the particle size analysis of the transect shows that five sub-zones have been recognized. These correlate with the salt marsh, higher mud flat and Arenicola or higher sand flat of Evans (1965) and Amos (1974).

The salt marsh is defined by surface vegetation but 2 subzones can sometimes be identified down a section (subzones 1 and 2) and in a seaward direction. The major change occurs at the limit of salt marsh vegetation. Sites 1 and 2 generally reveal, 6 out of 7 sections, < 2% fine sand down to approximately 35 cm. depth, while site 3 at the surface transition to the higher mud flat, has 10-35% fine sand. Site 4 reveals the second major transition, sub-zone 5, with over 50% fine sand. This zonation is thought to run approximately parallel to the coastline (Evans 1965); although there are noticeable variations in particle size distribution around the Wash (Randerson, unpub.) it may be postulated that within a section the relative changes through time may represent the changes in relative position of the site in the intertidal environment.

Section 5.1.2 : Diatom analysis

Diatoms have been used to study changes in salinity and water depth (Berglund 1971, Devoy 1979, Miller 1964, Tooley 1978a) by the interpretation of changes in assemblages held to represent the movement of the site relative to the tidal cycle and of inlet connection to the open sea. However there is no agreement over the method of either grouping the diatom species on a salinity scale or calculating the relative frequencies as percentages.

Two salinity classifications are in general use. Hustedt (1955) developed the halobian diagram in which there are 5 salinity groups. Each salinity group can be divided into planktonic, benthonic, and epiphytic groups. Van der Werff (1958-72) divides the species into seven groups according to the chloride content of the water body favoured by the species.

Methods of representing either the individual species or the groups of species vary. Florin (1946) calculated individual species frequencies as a percentage of the total valves counted. Devoy (1979) used the halobian spectrum for groups of planktonic, epiphytic and benthonic species calculated as a percentage of the total valves counted, while Berglund (1971) used a selected sum of valves for the denominator in the same way that the arboreal pollen sum is used in pollen analysis. A quite different approach is that of Van der Werff (1958-72) who favours the analysis of species, with the sum of species within each salinity class calculated as a percentage of the total number of species counted (Devoy 1979, DuSaar 1978 in Tooley 1978a).

For the present analysis the salinity classification proposed by Van der Werff (1958-72) has been used :

M	:	Marine	> 17000 mg Cl/L
MB	:	Marine/brackish	10000-17000 mg Cl/L
BM	:	Brackish/marine	5000-10000 mg Cl/L
B	:	Brackish	1000-5000 mg Cl/L
BF	:	Brackish/Fresh	500-1000 mg Cl/L
FB	:	Fresh/brackish	100-500 mg Cl/L
F	:	Fresh	< 100 mg Cl/L

A sub-division to benthonic, epiphytic and planktonic was made throughout the analysis. Approximately 200 valves were counted to enable either the calculation of the percentage of valves (% valves) or the percentage of species (% species) type of analysis to be performed.

7 samples were taken; surface samples at the pit and from the C1-4 boreholes, and 2 samples from the pit and borehole C1 at 5 cm. (P:5, C1:5, P:0, C1:0, C2:0, C3:0, C4:0). Since no great change in the sediment appeared in the top 5 cm. it is postulated that the 4 spectra P:0, P:5, C1:0 and C1:5 should give an estimation of within site variation while the comparison with the others should reveal any zonation down the marsh.

The computer program NEWPLOT can be used to calculate diatom frequencies. 40 different diatom species were identified (Appendix IV) of which 17 occurred in frequencies great enough to show significant changes as % total valves. The remaining 23 species occurred in low and sporadic frequencies and were grouped according to their salinity classification. Figure 5.2 shows the variations of the species including the 95% confidence bands (Mosimann 1965) and reveals that very few species show significant systematic changes. Nitzschia navicularis appears to increase at the highest sites but there are great differences between them, from 6.5 to 39.4%. Navicula digitoradiata shows statistically significant changes from C4:0 to P:0 but is not even identified in the subsurface samples. Stauroneis gregorii may be a significant indicator but it is only identified in one sample, where it is the dominant diatom, and may reflect

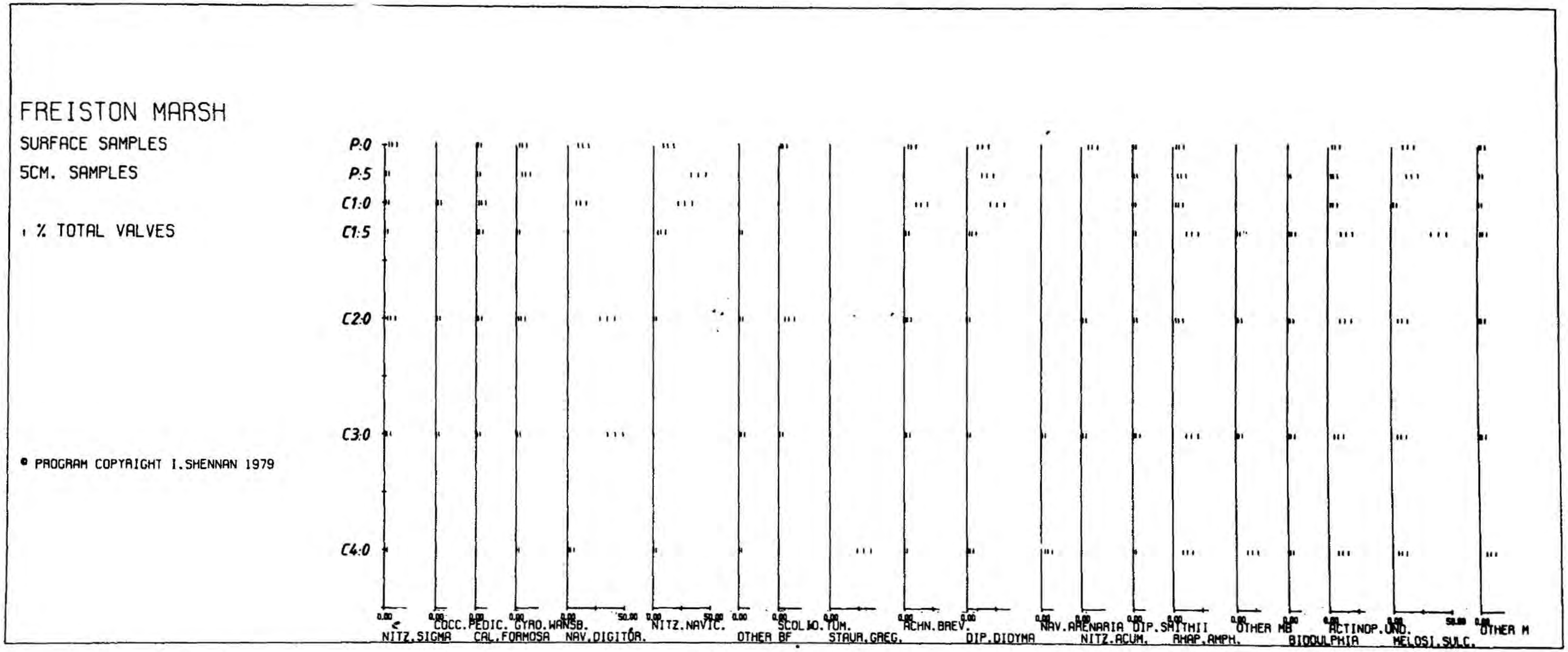


Figure 5.2: Freiston Marsh diatom diagram showing the main species (% values).

only local conditions. Finally Diploneis didyma shows a peak at the upper sites but again varies greatly, from 4.5% to 26.5% and the lower 95% confidence band at C1:5 is less than the mean at C4:0. Therefore it must be concluded that there are no unequivocal trends of individual diatom frequencies, as % total valves, along the section studied.

Simonsen (1969) suggests that in an estuarine environment, where there is a mixing of water bodies of different salinity, only the benthic diatoms should be used to identify the nature of the autochthonous flora. If an analogy can be made with the salt marsh environment then the individual benthonic species should be calculated as a proportion of the total benthonic count. Perhaps epiphytic diatoms could also be included although Hustedt and Aleem (1951) found that the diatom spectra from mud-flats near Plymouth also included species from 3 secondary sources, attached forms from the rock shore, pelagic forms from the plankton, and freshwater forms from rivers and lakes, in addition to those living freely and moving within the muddy substratum. Therefore the data were recalculated as a percentage of the total of benthonic valves, but the results were essentially the same with no significant changes along the section. Within site variation was as great as between site variation. This is in complete agreement with Hendey (1964), that the habitats are usually more restricted or local and therefore individual peaks of diatoms should only be considered in the context of the total change of the spectrum.

As an alternative the species were grouped according to van der Werff's classification and the possible combinations of the summary curves are shown in fig.5.3. The denominator is again total valves counted and each salinity class is shown for benthonic, epiphytic and planktonic species and finally all species. Once more the changes between the 4 samples P:0, P:5, Cl:0 and Cl:5 are as great as those to the samples from the more seaward locations.

Rather than reproduce 3 other diagrams similar to fig. 5.3 the final stages of analysis have been condensed in fig. 5.4 to compare the proposed methods of presentation of the diatom data. At the bottom of fig.5.4 there is the equivalent spectra from a single surface sample from a Phragmites bed at the limit to which tides flow, due to lock gates, along the River Welland at Spalding (TF 25952420). The section labelled "% Total Valves" is the combination of the 5 separate graphs at the right-hand end of fig. 5.3. The other 3 sections of that type in fig. 5.4 were redrawn from the same type of original figure.

The % Benthonic valves show large fluctuations, particularly between C4:0 and the other sites. However this is solely due to the dominance of Stauroneis gregorii, classified as brackish-marine, at C4:0. Therefore it appears that the periodicity of diatom growth is the over-riding factor and that, in agreement with Hendey (1964), the conditions on a salt marsh may well be

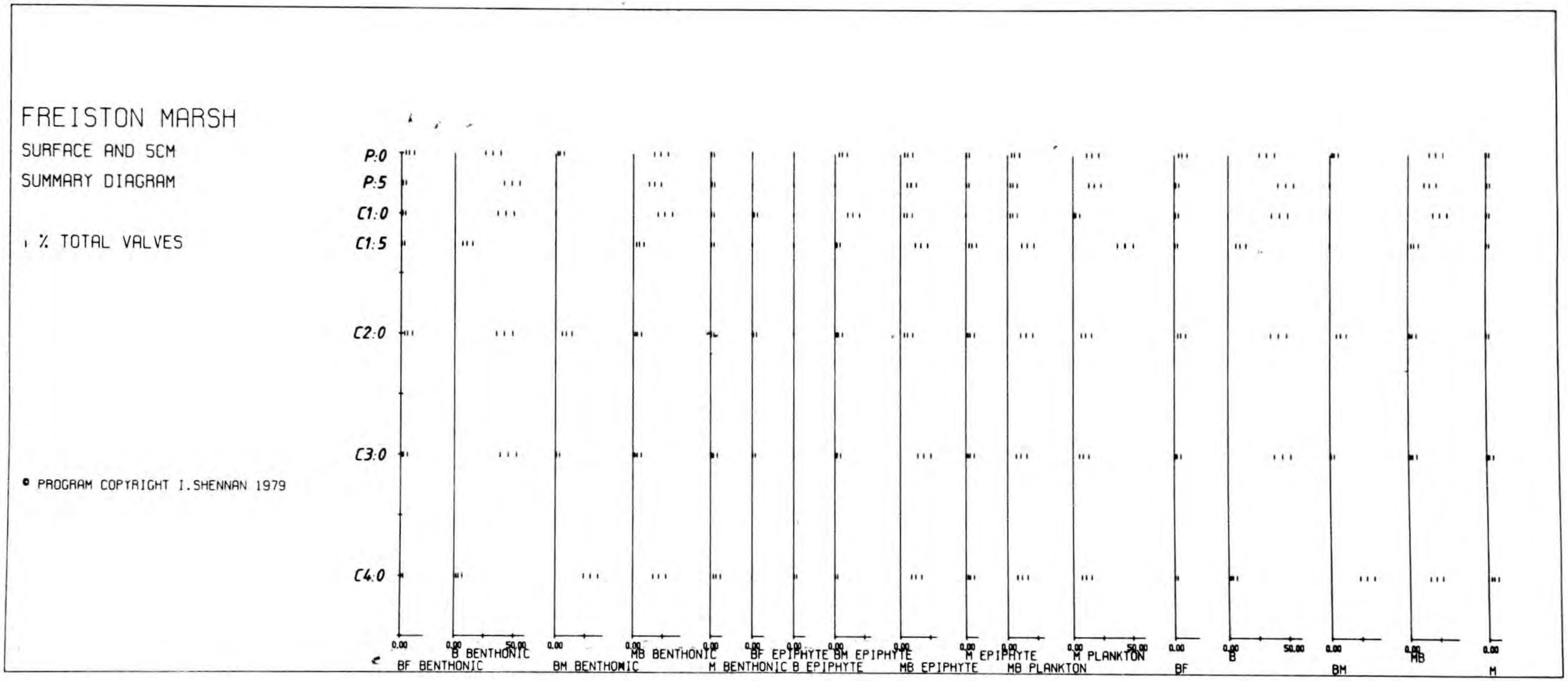


Figure 5.3 Freiston Marsh diatom diagram showing the salinity classes for benthonic, epiphytic and planktonic types with the summary classes shown at the right-hand end.

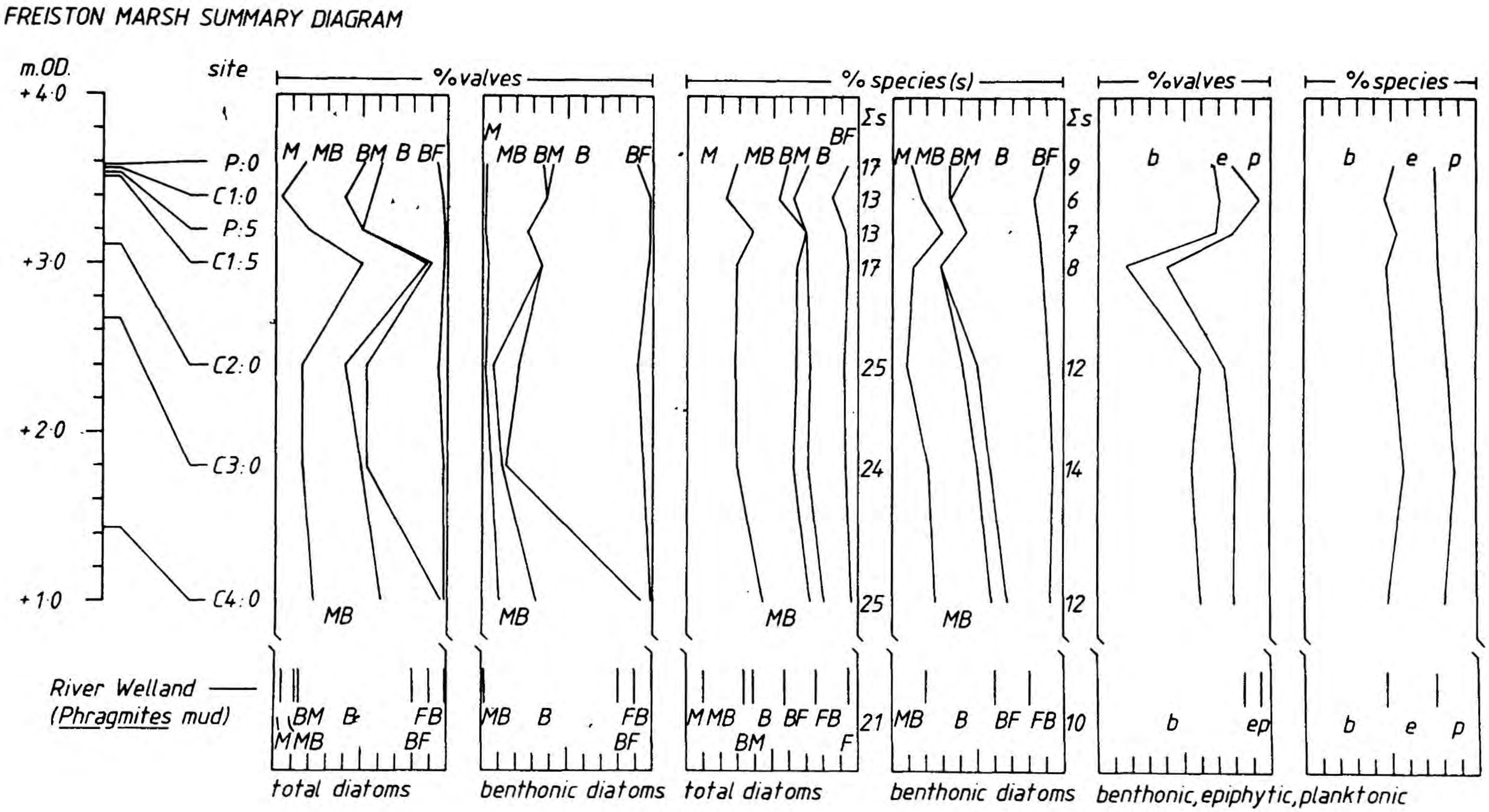


Figure 5.4 : Freiston Marsh summary diatom diagram.

described as a mosaic of micro-habitats. However, further comparison of sub-surface and surface samples may show that during the accumulation of a sediment the diatom assemblage is indeed more consistent than the study of purely surface samples suggest as the peaks of individual species become smoothed.

In an attempt to overcome the problem of these irregularities of individual diatom frequencies van der Werff (1958-72) advocated the "qualitative" approach, counting simply the number of species present within each class and representing these as a percentage of the total number of species present. The calculation of 95% confidence limits given by Mosimann (1965) cannot be used since once a species has been identified further occurrences are ignored. However with the total number of species generally between 10-50 it may be assumed that the 95% confidence bands will be quite broad. Further statistical research is necessary in this aspect. At the moment slight changes in percentages using this method must not be taken as significant.

The methods of calculating the frequencies as % Total Species % Benthonic Species, fig. 5.4 (cf. Devoy 1979, du Saar 1978) reveal equally inconclusive changes when the variation of the 4 within-site samples is taken into account(in addition to the comments on confidence bands) and does not suggest any great difference between C4:0 and the other samples as had been shown in % Benthonic valves (fig.5.4).

Finally the proportion of Benthonic, Epiphytic and Planktonic types as % valves and % species again shows the former to be highly fluctuating and inconclusive and the latter to be quite regular but with no difference down the section.

It is apparent that 7 samples are insufficient to study the complexities of diatom assemblages from one site. It is reasonable to suggest, however, that diatom assemblages cannot be used to distinguish between sites whose altitudes differ by over 2 m. in an area where this represents a change from just below MHWST to just below MHWNT. A noticeable feature of the Freiston Marsh analysis is the lack of fresh, or fresh-brackish diatoms, which accounts for much of the difference with the Spalding sample, and the latter site is dominated by brackish forms with a noticeable lack of marine forms. This confirms the conclusions of Carter (1932-3) that diatoms show no sharp zonation with regard to level across a salt marsh. However the Freiston site is far from natural since the embankment prevents a continuation toward a freshwater environment. The lack of freshwater input may be a significant difference to the natural system prior to reclamation and therefore the comparison to fossil communities may not be valid. However the analysis has shown that the whole spectrum needs to be taken into account when studying the changes of diatom assemblages. The method of calculation is important since neither % valves nor % species is satisfactory by itself. It is suggested that at least the methods shown in fig. 5.4 be used to study changes in diatom assemblages. The change in the benthonic types appears to be important, e.g. no marine benthonic forms were recorded at Spalding, and perhaps the most valid conclusions about diatom assemblage changes would be those that are consistent, in the seral sense, for all of the methods of calculation used.

Clearly the present study is not sufficient to relate present inter-tidal to fossil diatom assemblages. Much more detailed research would be necessary. The following generalisations can be made. Diatom assemblages should be calculated as %Total Valves, %Benthonic Valves, %Total Species % Benthonic Species and the proportion of benthonic, epiphytic and planktonic valves and species (fig. 5.4) in order to show consistent changes in salinity, input of freshwater, and exposure or distance to the open sea. Where the methods of calculation show similar changes all of the summary diagrams need not be presented. Therefore, for the other sites studied in this project the calculations outlined above were carried out but not always represented in the diagrams if the alternatives show no additional information. Diatom analysis does not appear to show the changes of conditions between lower than MHWST and lower than MHWNT at Freiston Marsh. Particle size distribution is a much better index to reveal changes in this section of the tidal zone. The embankment at Freiston Marsh prevents a continuation to a coastal fen where increased altitude and freshwater influence should reveal broader changes in the diatom assemblage and a continued fining of particle size. Unfortunately it is this transition which is of most interest to the study of Flandrian sea-level changes and only locally have such successions been described (e.g.Ranwell 1974)

Part 5.2 : Bourne Fen

Bourne Fen extends east of the fen edge town of Bourne (TF0920) to the River Glen (TF145179 to TF173225). It is divided into Bourne North Fen and Bourne South Fen by the Bourne Eau, an embanked watercourse carrying the outflow from a spring at Bourne to the River Glen. The unconsolidated Pleistocene and post-glacial deposits of Bourne Fen were first discussed by Skertchly (1877) and Smith (1970) briefly discussed the general stratigraphy using early 20th century borehole records.

The present investigations at Bourne Fen have involved levelling, stratigraphic analysis, diatom, pollen, chemical, particle size and radiocarbon analyses. This part is divided into 4 sections

5.2.1 : Stratigraphy of Bourne Fen
5.2.2 : Bourne Fen - 10
5.2.3 : Bourne Fen - P1
5.2.4 : Bourne Fen - P2

Section 5.2.1 : Stratigraphy of Bourne Fen

Bourne Fen is stratigraphically similar to many of the sections studied by Godwin in the Fenlands to the south (Godwin 1940a, 1978) with an X4 profile type : organic basal sequence, clastic sequence and organic cover sequence. Z-type profiles, the perimarine zone of Hageman (1969) are restricted to a narrow zone along the fen edge near Bourne. Agriculture has severely limited the extent of the organic cover sequence: often a peaty-clay soil is the only testament to its former existence. The surface peat sequence only extends a few kilometres north of Bourne North Fen to an area of surface silts and clays in Morton Fen. Inorganic surface deposits are continuous until the Witham Valley when surface organic soils are found once more.

The section studied follows the north bank of the Bourne Eau where a belt of grassland approximately 40 m. wide between the Eau and its counter drain has been less affected by soil erosion. 30 boreholes, 3 excavated pit sections and over 2 kilometres of cleaned dyke sections were used to study the stratigraphy. The boreholes and pits were each levelled to OD. while the dyke sections were used to confirm the continuity of the horizons. The ground surface levels for the Bourne Fen section can be considered to contain an error of ±0.02 m.

The location of the boreholes and pits are shown in fig.5.5, while fig. 5.6 represents the stratigraphy according to a modified version of Troels-Smith's scheme (Troels-Smith, 1955). Additional data are given in table 5.1 to avoid confusion in the profile, fig. 5.6, between BFP1 and BF27A.

The distance between BF16 and BF19 is 2.15 km.

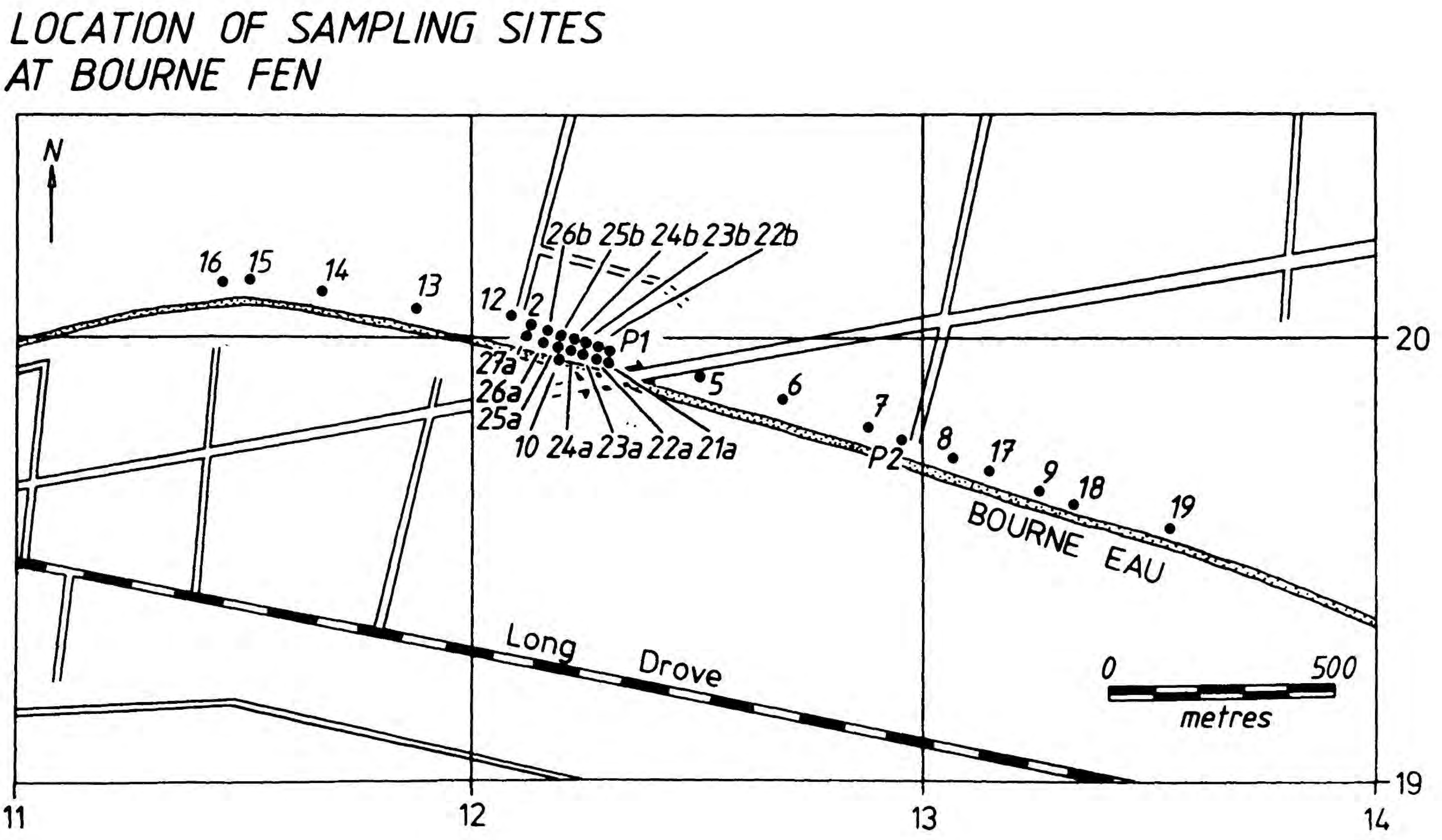
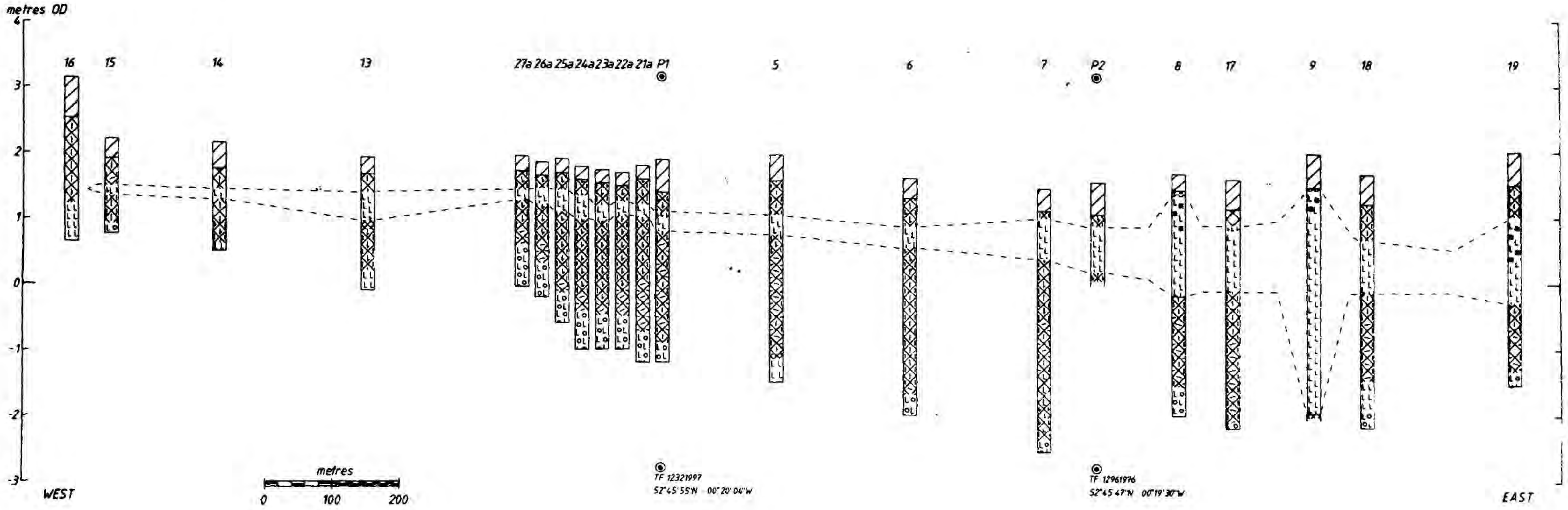


Figure 5.5 : Location of boreholes at Bourne Fen.

BOURNE FEN



TOTAL LENGTH OF SECTION 2150m
TF 11462013 to TF 13551957
52°46'00"N 00°20'50"W to 52°45'40"N 00°18'59"W

FIELDWORK 750705 to 780731
INTERPOLATED LEVELS OF THE CLAY/SILT HORIZON WERE EXPOSED IN CLEANED DYKE SECTIONS FROM 780701 TO 780830
SAMPLES TAKEN FOR POLLEN, DIATOM AND C 14 ANALYSES ◉
STRATIGRAPHIC SYMBOLS after TROELS-SMITH (1955)

Figure 5.6 : Bourne Fen stratigraphy.

TABLE 5.1 : Borehole data, BF27A to BFP1 (Fig. 5.5)

Borehole Number (BF)	altitude (m. OD)			
	ground surface	regression contact	transgression contact	base of Flandrian sequence
27A	1.96	1.44	1.29	0.61
26A	1.87	1.47	1.22	0.32
25A	1.91	1.44	1.11	-0.14
24A	1.80	1.35	1.01	-0.41
23A	1.75	1.20	0.97	-0.47
22A	1.71	1.26	1.06	-0.49
21A	1.82	1.22	1.04	-0.74
10	3.21	1.11	0.81	-0.21
2	1.91	-	-	0.11
26B	1.95	1.20	1.05	0.30
25B	2.00	1.24	1.11	0.00
24B	1.96	1.20	1.05	0.62
23B	1.82	1.04	0.72	0.75
22B	1.71	1.11	0.96	-0.99
P1	1.91	1.06	0.85	-0.93

with a surface height generally between +2.22 m.OD (BF15) and +1.46 m.OD (BF7) although BF16 (+3.15 m.OD) and BF10 (+3.20 m.OD) have much greater surface levels due to the application of an overburden during banking schemes. Indeed BF10 lies inside the north bank of the Bourne Eau.

The greatest altitudinal range for any boundary is for that between the pre-Flandrian deposits and the base of the organic sequence. There is a general decrease in height from west to east, +1.25 m.OD at BF16, -1.33 m.OD at BF19. The lowest altitude recorded for the surface of the pre-Flandrian deposits was at BF7, -2.30 m.OD, although it could have been lower at BFP2 or BF9. The nature of the pre-Flandrian sediments is variable. In most cases a weathered horizon of blue clay/silt with sand and organic roots was encountered, the thickness of this stratum varying from 0.10 m. to more than 0.60 m. At some locations the highest pre-Flandrian deposits were predominately sandy. Where the weathered horizon was a silty clay it usually passed down into a coarser deposit with pebbles of chalk, greensand and chert.

Only BF16 represents a Z1 profile type, the other boreholes reveal one clastic horizon between 2 organic layers. The distance between BF16 and BF15 is 60 m. and the limit of marine sedimentation must lie between these two sites. This is confirmed by the nature of the clastic horizon recorded at BF15, a clayey silt with abundant remains of Phragmites.

A few other boreholes in the western part of Bourne North Fen have revealed only a single thin organic horizon above pre-Flandrian sands. 0.4 m. of peat was recorded at TF 115208, near to the A151, which contrasts greatly with over 3 metres of peat from Barne's Drove (TF126218) reported by Smith (1970). Exploratory borings failed to find any such thick accumulations of peat and since Smith quoted a 1932 borehole record there is liable to have been some surface wastage.

The continuation of the X4 profile type eastwards is confirmed by 3 sources. Skertchly (1877) reports 0.6 m. of silty clay between two peat beds from near Tongue End (c.TF158185). Two boreholes by Pre-Piling Surveys Ltd. in 1961 at Tongue End revealed c.2.0 m. of clastic deposits between two organic layers (TF153184 and TF155183). The upper of the two organic layers is only preserved in these two boreholes which penetrate the banks of the River Glen and Counter Drain due to the protection afforded by the man made banks. Apart from Bourne South Fen the surrounding fields no longer reveal highly peaty soils. Finally, confirmation of the X4 sequence was provided by cleaned dyke sections west of the River Glen in Bourne South Fen (TF151185).

The area of Z1 profile types is greater in Thurlby Fen and Baston Common than in Bourne Fen. Unlevelled boreholes at Whattoffs Bridge (TF140174) and Mill Close (TF145178) revealed less than 1.0 m. of peat above a gravel/sand/clay matrix. Noble reported in 1896 a peaty soil c.1 m. thick above gravel at White House Farm, Baston Common (c.TF137149).

The basal peat in the Bourne Fen section can be divided into 3 characteristic units; a humified woody detrital peat, a humified monocotyledenous peat with rhizomes of Phragmites, and a silty monocot. gyttja with Phragmites rhizomes. The woody peat always occurs above the weathered glacial silts and sands and usually has a high gyttja content. Only BF7 revealed any inorganic matter within the horizon. The source of the wood is two-fold. Firstly remains of woody roots have occasionally been found in the sampler chamber in the pre-Flandrian silts and would represent the trees growing on the land surface prior to the growth of peat. Secondly the wood remains found above the basal layers represent trees of the fen wood, mostly Alnus, but Quercus, Taxus, Pinus and Salix may be expected (Godwin 1978), which would have been rooted in the growing peat itself. Therefore in the broadest sense the woody detrital peat represents the development of alder carr and fenwoods following the destruction of the forest which had grown on the pre-Flandrian deposits. The transition to a humified monocot. peat is very gradual and the levels indicated in fig. 5.6 purely represent the highest occurrence of pieces of wood in the chamber of the borer. The highest level recorded for this transition is at BFP1 since the greater sample size, the surface area of the pit compared to the chamber of a Russian borer, could be expected to record wood fragments more frequently.

The humified monocot. peat is represented in all of the boreholes and testifies to a rising freshwater table and the development of reedswamp conditions. Horizontally bedded rhizomes of Phragmites were usually an abundant constituent of the Turfa component.

The succession to a coastal sequence is confirmed by the silty monocot. gyttja which marks the base of the inorganic sequence. This horizon represents a natural transition to coastal inorganic deposition and its absence, in the end section of BFP2 and also revealed in the dyke sections at TF130198, suggest slight erosion during the transgressive phase.

The total thickness of the basal organic sequence varies from 98 cm. (BF15) to 273 cm. (BF7).

The inorganic deposits found in the Bourne Fen section are the equivalent of the "Fen clay" or "Buttery clay" of the southern Fenland. Field analyses, outlined by Troels-Smith (1955), showed only silt and clay size fractions. No sand was recorded. The organic content was very variable, being most abundant at the transitions to the peat layer and as the clastic horizon attenuated towards the west. Therefore at BF15 the whole horizon was only 15 cm. thick and was composed of about 50% Turfa, mainly Phragmites.

As the clastic horizon thickened to the east the organic content decreased, except at the transgressive and regressive contacts which were represented by a transitional deposit. The transgressive transition zone was usually much thinner than the regressive transition zóne, The former was erosional in three instances, at BF8, BF9, and exposed in the end section of BFP2. In these cases the contact was sharp, recorded as either lim.2 or 3 (Troels-Smith 1955). Conversely the regressive contact was always transitional. At BFP1 the transitional silty organic regressive layer was up to 13 cm. thick, while the predominately inorganic silty clay itself was only up to 14 cm. thick.

Two other important constituents of the clastic horizon were recorded in the field. At BF9 a 3 cm layer of shells, Hydrobia spp., was encountered, while at BF8, BF9 and BF19 hard iron concretions were recorded in the upper part of the horizon. The significance of these was revealed both by the ground levels and the exposures in the cleaned dyke sections. All three boreholes were at locations where the ground surface was at a local maximum and where the level of the top of the clastic layer rose. These seem to be the equivalent to small roddens (Fowler 1933) and represent the final inorganic sedimentation in channels prior to complete organic deposition (Godwin and Vishnu-Mittre 1975).

BF9 also contained the thickest inorganic sequence. It was only just possible to reach the top of the basal organic deposit with the Russian borer. The transgressive contact was erosional. It may be suggested that this represents a channel associated with the inorganic deposition which has retained its course during the period of clastic sedimentation. BF8 also reveals an erosional transgressive contact but no obvious deepening as was seen in the cleaned dyke section at BF9. However, the transgressive contact at BF19 was transitional and much more detailed mapping would be required to study the course of channels through the clastic horizon.

Aerial photographs from the collection held by Lincolnshire County Council were studied for the whole area but the ground conditions were not suitable to reveal the changes in near-surface facies or soil-type since crop growth was too advanced (Evans 1972).

There are 2 noticeable features about the altitudinal limits of the clastic horizon shown in fig. 5.6. Firstly the horizon thickens in the seaward direction, to the east, and secondly, apart from the supposed channel deposits at BF8, BF9 and BF19, there are no great undulations in the transgressive or regressive contacts, while the altitude of both decrease to the east. These visual conclusions can be tested not by the use of the mean and standard deviation statistics (cf. Tooley 1978a) but by regression analysis. The least squares linear regression statistics were calculated for three data sub-sets using a Texas TI Programmable-58 calculator.

The following three data sub-sets were used (prefix BF omitted) :

- set 1 : P1, 22b, 23b, 24b, 25b, 26b, 21a, 22a, 23a, 24a, 25a, 26a, 27a, since the 13 samples represent a small area 180 x 30 m. with a gradual increase in altitude of the glacial surface to the west and south.

- set 2 : the 13 samples of set 1 + 5, 6, 7, 10, 13, 14, 15, 17, 18 in order to study the interaction of the seaward thickening of the clastic deposits and the general decrease in altitude of the undulating glacial surface.

- set 3 : set 2 excluding 10, since the latter may be influenced by its overburden of bank material.

TABLE 5.2

T = altitude of the transgressive contact, metres OD.
R = altitude of the regressive contact, metres OD.
S = standard deviation

	set 1	set 2	set 3
$\overline{R}$	1.25	1.19	1.19
S_R	0.14	0.22	0.22
$\overline{T}$	1.03	0.87	0.88
S_T	0.15	0.40	0.41

The statistics in table 5.2 show that the transgressive and regressive contacts cannot be assumed horizontal and therefore adequately represented by the mean of the variates (cf. Tooley 1978a). Both R and T show differences for the mean and standard deviations of data sets 1 and 2. The effect is greater for T.

A least-squares linear regression was then applied to the 3 data sets for the variables given in table 5.3. For 5 of the 8 pairs of variables tested the correlation

TABLE 5.3 : Some linear regression statistics, Bourne Fen stratigraphic data

B = Base of Flandrian sequence
R = Regression contact
T = Transgression contact
} altitude in m.OD.

P = thickness of lower peat
D = distance from BF16
} metres

data set		linear regression equation	r	r^2
R.B	1	$R = 1.32 + 0.21B$	0.74	0.55
	2	$R = 1.30 + 0.22B$	0.86	0.74
	3	$R = 1.31 + 0.22B$	0.87	0.76
R.P	1	$R = 1.54 - 0.21P$	-0.62	0.38
	2	$R = 1.55 - 0.26P$	-0.68	0.46
	3	$R = 1.57 - 0.27P$	-0.70	0.49
B.D	1	$B = 5.81 - 0.008D$	-0.93	0.86
	2	$B = 1.00 - 0.0018D$	-0.87	0.75
	3	$B = 0.99 - 0.0018D$	-0.87	0.75
P.D	1	$P = -3.34 + 0.0061D$	0.87	0.75
	2	$P = 0.59 + 0.00091D$	0.67	0.45
	3	$P = 0.61 + 0.00091D$	0.67	0.45
R.D	1	$R = 2.50 - 0.0016D$	-0.68	0.46
	2	$R = 1.57 - 0.00045D$	-0.87	0.76
	3	$R = 1.58 - 0.00045D$	-0.88	0.78
T.D	1	$T = 2.32 - 0.00168D$	-0.68	0.46
	2	$T = 1.62 - 0.00087D$	-0.93	0.86
	3	$T = 1.63 - 0.00087D$	-0.93	0.87
T.B.	1	$T = 1.11 + 0.22B$	0.79	0.62
	2	$T = 1.08 + 0.38B$	0.85	0.71
	3	$T = 1.09 + 0.39B$	0.85	0.73

coefficient for set 2 was greater than that for set 1. The opposite was true for the relationships between the variables P,B and D. This may illustrate the effect of a regional phenomenon, the transgression which laid down the inorganic deposit superimposed over a locally undulating pre-Flandrian surface. Therefore as set 1 covers a sample where the boulder clay surface decreases in altitude with distance from the fen edge and sets 2 and 3 include those boreholes revealing undulations it may have been anticipated that the highest correlation coefficients would have been found with set 1 for BV.D and Pv.D. Unfortunately there are insufficient observations available to make detailed inferences about the relationships. It is only possible to comment on general trends and the discussion of these analyses in chapter 6 must be considered in this context.

The most significant feature of table 5.3 is the high correlation coefficient of all of the regression equations for variables paired with D, the distance from BF16. This is represented in fig. 5.7 which is drawn from the following relationships:

$B = 0.99 - 0.0018D \quad r = -0.87$

$R = 1.58 - 0.00045D \quad r = -0.88$

$T = 1.63 - 0.00087D \quad r = -0.93$

The slope of the regressive contact along the length of the section is given as 0.45 m/km. and the slope of the transgressive contact as 0.87m/km. The solution of the equation for the limit of marine sedimentation, when T = R, is +1.52 m.OD, which is the maximum level recorded in

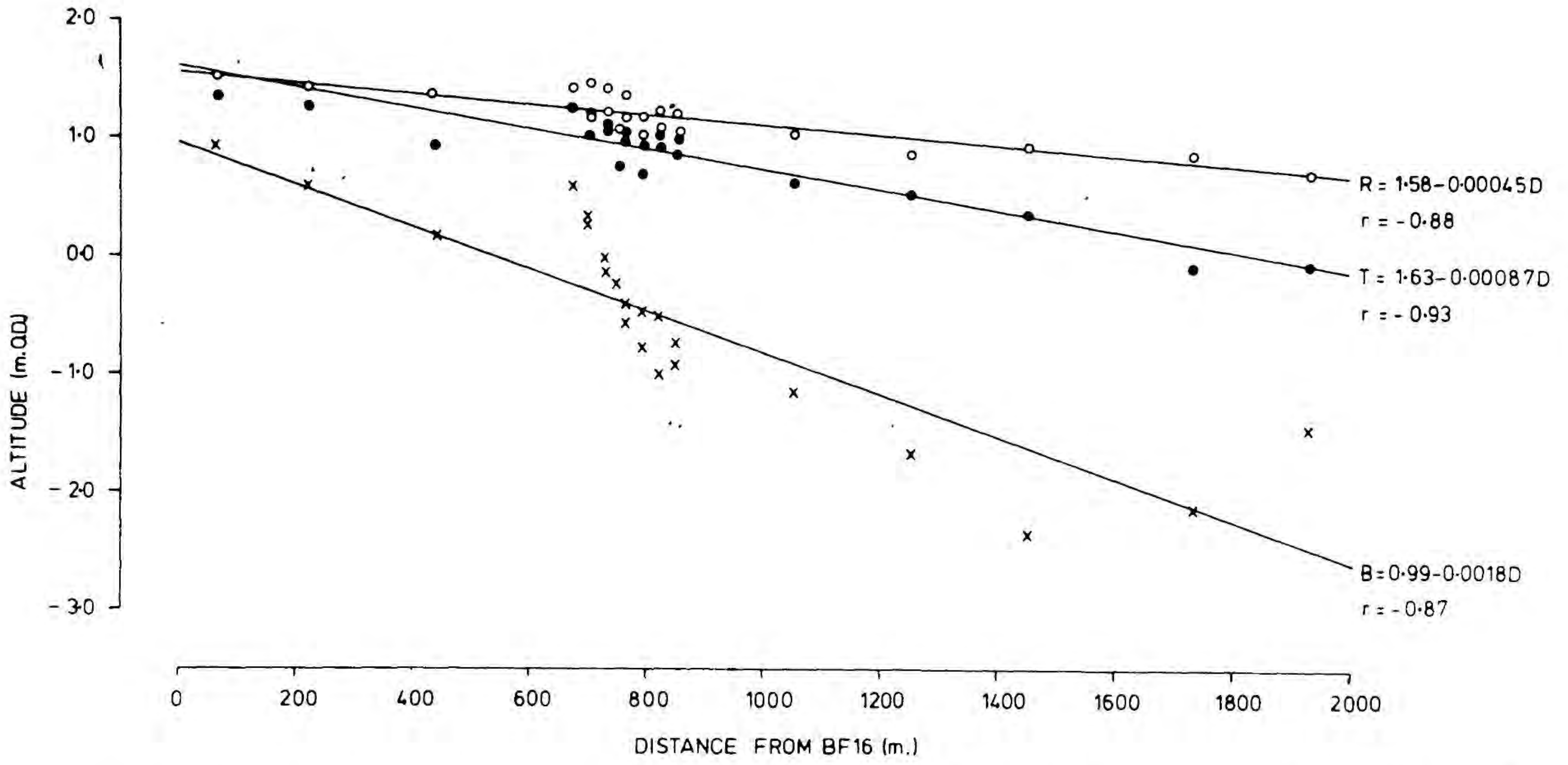


Figure 5.7 ;Regression lines for the regressive (R) and transgressive (T) overlaps and the base of the Flandrian sequence (B) in Bourne Fen.

Bourne Fen for the regressive contact (BF15). These are more useful figures to describe the variation in altitude of the transgressive/regressive sequence rather than the means of R and T which are difficult to interpret, given as +1.19 m.OD ± 0.22 m. and 0.88 m.OD ± 0.41 m. respectively in table 5.2.

The other relationships in table 5.3 are more difficult to interpret and certainly more data are needed.

The surface peat was found in each borehole except at BF2 and BF12 but due to surface wastage its thickness is very variable. The overburden at BF10 reduced such wastage and the thickest interval, 1.40 m., was recorded, while at BF8 and BF9 only a very crumbly humified black peat less than 10 cm. thick remained. At BF2 and BF12 the surface peat and the clastic horizon had both been removed and backfilled during some early excavation work.

The humification of the upper peat depended greatly on the depth from the surface and modern rootlets often penetrated down to the lower boundary. The peat is characteristically a monocot. peat with Phragmites, horizontally bedded and penetrating the Turfa, abundant in its lower layers. Occasionally wood remains have been found in borings and exposed in the dyke sections.

In conclusion, the stratigraphy of Bourne Fen is now well established. There is a general thickening of Flandrian deposits eastwards above an undulating boulder clay surface. The inorganic layer is seen to thicken in a general seaward direction with a slope of 0.45 m/km.

for the regressive contact. The highest altitude measured for marine/brackish sediments is +1.52 m.OD.

Section 5.2.2 : Bourne Fen-10.

Bourne Fen-10 (BF10) was chosen for pollen analysis in an attempt to provide a regional pollen diagram since it exhibited a thick, relatively unhumified, upper peat, a thin inorganic layer, and a typical lower organic sequence of monocot. gyttja above a woody detrital gyttja. In a stratigraphic sense it was typical of the whole Bourne Fen section. It is situated immediately north of the Bourne Eau, between the watercourse itself and its elevated northern bank, thus the ground level is some 1.4 m. higher than the adjacent boreholes. The material of the banks of the Bourne Eau has been brought in from outside the fen area in connection with drainage improvement schemes. However the older bank material is peat and therefore it was not known if the whole of the upper peat was in situ. It was hoped that pollen analysis would reveal any discontinuities since there was no apparent hiatus in the stratigraphy.

The stratigraphy of the core is given in fig. 5.8. The slightly organic silt at the surface was assumed to be of modern origin associated with bank improvement works. The whole of the core was below the present water-table.

In order to study the environmental changes at the site 24 samples were prepared for diatom analysis, 2 from

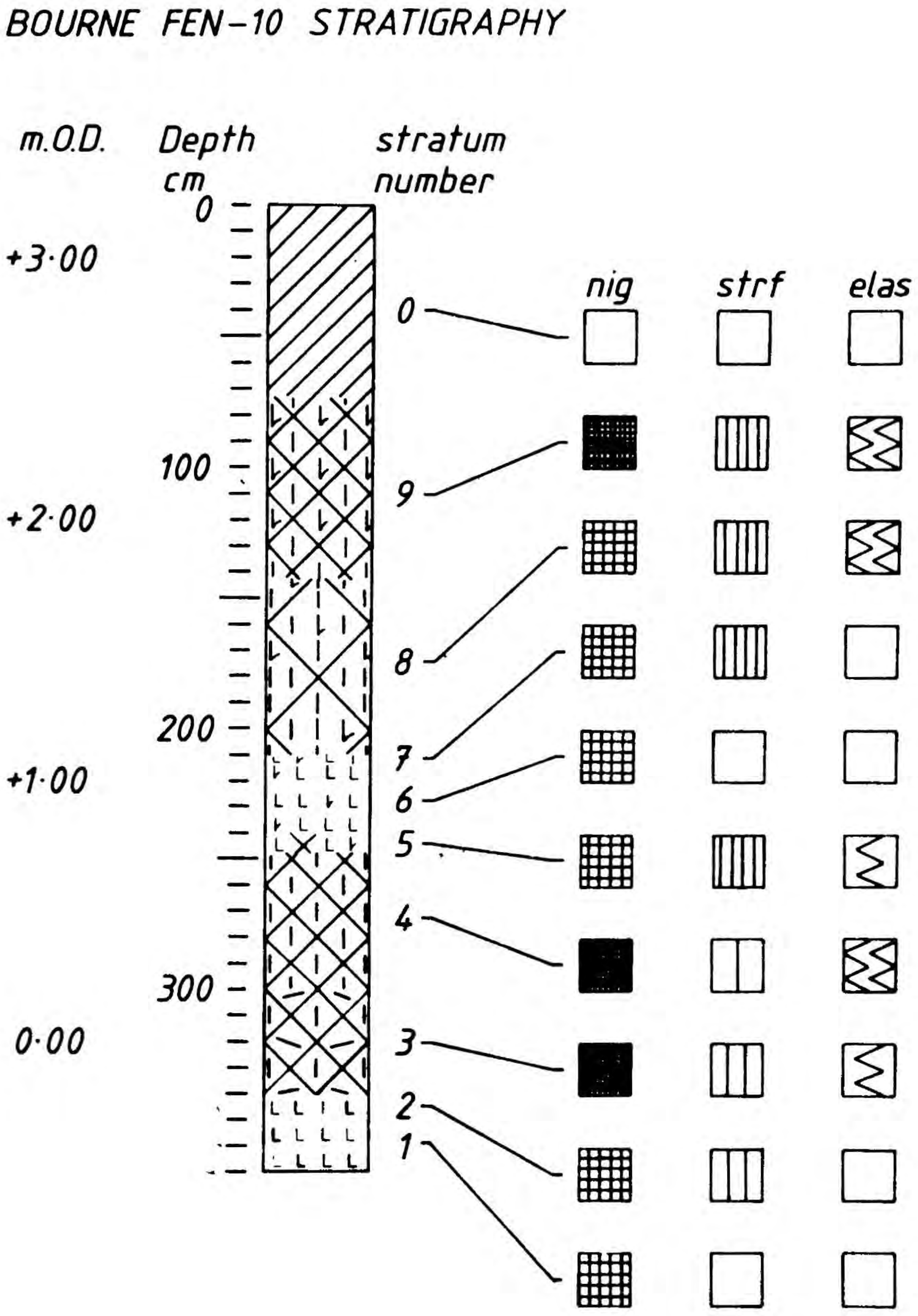


Figure 5.8 : Bourne Fen-10 stratigraphy

below the lowest peat and the rest between 246 and 204 cm., and 46 samples were prepared for pollen analysis, from 338 to 115 cm. (note depth from a datum line, the ground surface except for the 2 pits, is given in centimetres, while altitude, to Ordnance Datum, is in metres).

In the 24 diatom samples no diatoms were recorded.

The pollen analyses did not involve pollen concentration techniques and no samples were taken for ^{14}C dating. Only 23 of the 46 samples prepared yielded sufficient pollen to count. 7 samples from the clastic horizon, stratum 6 fig. 5.8, contained few pollen and of the few grains of arboreal taxa observed for those levels Quercus pollen always appeared dominant. The greatest frustration, however, was that pollen became too sparse to count above 195 cm. Samples were examined up to 115 cm., in which there was no pollen at all, while at 190 cm. a count of only 14 tree pollen, most of which were corroded, yielded 600 Filicales spores. Therefore it is not possible to say if the thick upper peat is in situ above 190 cm.

As a result of poor pollen preservation the pollen diagrams from BF10 consist of 23 levels from the lower peat and only 3 from the upper. It was not intended to study the detailed changes associated with clastic sedimentation and therefore the sampling interval was constant at 5 cm., except for the basal layer. The pollen data are presented in figs. 5.9, 5.10, 5.11, table 5.4 and the pollen counts are given in appendix IV. The herbaceous taxa which occur in low frequencies are grouped as described in chapter 4 and the pollen of aquatic taxa and spores of bryophytes

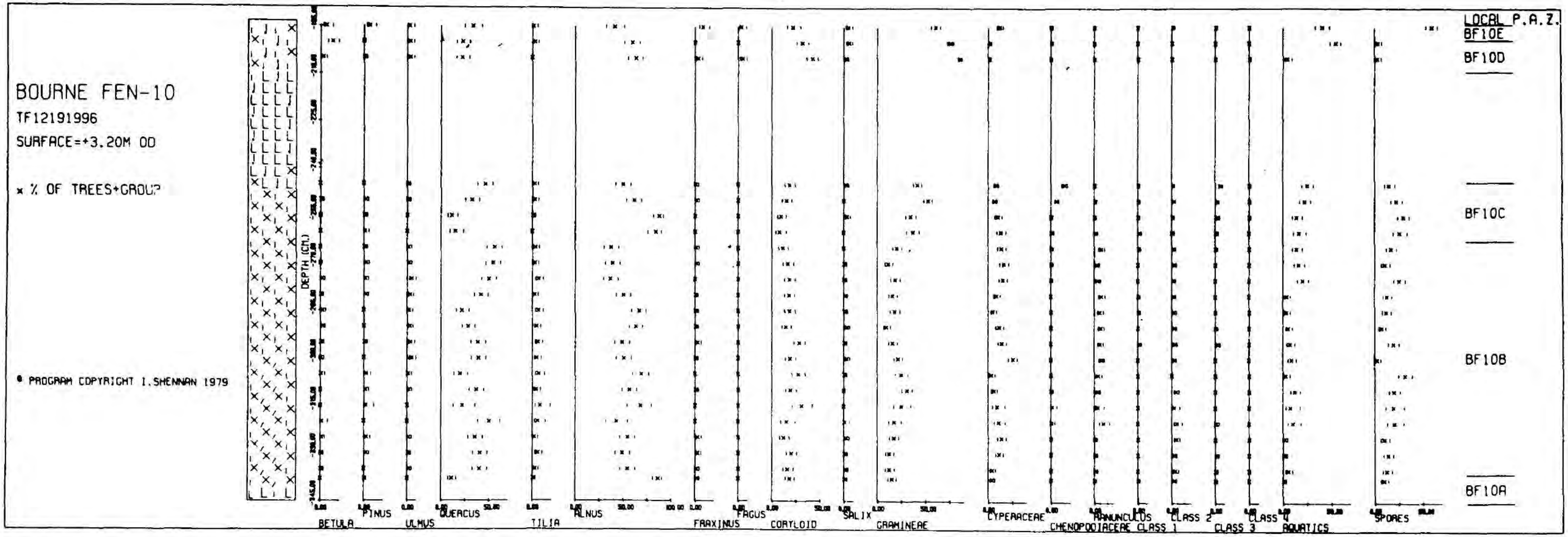


Figure 5.9 : BF10 %Trees+Group pollen diagram. The calculated 95% confidence limits are shown.

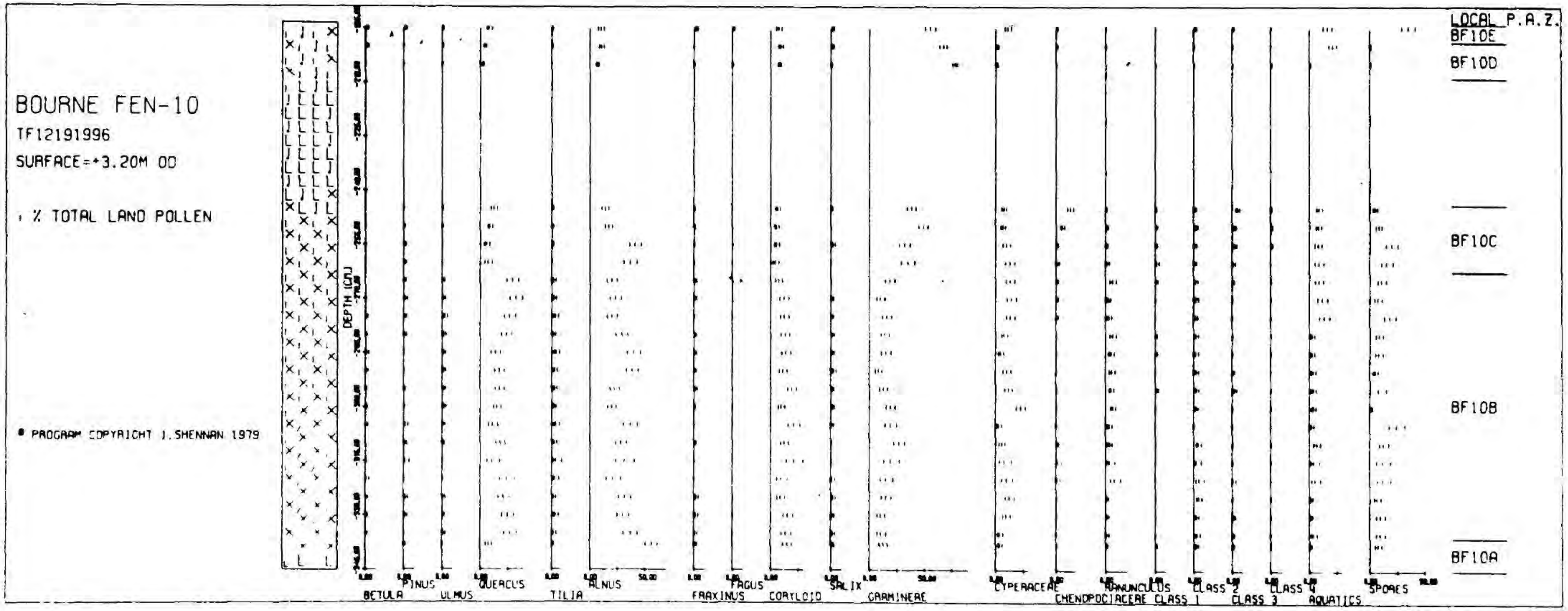


Figure 5.10 BF10 %Total Land Pollen diagram

BOURNE FEN-10 SUMMARY DIAGRAM

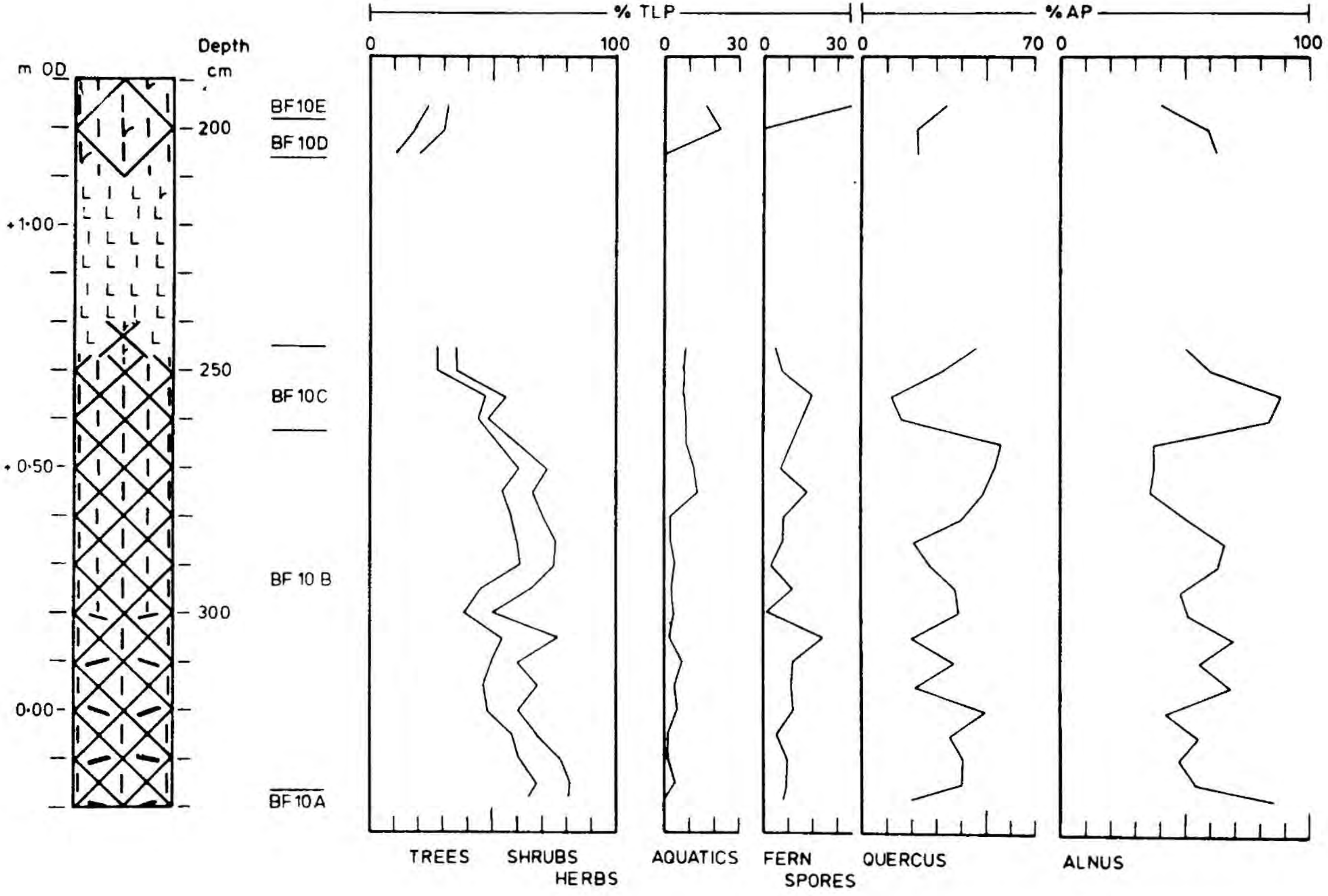


Figure 5.11: BF10 summary pollen diagram

and pteridophytes form 2 other groups. These latter 2 groups are presented in fig. 5.9 as calculated within the pollen sum (%AP + Group) while the pollen sum in fig.5.10 is Total Land Pollen and aquatics and spores are calculated outside the sum. These conventions are retained for all of the pollen diagrams unless stated otherwise. The classes used for grouping taxa in BF10 are given in table 5.4, with the number of levels in which each occurs and its maximum frequency, (%AP + Group).

BF10 is divided into 5 Local Pollen Assemblage Zones (LPAZ), zoned without reference to any other diagrams.

LPAZ	Depth	Characteristics
BF10A	338 cm.	The zone consists of one level, dominated by *Alnus*, 86% AP, 56% TLP, with correspondingly low *Quercus* frequencies. The upper boundary is defined by the non-overlapping confidence bands for both *Alnus* and *Quercus* as %AP and %TLP. Other pollen frequencies show no significant difference with the overlying zone.
BF10B	335 to 265 cm	*Alnus* and *Quercus* dominate the arboreal taxa, although *Tilia* is consistently above 3% AP, their inverse relationship reflects the calculation as % AP (fig. 5.11). *Alnus* shows more irregular changes between adjacent levels as % TLP (fig. 5.10). Gramineae, Cyperaceae,

Coryloid and aquatic pollen and spores of bryophytes and pteridophytes are important contributors to the pollen spectra. Towards the end of the zone aquatics increase to c.10% TLP and the upper boundary is defined by a significant fall in Quercus frequencies (%AP and %TLP), a rise in Alnus, complementary to the fall in Quercus as %AP but also evident as %TLP, and by a significant rise in Gramineae (%AP + Herbs and %TLP) which is also reflected in the summary, fig. 5.11,as non arboreal pollen dominates the spectra.

BF10C 260 to 245 cm. The diagnostic feature of this zone is the rise to dominance, 49% TLP, of Gramineae with a corresponding rise of Chenopodiaceae pollen to 13% TLP and a fall of Alnus, 41% to 14% TLP. Class 3 and 4 herbaceous pollen rise throughout this zone. The rise of Quercus as %AP + Group is a consequence of the relative fall of Alnus since fig.5.10, shows Quercus as %TLP to show consistently lower frequencies than in BF10B. The upper boundary is defined by lithostratigraphy, pollen was too sparse to count in the clastic layer above.

BF10D 205 to 200 cm. Gramineae pollen dominates this zone, 78% TLP. Alnus dominates the arboreal sum and Coryloid pollen reaches a peak as %AP + Group, although this does not show as % TLP due to the dominance of Gramineae. Betula reaches its maximum as 12% AP. The lower boundary is lithologic, the lowest countable layer above the clay/silts, and the upper boundary is defined by significant falls in the Gramineae curve (both %TLP and %AP + Herbs). Alnus (%AP) also shows a significant decline and spores, particularly Filicales, show a large increase.

BF10E 195 cm. Gramineae still dominates the spectrum, 55% TLP, but the zone is characterised by the presense of all of the arboreal taxa including Pinus, Fraxinus and Fagus. Filicales show a maximum, 57% AP + spores, and Cyperaceae, 11%TLP, and aquatic taxa are present.

No samples were taken for ^{14}C dating but the pollen diagram, fig. 5.9 clearly shows the whole succession to have low frequencies of Ulmus pollen and therefore an age younger than 5000 BP is assumed for the whole sequence. The environmental changes reflected by the pollen diagrams are discussed and compared to other sites, from Bourne

TABLE 5.4 : BF10 herbaceous, aquatic and spore classes (23 levels)

Class 1	Droseraceae	2:0.4%	*Rumex*-type	2:0.5%
	Taraxacum-type	7:1.5%	*Urtica*	4:1.3%
Class 2	*Caltha*	15:2.1%	*Cladium*	16:3.9%
	Filipendula	15:2.0%	*Mentha*	2:0.5%
	Succisa	4:0.6%		
Class 3	*Artemisia*	4:0.6%	*Cirsium*-type	5:3.1%
	Polygonum	2:0.5%	*Senecio*-type	1:1.8%
	Umbelliferae	4:2.2%		
Class 4	*Plantago maritima*	4:0.6%		
Aquatics	*Hydrocotyle*	1:0.3%	*Lemna*	13:12.4%
	Nuphar	3:6.3%	*Nymphaea*	9:3.6%
	Potamogeton	18:14.1%	*Typha angustifolia*-type	7:30.5%
	T.latifolia	13:18.o%		
Spores	*Equisetum*	3:3.2%	Filicales	23:57.0%
	Polypodium	16:11.8%	*Pteridium*	4:1.0%
	Sphagnum	2:166%		

Fen and more distant locations, in chapter 6.

Section 5.2.3 : Bourne Fen-P1.

Bourne Fen-P1 (BFP1) was an open face excavation, 2.5 x 1.0 x 1.4 m. deep, dug on the strip of grassland immediately north of the banks of the Bourne Eau, approximately 100 m. east of BF10. The aim was to study the lateral changes in the stratigraphy and to provide adequate material for ^{14}C analyses.

The pit was aligned in an east-west direction, the northern and western sections were carefully prepared for detailed stratigraphic analysis according to Troels-Smith (1955) and are presented in fig. 5.12. Two overlapping 50 cm. monolith samples were taken from the western end section for further laboratory analysis.

The sequence recorded is typical of the Bourne Fen section (fig.5.6). The woody detrital peat was only exposed in the end section since it was waterlogged below that level. A core was made through the base of the pit to measure the thickness of the basal peat. A silty sand with gravel was reached 1.40 m. below the top of the woody detrital peat.

Due to the level of the water-table the lowest stratum exposed along the whole section was a relatively uncompacted (elas.2) monocot. peat. Seeds were noted throughout the layer but have not been identified. The upper boundary was a thin, less than 2 cm, transition layer to a blue sticky silty clay with roots and stems of Phragmites and other Gramineae. The regressive transition layer, stratum 4,

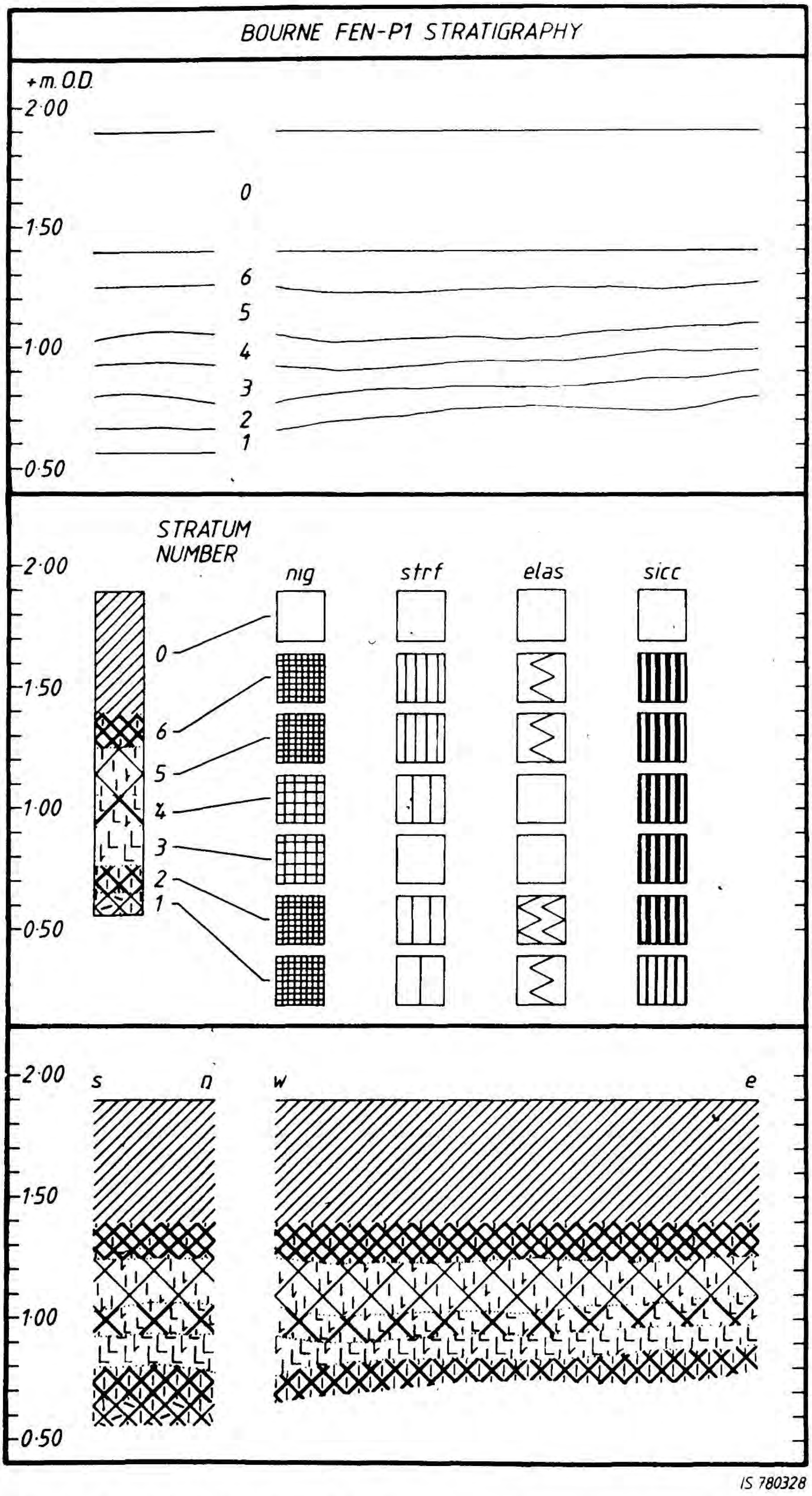


Figure 5.12 Bourne Fen-P1 stratigraphy. The monolith samples for laboratory analysis were taken from the southern side of the west face (below 'S')

was generally as thick as the blue inorganic layer itself, but was less homogeneous than stratum 3, with inclusions of higher organic content, particularly Phragmites, and yellow/brown concretions around some of the root channels.

Layers 5 and 6 were stratified biogenic sediments up to the present soil horizons (stratum confusum). The division was on the basis of humification and macrofossil content. Stratum 6 was very humified with a few modern rootlets at the upper contact and occasional elements of Detritus lignosus. Stratum 5 was a less humified monocot. peat, rich in macrofossil remains of Phragmites, grasses, and sedges, probably Cladium. The microscopic remains accounted for a greater proportion of the deposit in stratum 6, c.75%, than in stratum 5, c.25%. These layers were quite compacted compared to stratum 2, a possible reflection of seasonal changes in watertable.

The pit section revealed that the sequence of sediments only previously recorded by borehole analyses was quite homogenous over the area exposed, 2.5 x 1.4 m. The most variable feature of the peat horizons was the level at which macrofossil wood remains could be found. The transitions to the clastic horizon were uniformly gradual although the altitude was variable. This variation of the transgressive and regressive contacts proved to be the most interesting feature of the excavation.

The transgressive contact, represented by a 2 cm. transition layer, varied in altitude between +0.90-0.88 m.OD.

(50-52 cm.) at the eastern end of the face, to +0.77-0.75m. OD (63-65 cm.) at the western end section from where the monolith sample was taken. The regressive contact was more difficult to define. The stratum 3/4 boundary represents an increase in organic content while the stratum 4/5 boundary is the highest limit of inorganic sedimentation. This latter boundary is taken as the regressive contact and was recorded between +1.10 m.OD (30 cm.) and +1.02 m. OD (38 cm.).

Over the section exposed, 2.5 m., the transgressive contact showed an absolute variation of 13 cm. with an 8 cm. range for the regressive contact. Both of these values are less than the standard deviations calculated for the 13 boreholes, set 1 data, which covered an area 180 x 30 m. (Table 5.2). It appears that scale factors are an important consideration in the altitudinal variation of stratigraphic boundaries. A regional eastward slope of the transgressive and regressive contacts has been measured yet the section in BFP1 shows undulating boundaries with an overall slope to the west.

Ten samples, at 2 cm. intervals between 48 and 66 cm. were prepared for diatom analysis. Each slide was scanned carefully over 15 traverses of the slide, covering approximately 75% of an 11 x 11 mm. coverslip, but no level contained sufficient diatoms to count. Many broken valves were seen but the only whole specimens encountered within the 10 samples were Diploneis didyma, Campylodiscus echeneis, Cocconeis placentula and

Navicula lyra.

Pollen analysis was carried out on 22 samples between 80 and 5 cm. using pollen concentration techniques (Stockmarr 1971). As was the case in BF10 the higher peat levels contained too few pollen to count. The samples 5-25 cm. contained only Filicales spores and exotic *Lycopodium* spores. Therefore the pollen diagrams from BFP1, figs. 5.13, 5.14, 5.15, 5.16, cover the section 30-80 cm. from the monoliths. The counts are given in appendix IV and the cumulative herbaceous, aquatic and fern spore classes are shown in table 5.5, giving the number of levels, maximum of 17, and maximum frequency, as %AP + Group, for each pollen type.

BFP1 is divided into 5LPAZs based primarily on the %AP + Group and %TLP diagrams, and secondly on the concentration diagram (fig.5.15).

LPAZ	Depth	Characteristics
BFP1A	80 to 75 cm.	*Tilia* frequencies, <10%AP, are higher than in the rest of the diagram. *Quercus* is at a temporary maximum, *c*.20%AP, while *Alnus* is lower than in BFP1B. However *Quercus* is more constant as %TLP. A high Filicales peak at 80 cm. is replaced by an isolated *Sphagnum* maximum at 75 cm. Gramineae, at consistently high frequencies throughout the diagram, and Cyperaceae show frequencies <20%TLP. The upper boundary of the zone is defined by significant changes

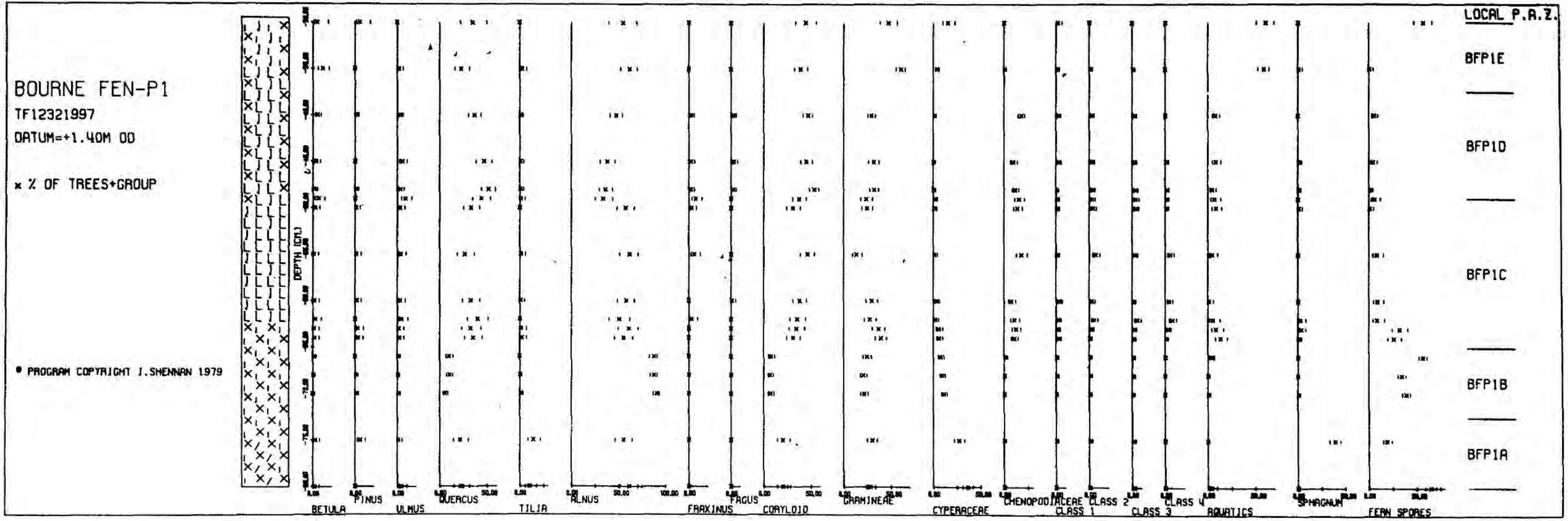


Figure 5.13 : BFP1 %Trees+Group pollen diagram. The results of 5 radiocarbon assays are shown in fig. 5.16.

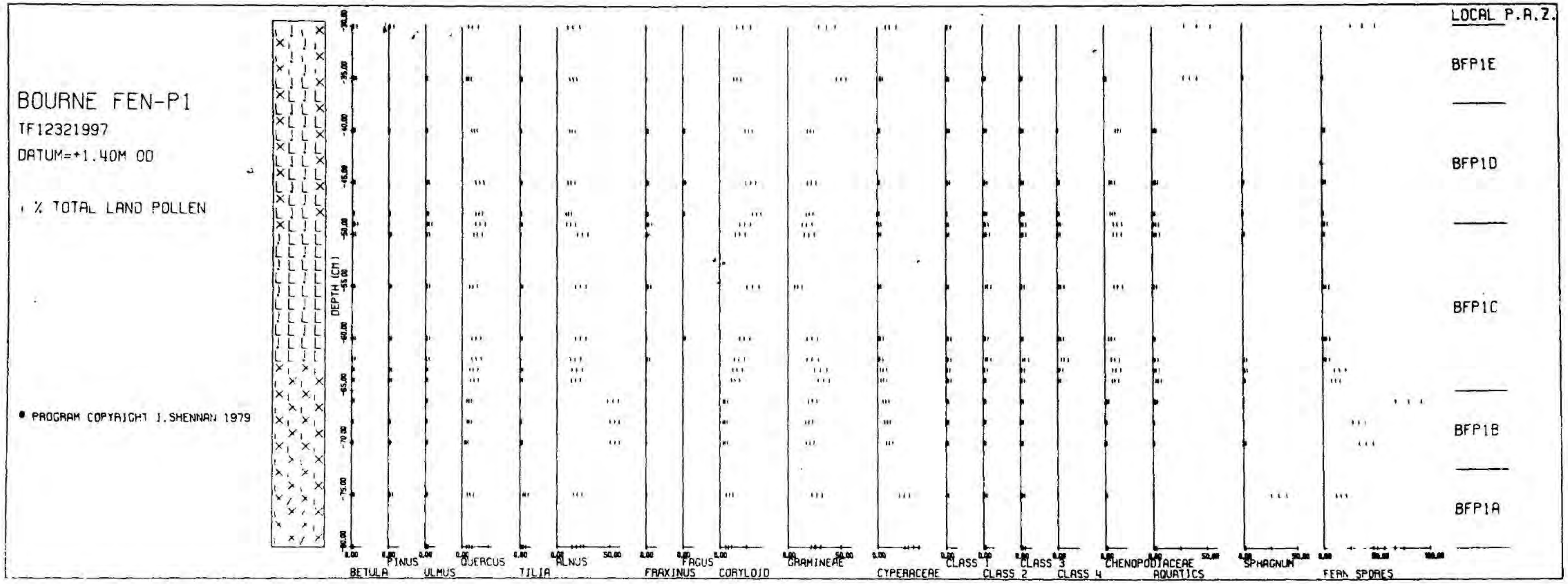


Figure 5.14 : BFP1 %Total Land Pollen diagram. The results of 5 radiocarbon assays are shown in fig. 5.16.

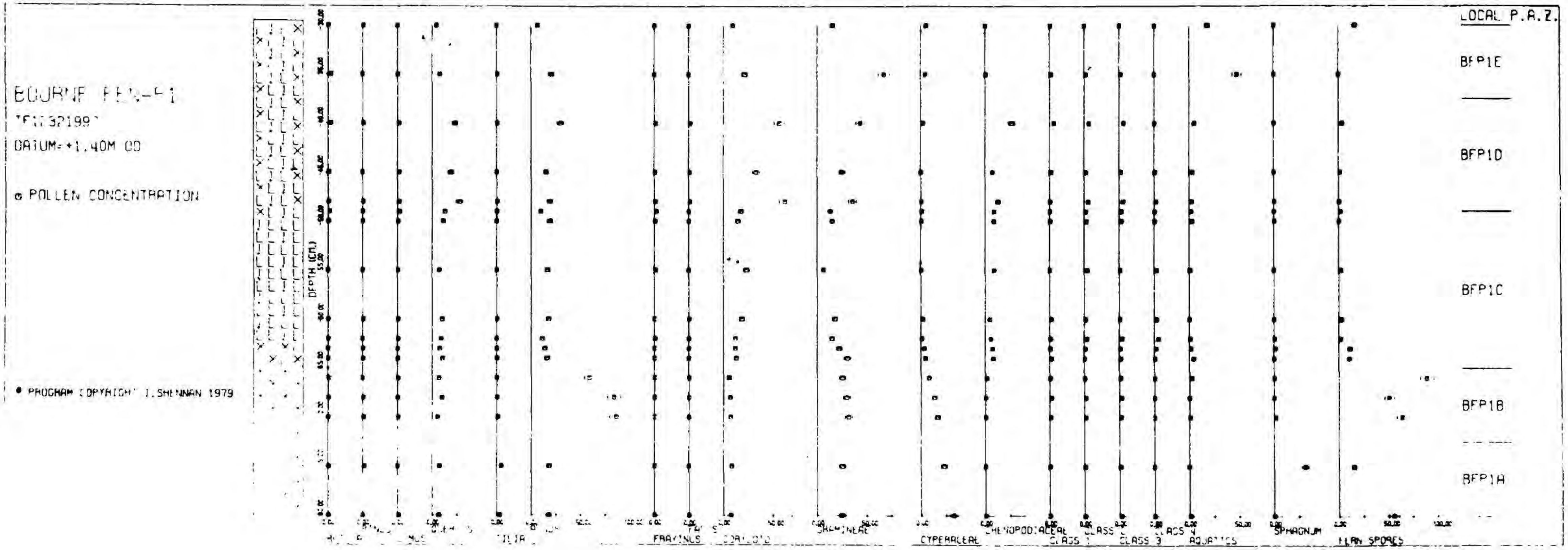


Figure 5.15 BFP1 Pollen Concentration (grains x 1000/cc) diagram. The results of 5 radiocarbon assays are shown in fig. 5.16.

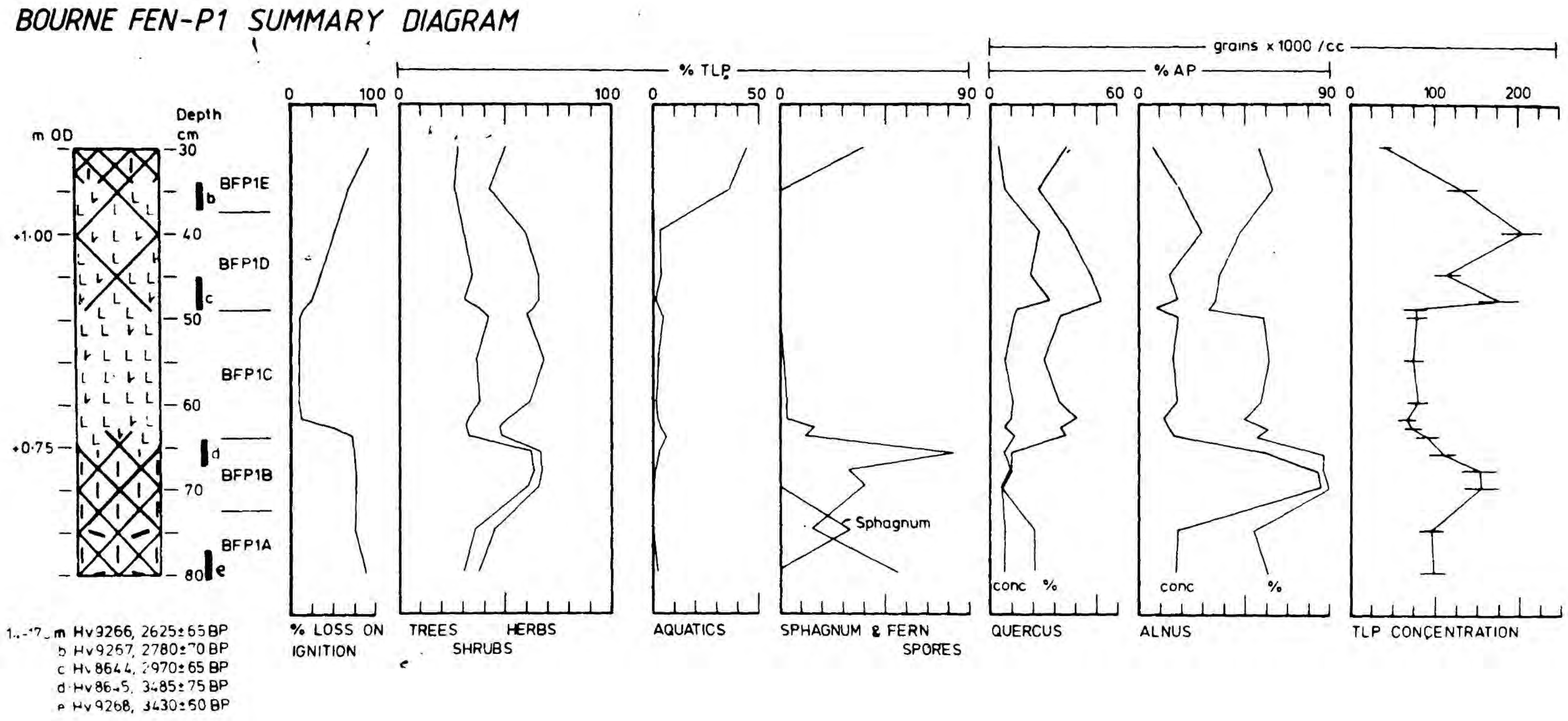


Figure 5.16 : BFP1 summary diagram.

in the %AP + Herbs curves for Quercus, Tilia, Alnus, and Cyperaceae.

BFP1B 70 to 66 cm. This zone is dominated by very high Alnus frequencies and concentrations : 91%AP, 53% TLP, 86 x 10^3 grains/cc. This shows corresponding minima for other curves as %AP + Group and %TLP, except for Filicales. The concentration curves show the increases for Filicales and Alnus while Quercus and Gramineae show similar concentrations as in BFP1. Cyperaceae curves fall in all three diagrams. The upper boundary is defined by significant falls in the Alnus and Filicales curves and increases in the Coryloid, Chenopodiaceae and Class 4 herbs.

BFP1C 64 to 49 cm. Quercus and Alnus fluctuate around 35%AP, 12% TLP, and 60%AP, 20%TLP, respectively. Coryloid frequencies rise to 35% AP + shrubs. Gramineae drops to 9%TLP in the middle of the zone but is an important constituent of the spectra at the top and bottom of the zone. Chenopodiaceae and salt marsh taxa are characteristic of this zone, up to 11% and 6% TLP respectively. TLP concentration is constant throughout the zone, 75 x 10^3 grains/cc and the rise to 170 x 10^3 grains/cc defines the boundary since many changes occur in the zone

50-48 cm : Alnus decreases, Quercus and Coryloid increase (%AP + Herbs) while salt marsh herbs start to decline.

BFP1D 48 to 40 cm. This zone is very similar to BFP1C except that pollen concentration is generally higher and more variable. Class 4, salt marsh, herbs are lower than in BFP1C and disappear by the end of the zone. After fluctuations at the boundary tree and shrub frequencies are similar to those in BFPIC. Fagus is present throughout the zone. The upper boundary is defined by a significant rise in the Gramineae and aquatic pollen and the disappearance of the Chenopodiaceae.

BFP1E 35 to 30 cm. Rising Gramineae, Cyperaceae, aquatics and Filicales curves characterise this zone. Pinus and Betula show low maxima, otherwise Alnus and Quercus are once more the major components of the tree pollen. Pollen concentrations fall at 30 cm. as pollen preservation becomes poor. Percentages may be more dominated by pollen preservation factors than usual.

The pollen diagrams from BFP1 are approximately equivalent to the BF10 diagrams from 265 to 195 cm. A more exact lithostratigraphic or biostratigraphic correlatinn is neither possible or desirable at this stage. It is sufficient to say

TABLE 5.5 : BFP1 herbaceous, aquatic and spore classes (17 levels)

Class 1	*Centaurea*	2:1.1%	*Cerealia*	2:0.4%
	Gentianella	3:1.4%	*Plantago lanceolata*	9:1.6%
	P.major/media	1:0.9%	Rosaceae	1:0.3%
	Rumex	5:1.1%	*Sanguisorba*	6:0.9%
	Taraxacum-type	4:0.7%	*Urtica*	1:0.6%
	Valeriana	1:0.4%	*Valerianella*	1:0.4%
Class 2	*Caltha*	4:1.7%	*Cladium*	2:0.7%
	Filipendula	10:1.6%	*Gentiana*	1:0.6%
	Ranunculus-type	14:3.2%	Rubiaceae	5:0.5%
	Succisa	12:2.3%	*Veronica*	2:0.8%
Class 3	*Artemisia*	11:1.9%	Caryophyllaceae	1:0.8%
	Cirsium-type	5:0.7%	Cruciferae	2:1.0%
	Matricaria-type	7:1.0%	*Polygonum*	13:3.7%
	Senecio-type	3:1.0%	*Triglochin*	3:0.5%
	Umbelliferae	3:0.5%		
Class 4	*Armeria*	5:2.1%	*Limonium*	2:0.5%
	Plantago maritima	9:4.3%		
Aquatics	*Hydrocotyle*	6:2.2%	*Lemna*	8:55.4%
	Myriophyllum vert.	1:1.1%	*Nuphar*	1:1.8%
	Nymphaea	1:1.0%	*Potamogeton*	6:7.9%
	Typha angustifolia	12:56.9%	*T.latifolia*	2:1.8%
Fern spores	Filicales	17:64.5%	*Polypodium*	8:1.2%
	Pteridium	8:4.0%		

that the stratigraphy and pollen analyses show broad similarities, with local differences, between the two sites.

Five samples have been submitted for radiocarbon analysis and are given in tables 5.6 and 7.1

TABLE 5.6 Radiocarbon dates for BFP1

	depth	altitude	BP	material
Hv 9266	14-17	+1.26 to 1.23	2625±65	Ld^{2}1,Th^{2}1,Th^{2}(*Phra*)1
Hv 9267	34-37	+1.06 to 1.03	2780±70	Ld^{3}1,Th^{3}1,Th^{2}(*Phra*)1,Ag1
Hv 8644	45-49	+0.95 to 0.91	2970±65	Ld^{3}1,Th^{3}(*Phra*)1,Ag2
Hv 8645	64-67	+0.76 to 0.73	3485±75	Ld^{3}2,Th^{2}2
Hv 9268	77-81	+0.63 to 0.59	3430±60	Ld^{2}2,Th^{2}1,DL1

The three dates above the clastic deposits give a consistent age gradient. Hv8644 dates the onset of organic accumulation while Hv 9267 dates the end of inorganic sedimentation, since above 34 cm. no inorganic fraction was recorded. Hv 9266 was in the peat where no pollen was preserved. These dates suggest mean peat accumulation rates of 6.05 cm/100 yr followed by 13.9 cm./100 yr, although allowance for the standard errors of the ^{14}C dates makes the distinction less clear, with both sections overlapping at an accumulation rate of *c*.9 cm./100 yr. The two dates below the clastic deposits unfortunately show no age gradient. These two dates can be considered identical since there is considerable overlap of the standard errors. Such dating problems are not uncommon in closely spaced sequences in Fenland deposits (see Table 3.1 and Godwin and Willis 1961 for other examples).

However discussion of the problems of dating Fenland sequences and correlation between sites is undertaken in chapters 6, 7 and 8.

Section 5.2.4 : Bourne Fen-P2

Bourne Fen-P2 (BFP2) is 680 m. east of BFP1 (fig.5.5) and had approximately the same dimensions.

The stratigraphy, as recorded in the field, is shown in fig. 5.17. Two overlapping monolith samples were taken from the centre of the west-east face for laboratory analysis. The more seaward location of BFP2 meant that much more of the exposure consisted of silt and clay dominated sediments as the transgression deposits thicken seawards. It was not possible to expose the woody detrital peat since the section was waterlogged 1.5 m. below ground level. Therefore the exposure just revealed two layers of monocot. peat with abundant Phragmites, separated by a blue silty clay.

Stratum 1, fig. 5.17, was a well-stratified, relatively uncompacted monocot. peat with well-preserved roots and rhizomes of Phragmites, along which the deposit could be easily broken into layers. This was overlain by a thin transition layer, stratum 2, to the grey/blue silty clay. However, this layer revealed evidence of slight erosion in the east section of BFP2. A small flame of monocot. peat interfingering stratum 2, and a sharper contact between strata 1 and 2, suggested slight erosion during the transgressive episode. The slope of stratum 2 indicates that a cross-section of a small channel may have been exposed. A similar channel sequence was revealed in a cleaned dyke section 50 m. to the north of BFP2.

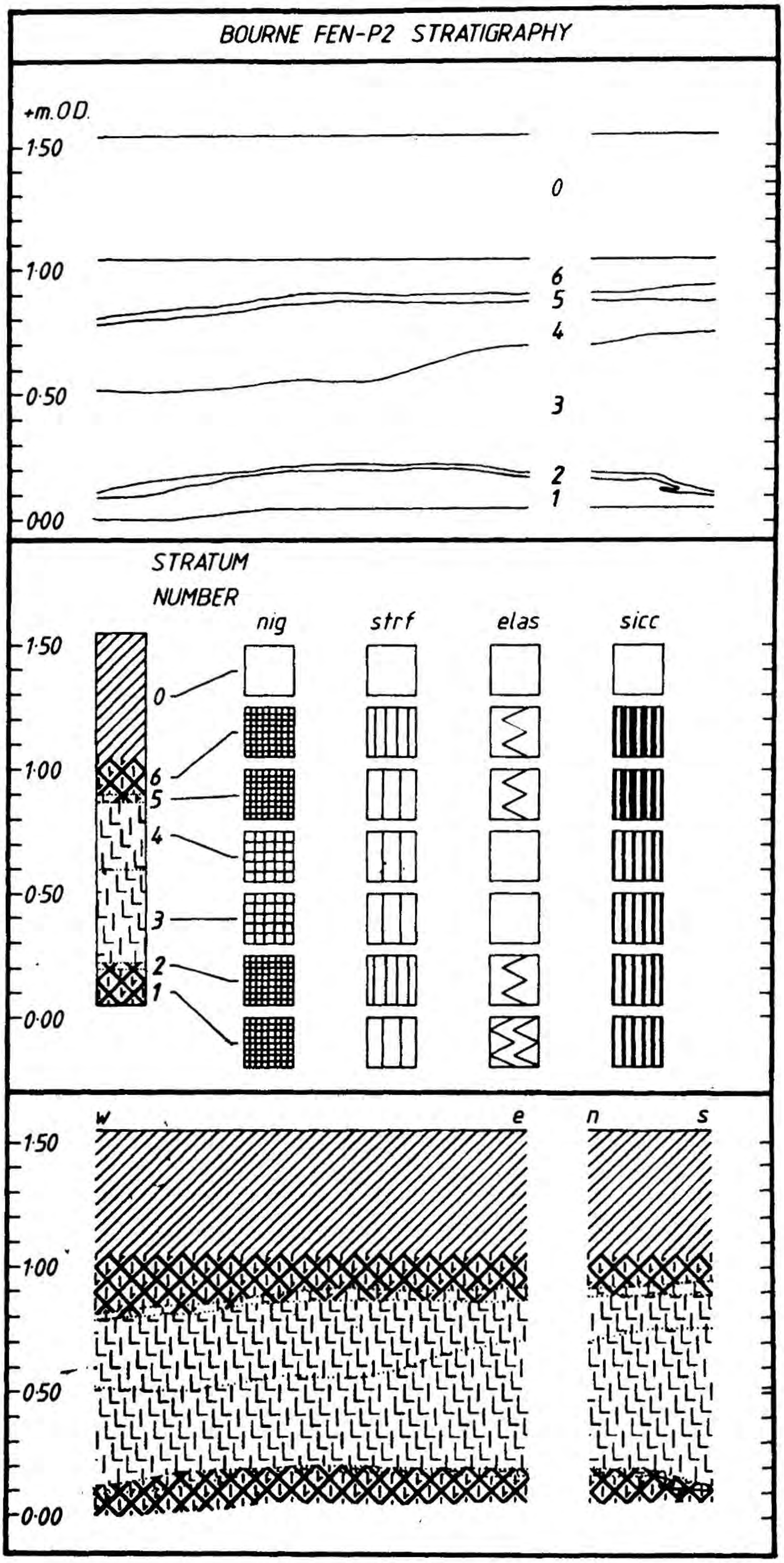


Figure 5.17 : Bourne Fen-P2 stratigraphy. The monolith samples for laboratory analysis were taken 50 cm. from the eastern end (e).

The clastic horizon can be divided into two. The upper division, stratum 4, was identified in the field as being slightly coarser, with a higher silt fraction. This was confirmed by particle size analysis in the laboratory. The strata 3/4 boundary had been recorded at 30 cm. Particle size analysis revealed an increase in the proportion of coarse silt from around c.10% below 30 cm. to c. 25% above (fig. 5.21). Root channels with a yellow powdery concretion (?sulphur components) became more frequent at the top of stratum 4. However these concretions were quite different to the ferric concretions observed in BF8, BF9 and BF19.

The upper peat horizon, stratum 6, was separated from the clastic facies by a much thinner transition zone than in BFP1. The transition was again a silty Phragmites gyttja, but never thicker than 3 cm. Yellow concretions were present around the Phragmites roots. The monocot. peat, stratum 6, was more compacted than stratum 1, and no woody detrital elements were recorded. The compacted nature of this layer and the yellow concretions around the root channels may be a result of water-level fluctuations following the general drainage of the fen.

The variation of the altitudinal limits of the inorganic sediments noted in BFP1 was also revealed in BFP2. Over the total section exposed in BFP2, 2.25 m. length, the transgressive contact, the strata 1/2 boundary, varied by a total of 11 cm, +0.20 to +0.09 m.OD (70 to 81 cm.), and the regressive contact, strata 5/6 boundary, by 13 cm, +0.81 to +0.94 m.OD (9 cm. below to +4 cm, above datum). These results are very similar to those from BFP1, 13 cm. and 8 cm. respectively.

Sixteen samples, at 10 cm. intervals between 5 and 65 cm. and less across the lithologic boundaries, were prepared for diatom analysis. No diatoms, nor fragments, were seen in the samples from 75, 70, 2, 0 and +5 cm. The samples from 3, 5, 10, 15, 68 and 69 contained broken valves but very few whole valves and therefore it was not possible to use those results in any quantitative manner. Five samples, 25-65 cm., contained sufficient numbers of diatoms to analyse. Though relatively rich in individuals (c.150 counted for each slide) the samples were poor in the number of species present. The total number of species counted for each level only varied between 8 and 11, of which between 5 and 8 were benthonic species. The diatoms identified are listed in appendix IV.

Considering the low number of species identified and the effect on confidence bands when small samples are used it seemed unrealistic to use a summary diagram based on the proportion of species in this case. However 4 methods of calculating the proportions of diatoms in each salinity class, using the classes of van der Werff (1958-74), were calculated; % valves, % benthonic valves, % species and % benthonic species. The results from these analyses are presented in fig. 5.21 but the last two are only discussed where significantly different classifications and relative changes are evident.

Only 3 species, all benthonic; Nitzschia navicularis, Diploneis didyma and Diploneis smithii, ever attain values in excess of 10% total valves. The % valves and % benthonic valves diagrams show the relative changes in the Marine, Brackish-Marine and Fresh-Brackish classes. The dominant change is an increase in marine influence represented by a change from dominance by N.navicularis, Brackish, to D.didyma and D.smithii, both Marine-Brackish. The species analysis gave greater weight to the low frequency types, one valve representing up to 13%. An increase of marine influence is suggested by 50% Marine species at 55 and 45 cm. However in this case, with low species totals, the consistent results of the %valves and %benthonic valves curves are preferred as an indicator of salinity changes.

The fact that all of the more frequent diatoms are benthonic forms, 69-93% total valves, the absence of freshwater species, the high numbers of broken valves, and the high clay content of the sediment (fig. 5.21), point to a rather low energy high tidal sedimentation area, with a strong brackish-marine influence rather than fresh-water input, and reached by the highest tides. It was not possible to study the reversal to the regressive contact due to poor diatom preservation. However, it should be noted that the levels with no diatoms are the organic transition layers and the monocot. peats while the levels with extreme numbers of diatom fragments are those with a high proportion of coarse silt, both at the transgressive contact and above 30 cm.

Pollen concentration techniques were applied to 25 samples between 84 cm. and +9 cm. (Note that the ' - ' has been omitted for depths below the pit datum, while '+' signifies above pit datum. This is the only site with values above the datum). All of the samples contained sufficient pollen to count and the data are given in appendix IV. The frequencies are shown in figs. 5.18, 5.19, 5.20 and 5.21 with the cumulative classes given in table 5.7.

In comparison with BF10 and BFP1, the BFP2 diagrams cover a longer period of clastic sedimentation and a relatively short period of semi-terrestrial conditions. This is evident in the zonation of the pollen diagrams, figs. 5.18 to 5.21 inclusive. The curves for the tree taxa, %AP, show a greater consistency than in BFP1 and BF10 which reflects a regional component of the pollen rain less susceptible to the changes in local fenwoods and alder carr at the more landward locations during the same time period. Therefore the local zonation of BFP2 is based on changes in the herbaceous and aquatic taxa, using the two percentage diagrams and the pollen concentration diagram to reflect the local and regional changes.

LPAZ	Depth	Characteristics
BFP2A	84 to 69 cm.	Arboreal pollen declines from 36% to 14% TLP, with *Quercus*, *Alnus*, and *Tilia* as %TLP falling throughout the zone, while Gramineae, Typha latifolia and Cyperaceae rise throughout. The upper limit of the zone is a transition

TABLE 5.7 : BFP2 herbaceous, aquatic and spore classes (25 levels)

Class 1	*Cerealia*	5:1.4%	*Malva*	1:0.2%
	Taraxacum-type	6:1.0%	*Plantago lanceolata*	3:0.4%
Class 2	*Caltha*	3:0.5%	*Cladium*	4:1.4%
	Filipendula	10.1.1%	*Ranunculus*-type	17:2.1%
	Rubiaceae	3:0.3%	*Succisa*	13:1.5%
	Umbelliferae	2:0.4:		
Class 3	*Artemisia*	13:5.2%	Caryophyllaceae	3:3.2%
	Cirsium-type	4:0.7%	Cruciferae	1:0.1%
	Polygonum	9:3.7%	*Senecio*-type	2:0.4%
Class 4	*Armeria*	6:14%	*Limonium*	4:3.4%
	Plantago coronopus	1:0.1%	*P.maritima*	6:4.3%
Aquatics	*Hydrocotyle*	5:5.7%	*Lemna*	11:13.2%
	Nuphar	9:10.0%	*Nymphaea*	1:2.8%
	Potamogeton	14:15.8%	*Typha angustifolia*	8:63.3%
	T.latifolia	13:35.4%		
Spores	*Equisetum*	2:3.7%	Filicales	23:73.8%
	Polypodium	9:5.9%	*Pteridium*	12:24.0%

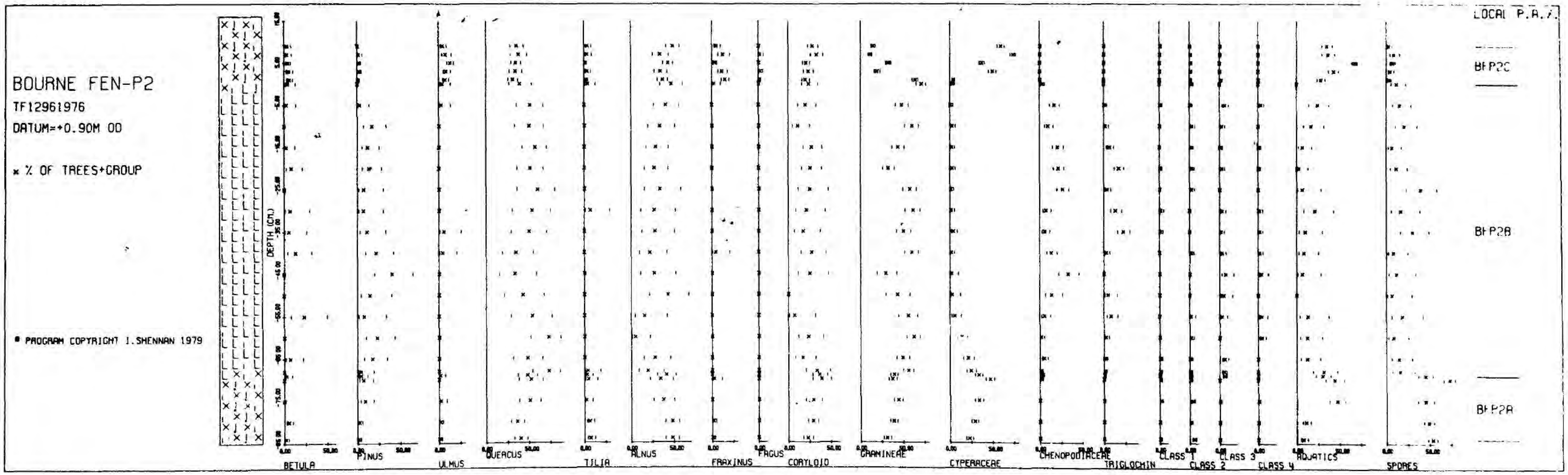


Figure 5.18 BFP2 %Trees & Group pollen diagram. The results of 5 radiocarbon assays are shown in fig. 5.21.

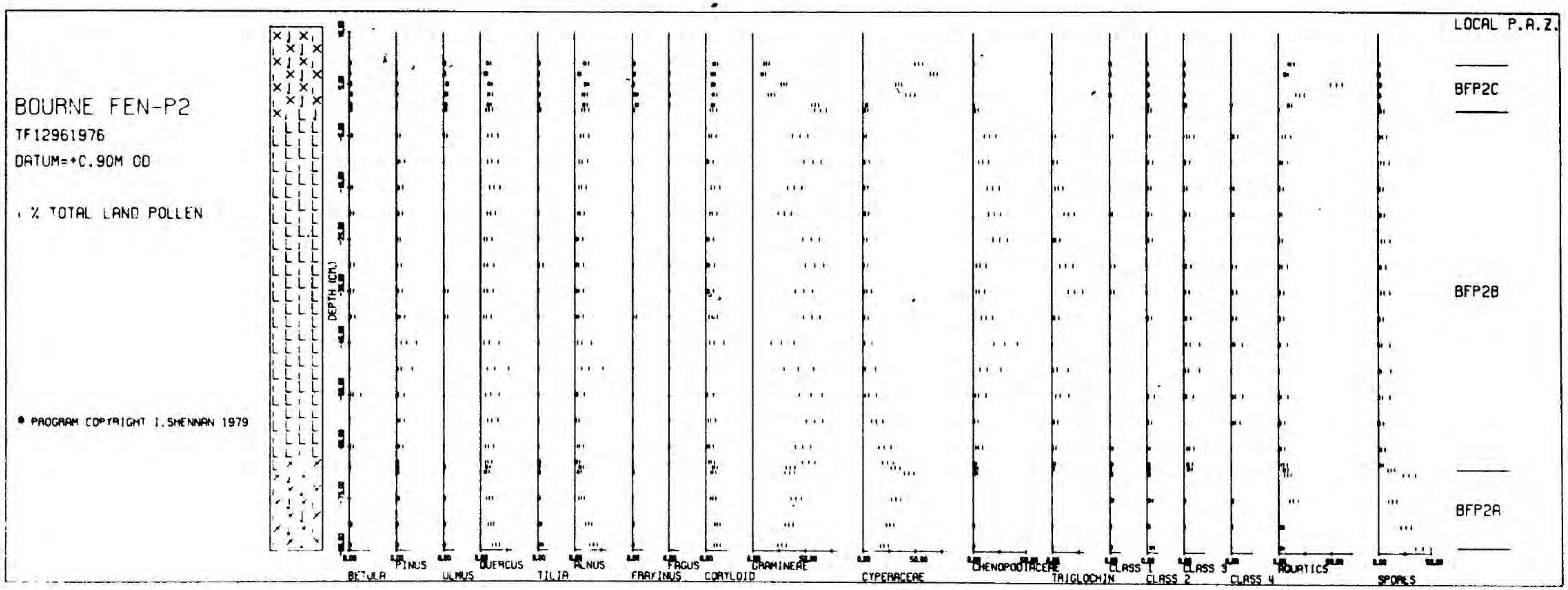


Figure 5.19 : BFP2 %Total Land Pollen diagram. The results of 5 radiocarbon assays are shown in fig. 5.20.

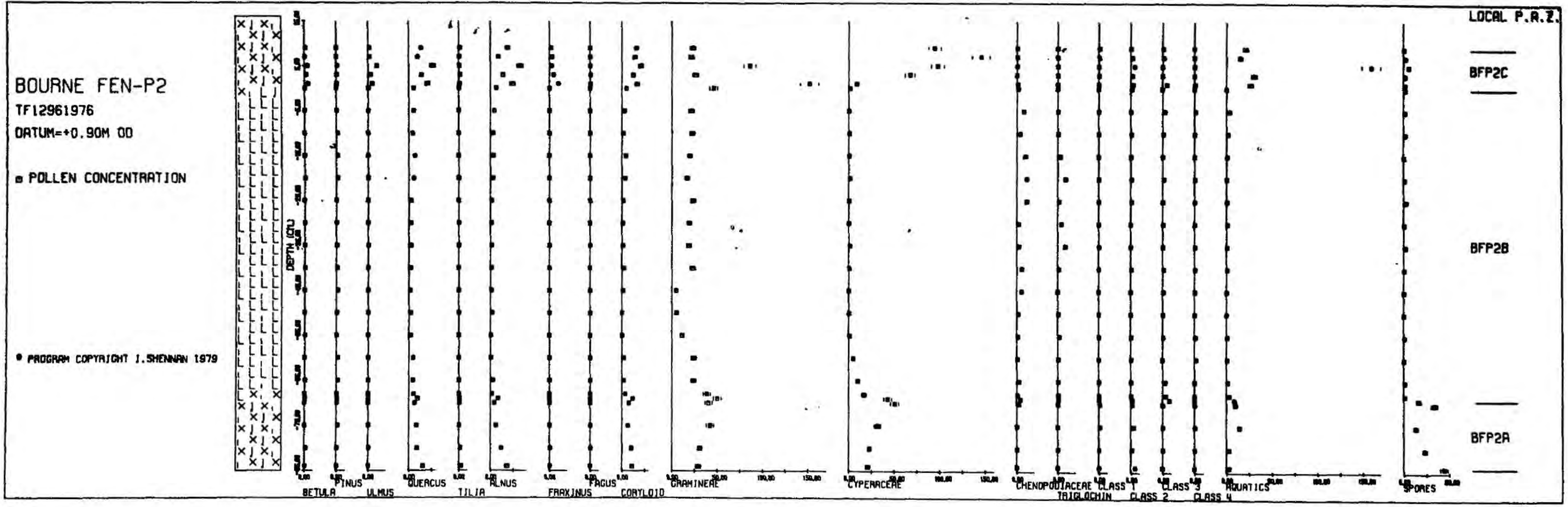


Figure 5.20: BFP2 Pollen Concentration (grains x 1000/cc) diagram. The results of 5 radiocarbon assays are shown in fig. 5.21.

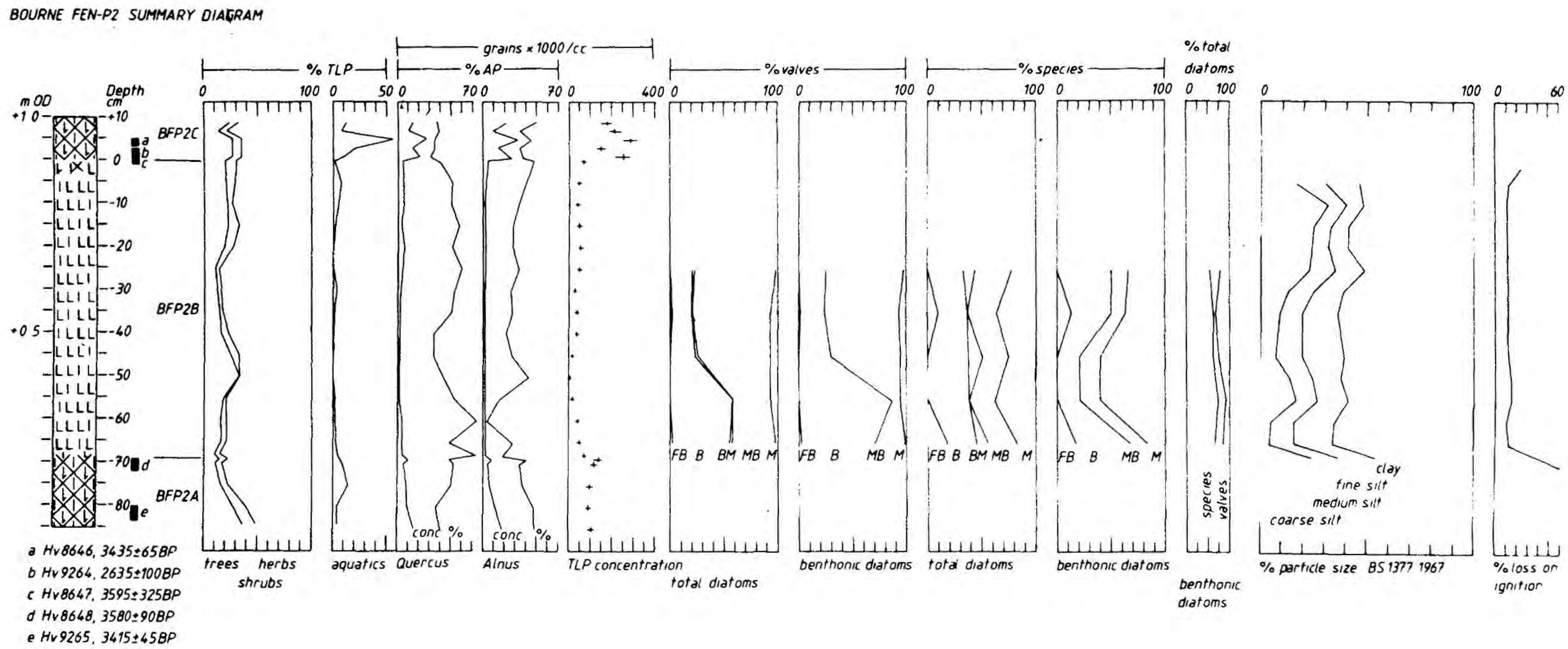


Figure 5.21 BFP2 summary diagram

from 70 to 68 cm. where many taxa show significant changes, TLP concentration also starts to decline. Gramineae, Chenopodiaceae and *Triglochin* show significant increases over the 2 cm. transition while Cyperaceae and Filicales decrease over the same levels.

BFP2B 69 cm to pit datum

This zone is characterised by high Gramineae percentages, reaching a maximum of 65%TLP at 0 cm, (pit datum), low Cyperaceae frequencies, and high frequencies of coastal species, such as Chenopodiaceae and *Triglochin*, around 20% TLP. Total Land Pollen concentrations are low throughout but the %AP curve reflects the nature of the regional pollen rain; *Betula*, *Quercus*, *Pinus* and *Alnus*. *Pinus* percentages are higher than in other zones while *Ulmus* and *Fraxinus* are very infrequent. The upper boundary is a zone, from 0 cm. to +1 cm. over which total concentration increases. Therefore even though increasing in concentration Gramineae percentages decrease, to less than 30% TLP, while Cyperaceae and aquatic pollen dominate the spectra. The boundary is given as 0 cm. due to the completed decline of Chenopodiaceae and *Triglochin* by that level.

BFP2C Ocm. to +9 cm. This zone is dominated by Cyperaceae, Gramineae and aquatic pollen types. Each reveal peaks at different levels, with the fluctuations best revealed by the concentration diagram, fig. 5.20. *Potamogeton*, *Lemna*, and *Typha angustifolia*-type all reach maxima, see Appendix IV, although the latter is the most consistent. *Fraxinus* and *Ulmus* both show significantly higher %AP, *c*.5-15%AP, throughout the zone.

BFP2 is the most seaward of the three sites in Bourne Fen and the pollen diagrams reflect the environmental changes associated with the transgressive and regressive phases of the period of inundation which extended about 1.5 km. further inland. Therefore the pollen spectra are of a more regional nature than those identified in the more landward sites BF10 and BFP1. Correlation with these sites is discussed in chapter 6.

Five samples were submitted from BFP2 for radiocarbon analysis and are listed in tables 7.1 and 5.8

TABLE 5.8 Radiocarbon dates for BFP2

Lab.Code	Depth:cm	Altitude:m.OD	Date :BP	Material
Hv8646	+3 to +5	+0.93 to 0.95	3435±65	Ld^{3}2,Th^{2}1,Th^2(*Phra*)1
Hv9264	+1 to +3	+0.91 to 0.93	2635±100	Ld^{3}2,Th^{2}1,Th^2(*Phra*)1
Hv8647	1 to +1	+0.89 to 0.91	3595±325	Ag1,Ld^{3}1,Th^{2}1,Th^2(*Phra*)1
Hv8648	69 to 72	+0.18 to 0.21	3580±90	Ag1,Ld^{3}2,Th^{2}1
Hv9265	80 to 84	+0.06 to 0.10	3415±45	Ld^{3}2,Th^{2}1,Th^2(*Phra*)1

This series of dates from BFP2 are inconsistent. HV8648 and Hv9265 show no age gradient for the 15 cm. of organic deposition prior to the arrival of inorganic deposits. However the allochthonous nature of part of Hv8648 sample may have included older carbon bearing sediment.

The three contiguous samples, Hv8646, Hv9264 and Hv8647 reveal a discrepancy of 960 years. Hv8647 contained a high proportion of inorganic sediment, with too little carbon content to give an age estimate with an acceptable standard error. Therefore it was deemed unacceptable and Hv9264 was submitted for dating. The difference between Hv8646 and Hv9264 is difficult to explain from a visual analysis of the original samples. Both were treated similarly, they came from the same monolith, _Phragmites_ rhizomes and rootlets were removed before submission, although Hv9264 was submitted for dating 7 months after Hv8646. Comparison with Hv9265 and the series of dates from BFP1, section 5.2.3, would suggest that, for some reason as yet unknown, Hv8646 is too old by some 800 years. However this possible interpretation is discussed in further detail in chapter 6.

Part 5.3 : Cowbit Wash

Cowbit Wash is the low-lying land (_c._ + 3m.OD) south of Spalding between the east bank of the River Welland and the barrier bank along which the A1073 trunk road runs. These washes (e.g. Cowbit Wash, Crowland Fodder Lots and

Crowland High Wash) are intensively farmed but also are the areas for storing flood water from the Welland when required.

Six borings were put down across Cowbit Wash in 1978, 4 parallel Handkerchief Hall Drove and 2 parallel to the New River, with an aim to sample the peat and clastic deposits which had been recorded, and ^{14}C dated, by the Institute of Geological Sciences (IGS) during survey work for the proposed Spalding by-pass. 13 dates were reported for the Spalding series, of which nine were from 4 boreholes close to Cowbit Wash. The location of these, Spalding-0, Sp-1, Sp-2 and Sp-4, are shown in fig. 5.22.

The six boreholes in 1978, CW1 to CW6 fig. 5.22, were made using a Duit's gouge sampler, but even with this relatively light-weight equipment it was not possible to reach the lowest peat beds recorded below -6.0 m.OD by I.G.S. However with the percussion drill and piston corer available in 1979 it became possible to sample through the whole post-glacial sequence and the combined pollen, diatom and particle size analysis of CW7 with the previously published ^{14}C results provide satisfactory data on sea-level changes in this part of the Fenlands.

The analysis of the stratigraphy of the area around Spalding was first attempted by Smith (1970) using selected commercial borehole records. These boreholes, and two made by Jennings (reported by Smith 1970) beside the Coronation Channel, or Welland Deviation, at Spalding, TF25962257, and at Broadgate Farm, Weston Fen, TF27711649, recorded up to three peat beds at any one location, ranging in altitude

COWBIT WASH

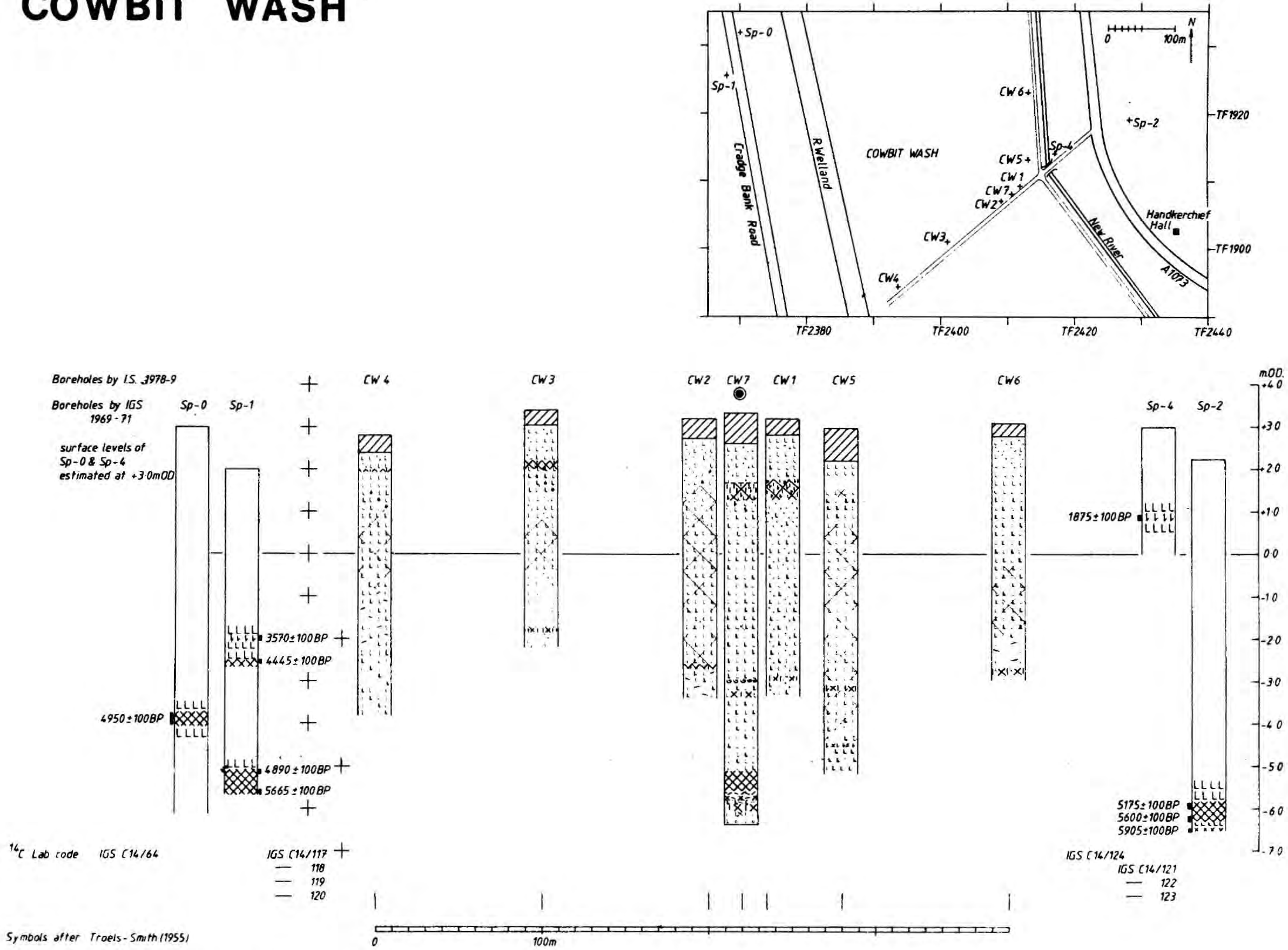


Figure 5.22 : Cowbit Wash stratigraphy

from c.+2 m. to c.-8 m.OD, although the variation between boreholes was quite considerable. The reliability of commercial boreholes in recording the altitude of peat/clay interfaces is low and therefore greater reliability is placed on the boreholes of Jennings.

During the present analysis, boreholes CW1 to CW6 all failed to reach the base of the Flandrian sequence. The Duit's gouge sampler used for CW1 to CW6 did not always bring up complete samples and often there was mixing of sediments due to shearing during sampling or extrusion. This made the identification of some of the thinner layers very difficult. A Duit's gouge sample taken adjacent to the piston core sample CW7 showed that the peat/clay transitions, sometimes revealing the shearing of adjacent sediments through the core, were recorded at depths differing by up to 20 cm. Furthermore the comparison of the two boreholes made at CW7 showed that the organic content of the silty clays revealed in all boreholes between c.+1.5 m. and -5.0 m.OD was very variable. The organic constituent was made up of two quite different components. There was black organic staining throughout the silty clay, often concentrated along root channels. This was recorded as an Ld^4 component and varied between Ld^4+ and $Ld^4$1-. The representation of $Ld^4$1- and not Ld^4+ on fig. 5.22 rather overemphasizes the variation found in the field even though a lighter symbol than that proposed by Troels-Smith (1955) has been used. The greater diameter piston core, CW7, showed how variable this organic content was in a core cross-section. This could not be seen in the Duit's gouge sample. The other organic component within the silty clay horizons were discrete balls of eroded and redeposited monocot. peat. The frequency was again variable and the difference between Dh+ and Dh1- is visually overemphasized in the diagram. In general reworked peat was not common above -1.0 m. OD.

Therefore, due to the greater sampling errors inherent in the boreholes CW1 to CW6, the Cowbit Wash sequence is best described by considering CW7 in detail and comparing the other boreholes with this "type" core.

COWBIT WASH : CW7. Field description of constituents only.
Lim. sup. = 0 unless stated otherwise.

Stratum	Height	Depth	Description
24	+2.62 to +2.01	74 to 135	Ag3, Ga1, part. test. (moll.)+, Lf+. Brown sandy silt with iron concretions
23	+2.01 to +1.67	135 to 169	Ag3, Ga1, Part. test. (moll.)+ Grey sandy silt
22	+1.67 to +1.39	169 to 197	Ld^{2}3, Ld^{3}1. Stratified monocot. peat, sharp upper boundary Lim.sup. 3+
21	+1.39 to +1.27	197 to 209	Ld^{2}2, Th^{2} (*Phra*)1, Ag1, Ga+ Silty *Phragmites* monocot. peat.
20	+1.27 to +0.96	209 to 240	Ag2, Ga1, Th^{2} (*Phra*)1. Sandy silt with *Phragmites* rhizomes
19	+0.96 to +0.80	240 to 256	Ag2, As2, Ld^{4}+ Light yellow/grey clayey silt
18	+0.80 to -0.52	256 to 355	Ag2+, As2-, Ga+, test.(moll.)+, Ld^{4}+, Th^{2} (*Phra*)+. Clayey blue silt, some shells, fine sand, humification products in root channels, better preserved rhizomes of *Phragmites*.

Stratum number	Height m.OD.	Depth cm	Description
17	-0.52 to -1.22	388 to 458	Ag3, As1, Ga+, test. (moll.)+, Ld^4+. Slightly coarser than stratum 18.
16	-1.22 to -1.61	458 to 497	As3, Ag1, Dh+, test.(moll.)+, Ld^4+. Silty clay with balls of eroded peat and organic staining.
15	-1.61 to -1.80	497 to 516	As2+, Ag1, Ld^{4}1-, test. (moll.)+. Organically stained silty clay.
14	-1.80 to -2.97	516 to 633	As3, Ag1, Dh+, Ld^4+, test. (moll.)+. Blue silty clay with organic staining, shells and reworked peat.
13 and 13a	-2.97 to -3.31	633 to 667	As2, Ag2, Dh+, test. (molL)+, Ld^4+. Blue clayey silt. From 633 to 637 abundant shells *Hydrobia* spp., stratum 13a : test. (moll.) 3, Ag1.
12	-3.31 to -3.33	667 to 669	Ld^{3}2, As2. Clayey gyttja
11	-3.33 to -4.34	669 to 770	As2, Ag2, Dh+, Ld^4+, test.(moll.)+ Blue clayey silt, some shells, organic staining and reworked peat.
10	-4.34 to -4.54	770 to 790	Ag3, As1, Dh++, Blue clayey silt with many balls of eroded peat.
9	-4.54 to -5.14	790 to 850	Ag3, As1, Dh+ Blue clayey silt.
8	-5.14 to	850 to	Ld^{3}3, As1, Th^3+. Transition zone.
7	-5.16 to -5.64	852 to 900	Ld^{3}4, Dl+, Th^3+. Compressed peaty gyttja with some wood and monocot. rootlets.
6	-5.64 to -5.72	900 to 908	DL3, Ld^{3}1. Piece of wood
5	-5.72 to -5.87	908 to 923	Ld^{3}3, DL1, Th^3+ Fragments of wood in a humified gyttja.
4	-5.87 to -5.90	923 to 926	As2, Ag1+, DL1-, Blue silty clay, wood at the upper contact. Lim.sup 1.

Stratum	Height	Depth	Description
3	-5.90 to -5.93	926 to 929	Ld^{4}2, Th^{3}l, Asl. Slightly silty gyttja with monocot. rootlets.
2	-5.93 to -6.07	929 to 943	Ld^{4}2, Th^{3}2-, DL+. Humified, compacted monocot, gyttja with pieces of wood.
1	-6.07 to -6.20	943 to 956	Ag^{3}, Ld^{4}l, Ga+, Th^{2}+ Organic silt, with fine sand and herbaceous roots. Becoming sandier at depth with chalk and pebbles.

The Cowbit Wash series of boreholes revealed up to 4 organic layers within a predominantly clastic sequence of varying proportions of silt and clay sized particles. The proportion of fine sand was generally low below the highest organic layer (strata 21, 22) although the surface deposits appeared coarser during field analysis. Particle size analysis in the laboratory (British Standards Institution 1967) did not always corroborate the field analysis. The proportion of fine sand never exceeded 8% in any of the 16 samples, taken at 50 cm. intervals, where possible, through the core; Table 5.9. The classification 'Ga' coincided with high proportions of the coarse silt rather than sand. For example 4 samples from strata 17 and 18 showed coarse silt between 42 and 53%, but designated Ga+ in the field, while 3 samples, from strata 20, 23, 24, designated Gal, showed 83%, 74%, 69% coarse silt respectively.

Four clastic horizons are revealed in CW7. The lowest, from -5.90 to -5.87 m. OD lies between two layers of woody detrital peat. The transgressive boundary is marked by a 3 cm. transition zone while the regressive

TABLE 5.9 : Particle-size analysis : CW7

Depth cm.	% Fine sand	% Coarse silt	% Medium silt	% Fine silt	% Clay	Stratum number	Field Analysis
850-845	< 1	6	18	18	58	9	Ag3, As1
800-795	< 1	13	16	16	55	9	Ag3, As1
750-745	< 1	23	23	44	10	11	Ag2, As2
700-695	< 1	40	14	12	33	11	Ag2, As2
650-645	< 1	25	15	11	48	13	Ag2, As2
600-595	< 1	25	16	12	46	14	Ag1, As3
550-545	4	41	16	8	31	14	Ag1, As3
500-495	< 1	14	22	18	45	15/16	Ag1, As3 (Ld1)
450-445	8	50	10	7	25	17	Ag3, As1, Ga+
400-395	3	50	10	7	30	17	Ag3, As1, Ga+
350-345	< 1	42	13	10	35	18	Ag2, As2, Ga+
300-295	3	53	12	6	26	18	Ag2, As2, Ga+
250-245	< 1	16	18	16	49	19	Ag2, As2
220-215	3	83	4	2	8	20	Ag2, Ga1, Th1
150-145	5	74	5	2	14	23	Ag3, Ga1
100-95	5	69	6	4	17	24	Ag3, Ga1

boundary appears sharp due to woody pieces being quite abundant across the contact. Although only a thin layer the horizon has also been recorded at Sp-2, fig. 5.2.

The second clastic horizon is recorded at CW7 from -5.14 m. to -3.33 m. OD (strata 9-11). The proportions of silt and clay vary and there is a trace of fine sand throughout (<1%). The proportion of clay falls from 58% at the transgressive contact to 10% at 750-745 cm. (c.-4.14 m. OD), although fine silt does rise to 44%, and starts to rise again towards the regressive contact, although the latter level itself was not analysed.

The break in clastic sedimentation is recorded in CW7 at -3.33 m.OD by a very thin gyttja horizon with a high inorganic content. Less inorganic layers are recorded at similar altitudes, (table 10).

TABLE 5.10 : Thin organic layers below OD correlated with CW7

	Description		Altitude, m.OD.
CW7	Clay gyttja	$As3, Ld^3 2$	-3.33 to -3.31
CW1	Silty peaty gyttja	$Ld^3 2, Th^2 1, Ag1$	-2.90 to -2.93
CW2	monocot.peat	$Th^3 1, Ld^3 3$	-2.58 to -2.67
CW3	monocot.peat	$Th^2 2, Ld^3 2$	-1.75 to -1.85
CW4	not recorded		
CW5	monocot.peat	$Th^2 1$, Th^2 (*Phra*)1 $Ld^3 2$	-3.17 to -3.22
CW6	silty gyttja	$Ag2, Ld^3 1, Th^2 1$	-2.63 to -2.70
Sp-1	peat		-2.52 to >-2.55
Broadgate Farm	peat		-2.66 to -2.76

The variation in altitude of this organic layer is large although sampling difficulties may explain some of the differences. The clay gyttja in CW7 was indeed the lowest organic and thinnest representation of this layer. It is not possible to say if CW3 reveals the same layer or not for it is recorded at a much greater altitude not explicable by sampling errors and unfortunately the borehole does not reach the altitude at which the organic horizon in CW7 was recorded. The variable nature of the layer may indicate the area is marginal to the maximum seaward extension of the layer. However its areal significance may be expressed by the recording of peat layers at Spalding-1 and Broadgate Farm, Weston Fen (Smith 1970).

The clastic horizon above this thin organic layer is recorded in CW7 by strata 13-20. The proportion of clay falls from 48% at 650-645 cm. (c -3.14 m.OD) to 25% at 450-445 cm (c.-1.14 m. OD), at the level where fine sand is 8%. The proportion of coarse silt stays high, >40%, and clay lower, until 250-245 where the proportion of clay returns to 49%. Above 240 cm., stratum 20, the clastic horizon is quite different. The blue/grey organic staining was replaced by a yellow/brown colour, some concretions were present and there was a coarsening of the deposit, recorded both by field analysis and confirmed in the laboratory, 3% fine sand and 83% coarse silt. The majority of this clastic horizon however was a silty clay with black organic staining, particularly along old root channels and balls of eroded and reworked peat were recorded in all the Cowbit Wash boreholes. Fragments of shells and whole valves of Hydrobia spp were found throughout and a particularly rich horizon was recorded at -2.97 to -3.01 m.OD in CW7. Seeds of Suaeda maritima were also recorded.

Stratum 20 was overlain at +1.27 m, in CW7, by a silty Phragmites gyttja which marked the transition, over 9 cm, to a stratified monocot. peat. This peat layer, though nearly 30 cm. thick at CW7 was not recorded in CW2, CW5 and CW6 and was considerably thinner in CW4 and CW3. This peat bed was covered by a sandy silt characterised by ferric concretions and parts of shells. The boundary between the layers was sharp.

The stratigraphy of the Flandrian sediments of Cowbit Wash has been presented. Notwithstanding the sampling difficulties encountered, the core CW7 can be taken as representative of the sequence. Above a weathered glacial till, containing gravel-size particles including chalk, a sequence of interrelated peats and silts/clays developed. Up to 4 separate peat horizons have been recorded.

Thirty-two samples were prepared for pollen analysis of the peats and clays from CW7. The only inorganic samples analysed were those adjacent to the organic layers in order to study the changes in the pollen spectra associated with the alteration of the sedimentary environment. There was insufficient time to study the pollen content of the majority of the clastic sequence. 4 pollen diagrams are presented; figs. 5.23, 5.24, 5.25, 5.26. They are from the selected sections of the core, mainly the organic layers, with the full clastic layers not shown in the stratigraphic section in order to clarify the diagram since the samples analysed cover such a small fraction of the core. Fig. 5.23, %AP+Group, does not include the samples from 170 to 200 cm. since the low tree pollen counts, and concentrations, give unacceptable percentages, e.g. *Pinus* at 200 cm. is estimated at 22%AP, with the 95% confidence limits given as 6 and 55%. The grouped herbaceous, aquatic and fern taxa are given in table 5.11. 6 samples, from 860 to 900 cm. at 8 cm. intervals, did not contain sufficient pollen to count, e.g. for the sample from 900 cm 50 *Lycopodium* spores were counted while only two other grains were seen.

6 Local Pollen Assemblage Zones have been identified.

LPAZ	Depth	Description
CW7A	942 to 938 cm.	The zone is defined by a high, but falling, *Alnus* contribution to the arboreal pollen sum and a constant TLP concentration at *c.*70 x 10^3 grains/cc. The arboreal pollen sum decreases from 56-27% TLP mainly due to an increase in the concentration of Gramineae and Chenopodiaceae. All other contributors to Σ TLP decrease in concentration through the zone. The Chenopodiaceae show an isolated peak, 21%AP+Group, at 938 cm. The upper boundary is defined

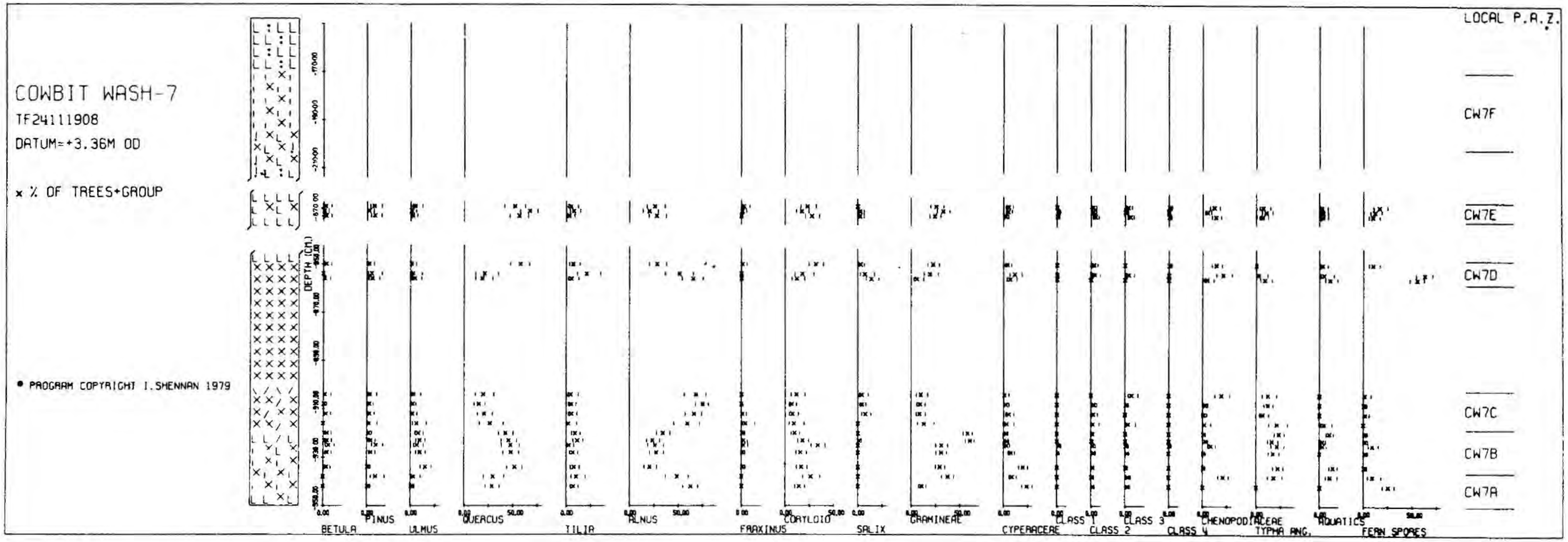


Figure 5.23 :CW7 %Trees+Group pollen diagram. Samples from 170-200 cm. are not shown due to very low tree pollen sums

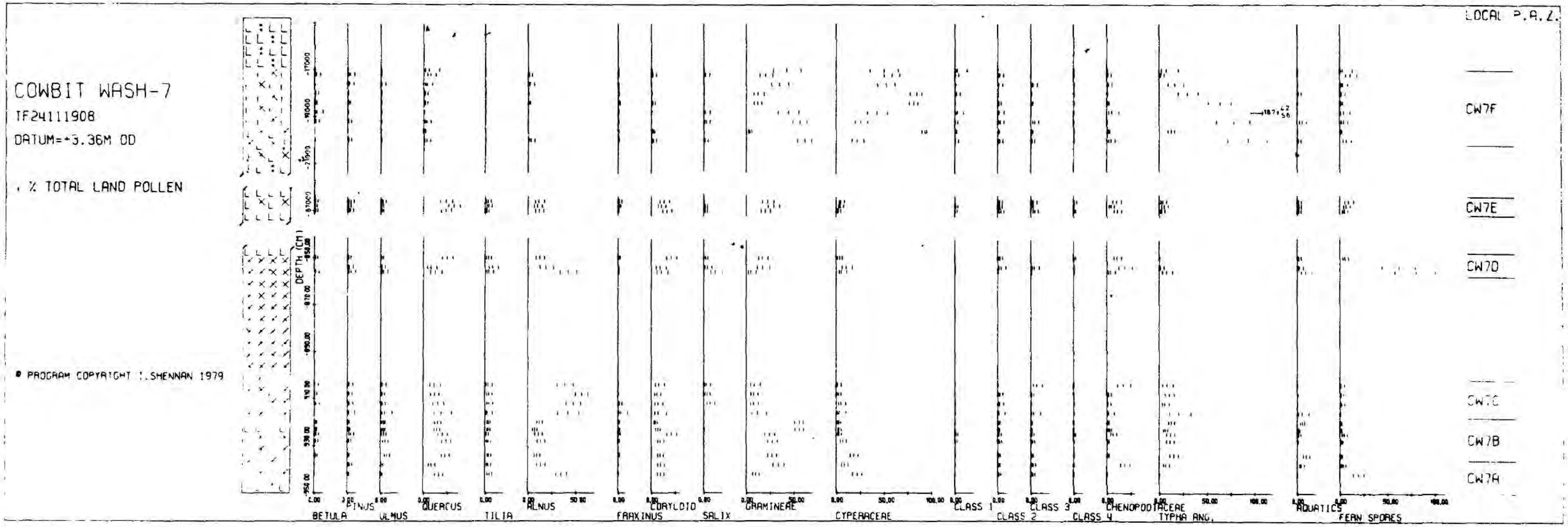


Figure 5.24 : CW7 %Total Land Pollen diagram.

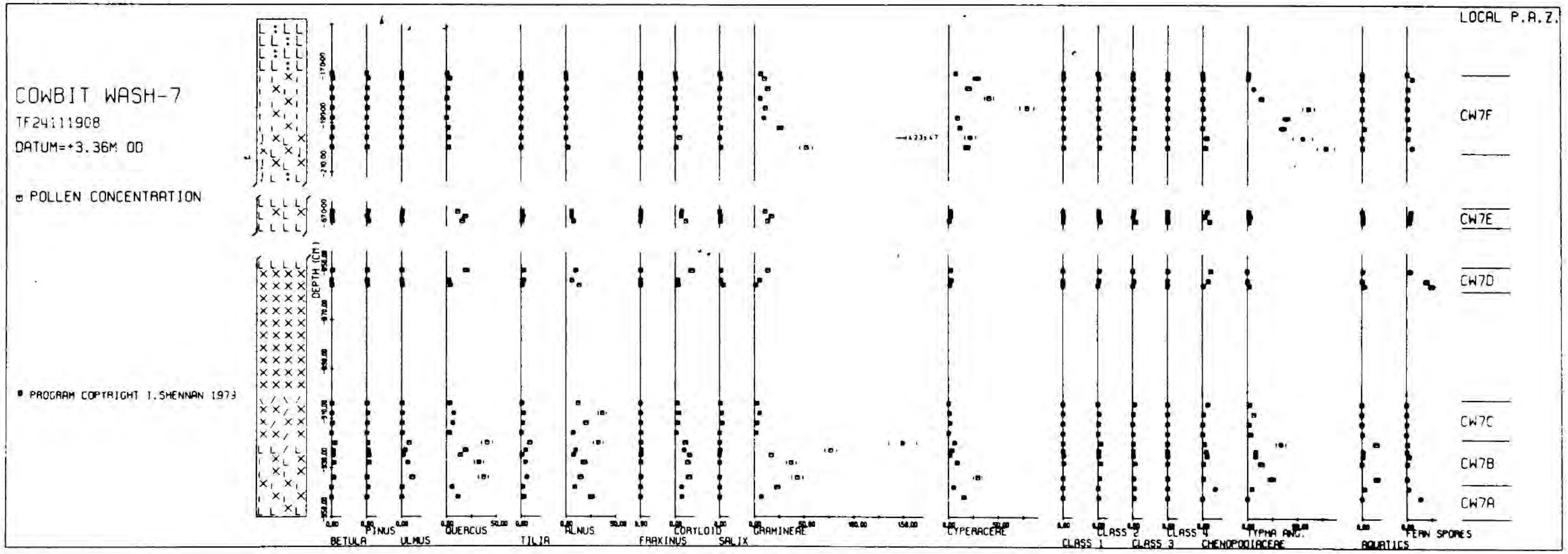


Figure 5.25 : CW7 Pollen Concentration (grains x 1000/cc) diagram.

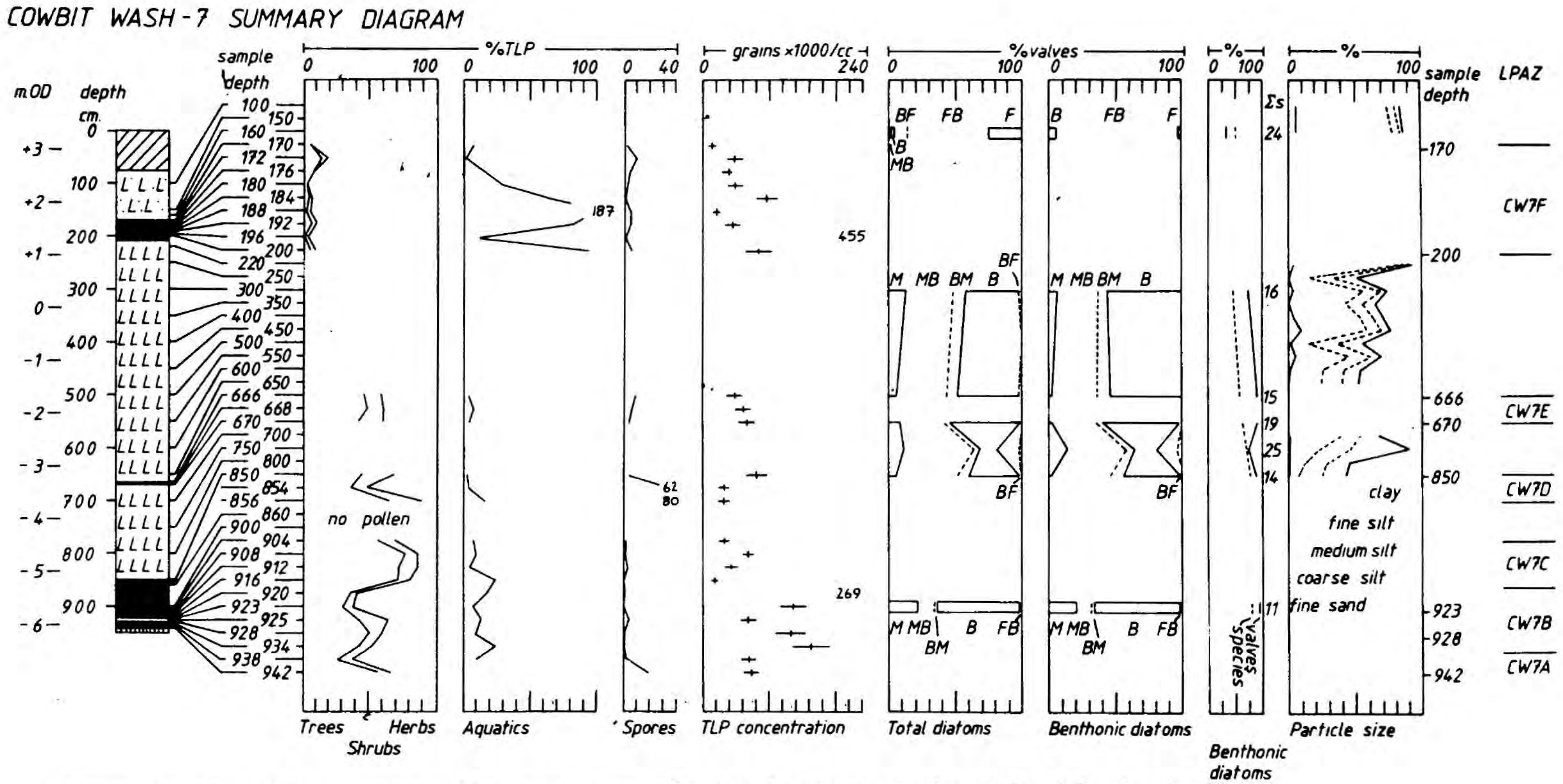


Figure 5.26 : CW7 summary diagram. Organic horizons are shown by black shading.

	by a fall in *Alnus*, 49%-20% AP, with a complementary rise in *Quercus*, and a significant increase in pollen concentration of all taxa.
CW7B 934 to 920 cm.	CW7B is characterised by *Quercus* frequencies consistently greater than those of *Alnus*. Gramineae are high, reaching a maximum of 56%TLP at the top of the zone. Many taxa show an almost symmetrical fluctuation around the middle of the zone at 925 m. Chenopodiaceae, although lower than the peak at 938 cm, shows a rise and fall, to 8.5% AP+Herbs maximum. Similarly *Pinus*, Coryloid and Filicales have small maxima at that level. Pollen concentration is more variable, compared to CW7A and CW7B, with generally high concentrations up to 269×10^3 grains/cc, but falling to 68×10^3 grains/cc at 925 cm. The upper boundary is defined by significant changes in the Gramineae and *Alnus* curves and in a sharp fall in TLP concentration.
CW7C 916 to 904 cm.	This zone is very similar to the opening of CW7A except *Salix* rises to 7.5% AP+Shrubs. The dramatic

	fall in the concentration of Gramineae in CW7B accounts for the lower TLP concentrations in CW7C and the dominance of arboreal taxa, especially *Alnus*; up to 50% TLP. The Chenopodiaceae show a further peak at 904 cm. The top of the zone is given by the absence of pollen in the samples from 900 to 860 cm.
CW7D 856 to 850 cm.	This is a transition zone with the opening being very similar to the end of CW7C, apart from a peak of Filicales; 80%TLP, but most taxa showing significant changes through the zone. *Quercus* replaces *Alnus* as the dominant arboreal pollen, Gramineae and Coryloid pollen rise through the zone while *Salix*, *Typha angustifolia*-type, aquatics and fern spores decline. Chenopodiaceae are consistently present. TLP concentration rises from 33 to 80 x 10^3 grains/cc.
CW7E 670 to 666cm.	CW7E is almost indistinguishable from the top of CW7D although 180 cm. of clastic deposits separate them. Most of the % curves are almost symmetrical around 668 cm. although the confidence limits overlap in most cases;

Chenopodiaceae and other coastal indicators, Classes 3 and 4, showing minima at 668 while the aquatics, Typha angustifolia-type and Gramineae reveal small maxima.

CW7F 200 to 170 cm. This zone is quite different to the rest of the diagram with low pollen concentrations of all types except Gramineae, Cyperaceae and T.angustifolia-type. The great variation in concentration of thsee 3 types from level to level produces irregular changes in the % diagrams. Herbaceous pollen dominates ΣTLP, up to 97%.

Pollen analysis of the biogenic layers of CW-7 has been used to provide information on the local and regional environmental changes. The pollen assemblages of the uppermost biogenic layer are clearly quite different from those of the three below it. Chenopodiaceae and class 3 herbaceous pollen types have been identified in almost every level, with intermittent occurrences of Limonium, Plantago coronopus and P.maritima, which may be interpreted as indicating proximity to the coastal zone. However further discussion of environmental interpretations will be made in Chapter 6.

The pollen analyses can only provide a rough guide

TABLE 5.11 : CW7 herbaceous, aquatic and spore classes (26 levels)

Class I	*Centaurea*	1:0.5%	*Mercurialis*	3:2.5%TLP
	Plantago lanceolata	1:0.6%TLP	*P.major-type*	3:0.5%
	Rumex	4:0.7%	*Taraxacum*-type	3:1.0%
Class 2	*Caltha*	4:1.0%	*Cladium*	2:0.7%TLP
	Filipendula	5:1.1%	*Iris*	1:0.4%
	Ranunculus-type	16:2.6%	Rubiaceae	9:1.0%
	Succisa	1:1.0%TLP		
Class 3	*Artemisia*	3:1.5%	*Calystegia*	1:1.0%TLP
	Caryophyllaceae	1:0.4%TLP	*Cirsium*-type	2:0.6%
	Cruciferae	1:5.8%	*Matricaria*-type	1:1.2%TLP
	Polygonum	5:1.3%	*Senecio*-type	10:2.9%
	Spergula	4:3.2%	*Triglochin*	3:3.2%
	Umbelliferae	7:1.5%		
Class 4	*Limonium*	2:0.6%	*Plantago coronopus*	1:0.5%
	P.maritima	1:0.6%		
Aquatics	*Hydrocotyle*	3:2.2%	*Lemna*	9:13.6%
	Myriophyllum spic.	1:2.7%	*Nuphar*	1:0.8%
	Nymphaea	1:9.7%	*Potamogeton*	5:2.2%
	Typha latifolia	4:9.5%		
Fern spores	Filicales	23:61%	*Polypodium*	11:3.6%
	Pteridium	8:0.9%TLP		

NB. Where the maximum value falls in the range of samples 170-200 cm. where $\sum AP$ is very low and the levels not shown on fig. 5.23, the value is given as %TLP.

to absolute dating of the sequence. The high Alnus frequencies throughout, excluding CW7F, show that the oldest levels are of Atlantic age, 7000-5000 BP. Due to the complexities as a result of local water-level changes the Ulmus-decline is not clearly revealed in the diagram. Ulmus reaches a maximum of 15% in CW7B, falls to 6% at 916 cm, the opening of CW7C, and continues to 1.8% AP at 912 cm. However the confidence bands of these two samples overlap and furthermore Ulmus has risen to 4% AP by CW7D. Therefore while there is a general decline of Ulmus from CW7B to CW7C, an actual boundary cannot be given within or between CW7C and CW7D.

Diatom samples were prepared from 12 samples. The counts are given in Appendix IV.

Diatom preservation was variable. No diatoms or fragments were found in the samples from 949, 925 or 212 cm, while only occasional fragments were seen from 250 cm. At 928 cm. no whole frustiles were seen although fragments were abundant. Within the 7 levels which contained sufficient diatoms to count considerable variation in species and preservation was noted. The data are summarized in fig. 5.26. The samples analysed can be divided into 4 broad groups.

Firstly the single sample taken from below the lowest peat, from 949 cm, was to check that the inorganic layer was not of marine origin, or even a freshwater limnic deposit. The lack of either diatoms or fragments does not prove that it is not of marine origin, similarly it does not show that it is, but with the chalky coarser material below the silty clay from which the sample was taken it does seem reasonable to conclude that the layer represents the weathered glacial till.

The samples from 928, 925 and 923 cm. were to study the nature of the thin inorganic layer, strata 3 and 4. The lower two layers did not provide a quantitative count while 923 revealed a strong brackish influence. *Nitzschia navicularis* was the dominant species although there was a high proportion of fragments and this particular diatom can be easily recognized from fragments whereas many other fragments are recorded as "indeterminable". Only 11 species were identified, giving an M-B-F species ratio of 54-27-9 compared to 36-65-1 for valves. This would suggest a possibly stronger marine influence but 2 of the 4 Marine or Marine/Brackish species were represented by only one valve each. The dominance of one species, 43% Total Valves, may be explained by diatom productivity but whichever method is employed the benthonic diatom spectra reveal similar M-B-F ratios and therefore there is unequivocal evidence that the thin inorganic layer is of brackish/marine origin. The character and state of preservation of the assemblage point to sedimentation in the tidal area.

The samples from 850,750,670,666,300,250 and 212 cm. represent the main period of clastic sedimentation at CW-7 with the small interruption revealed by the organic gyttja at 669 to 667 cm. The sample from 850 cm. represents the beginning of this predominantly clastic sedimentation.

Diatom preservation was very good and rich in the number of individuals although only 14 species were identified. The assemblage was dominated by 2 species, Nitzschia navicularis and N. granulata, 38% and 31% valves respectively. The M-B-F valves ratio was 51-49-0 and 46-54-0 for benthonic valves. This assemblage and the diatom preservation may indicate a low energy brackish/ marine environment.

The assemblage at 750 cm. was rich in species and individuals. The most frequent, Diploneis didyma, represents only 15% total valves counted. 74% of the individuals were benthonic forms which is lower than at 850 cm. The M-B-F ratio is 62-30-8 for individuals, 59-33-8 for species, 58-40-2 for benthonic valves and 50-39-11 for benthonic species. The closer agreement between the use of Σspecies or Σvalves is due to, firstly, no one type dominating the valves total and, secondly, more species, 25, being present. The M-B-F ratios show an increased freshwater ratio and also an increased totally marine influence. This is associated with a higher proportion of non-benthonic species and may represent a more open environment with mixing of marine and freshwater.

The assemblages from 670 and 666 are very similar to 850 cm, dominated by Nitzschia navicularis with N.granulata, N. punctata and Diploneis didyma the other more frequent types. M-B-F ratios in the order of

c. 40-60-0 with good diatom preservation suggest a low energy brackish/marine environment.

Low frequencies of diatoms at 300 cm. made analysis slow and the total count, 69 identified valves, 16 species, and 15 fragments, make the results less reliable from this level and the M-B-F ratios vary considerably, 50-50-0 valves, 37-63-0 benthonic valves, 63-37-0 species, 50-50-0 benthonic species, but a brackish/marine environment is again evident.

It was disappointing that the nature of the final stages of clastic sedimentation was represented by samples with no diatoms, at 250 and 212 cm, particularly since there was a definite coarsening of the sediments, stratum 20, see table 5.9.

The sample from 160 cm. proved very important since the nature of the sediment above the highest peat layer was quite different to the majority of the other inorganic layers, being generally coarser. The diatom assemblage was rich in species and quite rich in individuals. 24 species were recorded and the assemblage was dominated by Cocconeis placentula, Epithemia turgida and Navicula radiosa, representing 24%, 15% and 14% total valves respectively. Species and valves M-B-F ratios were quite similar, since no single species totally dominated and 24 species were present, although only 33% of the valves, 50% species, were benthonic forms. The M-B-F valves ratio was 1-13-86 and for benthonic valves it was 0-4-96. This represents an almost totally freshwater environment for the surface sandy-silt at CW7.

Therefore preliminary diatom analysis has shown that the sequence at CW7 reveals 3 periods of marine/brackish sedimentation, -5.90 to -5.87 m. OD (926-923 cm.), -5.14 to -3.33 m.OD (850-669 cm), and -3.31 to +1.26 m.OD (667-210 cm), assuming that the sediments from 250-212 which do not contain diatoms are of marine influenced environments. However the sandy silts above the highest peat are of freshwater origin.

Six samples have been submitted for ^{14}C analysis. Results are not available.

Hv CW7 : 170-175
Hv CW7 : 191-196
Hv CW7 : 854-859
Hv CW7 : 917-922
Hv CW7 : 928-934
Hv CW7 : 938-943

Part 5.4 : Adventurers' Land, Guyhirn

Adventurers' Land is situated immediately north of the embanked River Nene, to the west of Guyhirn, and south of the Guyhirn-Thorney, A47, trunk road, fig. 5.27. The intercalated Flandrian silts, clays and peats were first recorded by Godwin and Clifford (1938), when the site was called Bankhouse Farm-G, and formed part of the Dog-in-a-Doublet to Pear Tree Hill section. The Bankhouse Farm-G borehole was also referred to by Smith (1970).

Tooley (1978a) reported stratigraphic and pollen analytical investigations from a site AL-2, although this was the first sampling site named Adventurers' Land and has now been designated AL1. Comparison of the altitudinal limits of the peat/clay transitions given by Godwin and Clifford and Tooley reveals very little correlation. Godwin and Clifford (1938) recorded 5 organic layers at approximately +0.40 to -0.30 m.OD, -4.00 to -4.60 m.OD, -6.50 to -6.80 m.OD, -7.85 to -8.00 m.OD and -8.20 to -8.25 m.OD, (altitudes taken from original text figure 27). Tooley (1978a) also recorded 5 organic layers but at -2.96 to -3.22 m.OD, -3.59 to 3.66 m.OD, -4.36 to -4.51 m.OD, -5.66 to -5.83 m.OD and -7.00 to -7.74m.OD. Pollen analysis showed the basal organic layer to be of Flandrian II age.

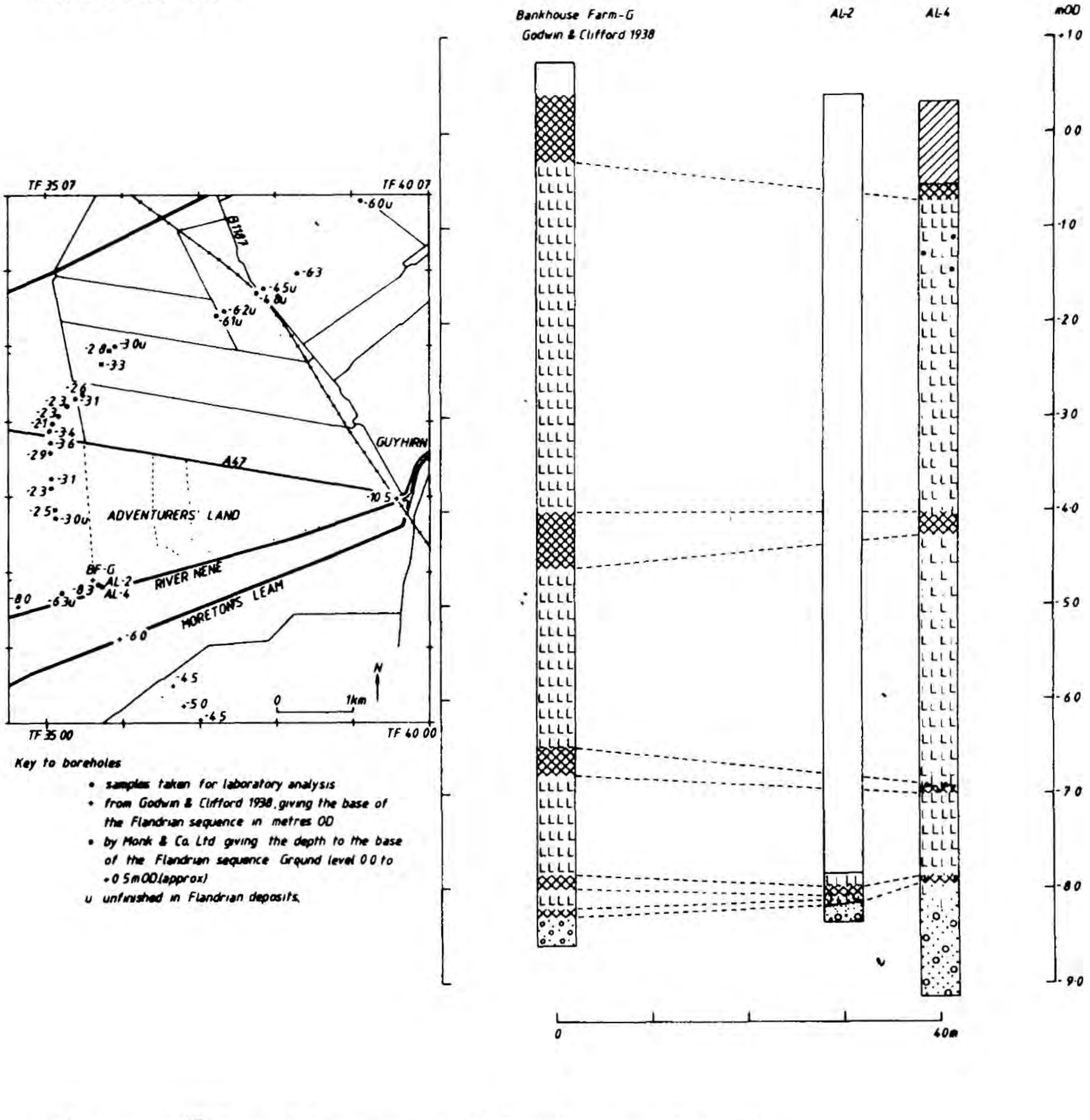
In an attempt to resolve the sequence at Adventurers' Land a U-4 borehole was obtained in 1976. This was designated AL2 but the results proved very disappointing. The samples were of very poor quality with the sediments often found on extraction to be mixed and twisted. Only the lowest 50 cm. sample appeared to be suitable for further analysis, although the upper surface of the basal sand was found to vary by 4 cm. across the diameter of the core. Detailed pollen and diatom analyses however showed that the samples were undisturbed. Therefore AL2 only consists of a 50 cm. section from -7.85 to -8.35 m. OD, 825 to 875 cm. depth.

Further stratigraphic analysis was not possible until 1979 when a piston corer and percussion drill were obtained. Two boreholes were made between 790328 and 790330. AL3 was a Duit's-type gouge sampled borehole taken for investigative purposes while AL4 was made with the modified Livingstone piston corer. AL3, situated adjacent to the outbuildings of Bankhouse Farm, revealed 7 organic horizons. AL4 was 10 m. south of AL2. The stratigraphy of Bankhouse Farm-G, AL2 and AL4 are shown in fig. 5.27 and show a very consistent sequence. AL1 and AL3 both gave poor correlation with these and with each other, and this can be explained by sampling difficulties of the sediments with the Duit's-type corers. AL3 revealed 5 organic layers at similar altitudes to BFG, AL2 and AL4, but 2 extra organic layers were recorded in the chamber where mixing or shearing of the sediments was apparent. Similar problems of sampling can be postulated for AL1. Therefore until further undisturbed samples prove otherwise the stratigraphy of the section is best described by reference to BFG, AL2 and AL4.

The pre-Flandrian deposits are reached at c.-8.25 m. OD in BFG, -8.13 to -8.17 m. OD in AL2, and at -7.95 m.OD in AL4. AL2 shows the pre-Flandrian deposits as a layer of brown sand to -8.25 m. OD above compacted gravel and sand. The character of the deposit is quite different at AL4. A silty sand with organic staining and herbaceous roots extends to -8.05 m. OD above a blue/yellow silty sand to -8.24 m. OD before a yellow/grey sand with small gravel is reached.

The thickness of the silty sands above the gravel

ADVENTURERS' LAND
GUYHIRN



Key to boreholes

- samples taken for laboratory analysis
- from Godwin & Clifford 1938, giving the base of the Flandrian sequence in metres OD
- by Monk & Co. Ltd giving the depth to the base of the Flandrian sequence. Ground level 0·0 to +0·5mOD(approx)

u unfinished in Flandrian deposits.

Figure 5.27 : Adventurers' Land stratigraphy

at AL4 compared to AL2 is the probable explanation for the absence of the lowest clastic deposits recorded in AL2 and BFG, at -8.08 to -8.12 m.OD and c.-8.00 to -8.20 m.OD respectively.

The lowest clastic deposits, designated Guyhirn-1 (G1), are recorded at AL2 as a clayey silt with slight gyttja content, with some flames of enriched gyttja and a slight fine sand fraction. This is overlain by 10 cm. of dark brown gyttja with monocot. fragments well-laminated in the top 6 cm. This is correlated with the peat layer between c.-7.85 and -8.00 m.OD at BFG and a monocot. gyttja, with rhizomes of Phragmites and a few small wood fragments, between -7.95 and -7.87 m.OD at AL4. The second clastic horizon, G2, has a transgressive contact measured at -7.85, -7.87 and -7.87 m.OD. Both AL2 and AL4 show this clastic deposit to be a silty clay with a slight gyttja content, shell fragments, some reworked peat in the lowest centimetres, and a quite sharp lower boundary, recorded as Limes 1 or 2. The regressive contact of G2 is recorded in AL4 at -6.97 m.OD where there is a transition to a 4 cm. thick, slightly clayey compressed monocot. gyttja with rhizomes of Phragmites and fragments of shell. The transition to the overlying clastic layer, G3, is represented by a clay gyttja with shells and flames of Phragmites peat between -6.93 and -6.90 m.OD. This contact may indicate some erosion during the onset of clastic sedimentation. The biogenic deposits in AL4 from -6.97 to -6.90 m.OD were recorded by Godwin and Clifford (1938) as a leaf of the lower peat at an altitude of c.-6.50 to -6.80 m.OD.

The overlying clastic horizon continues until -4.32 m.OD. Shells were recorded in its lower levels up to -6.64 m.OD while the gyttja content is highest below -6.76 m.OD and above -4.84 m.OD. Rhizomes of Phragmites are also found above this level. The transition to overlying organic sedimentation is correlated with the peat at -4.60 to -4.00 m.OD at BFG.

The humified monocot. peat, stratified along rhizomes of Phragmites, is overlain by a 4 cm. layer of flames of peat and clayey gyttja to -4.02 m.OD. The next clastic horizon, G4, contained some rootlets and a few shells at its base while at -1.53 m.OD the nature of the sediment changed with the presence of ferric concretions. At -0.73 m.OD a crumbly humified monocot, peat or gyttja was recorded, equivalent to the peat bed from -0.30 to +0.40 m.OD at BFG. Godwin and Clifford (1938) recorded the Romano-British Silt above this peat layer but at AL4 the surface deposit was not sampled in an undisturbed core. However disturbed samples showed that it was a slightly sandy silt. Modern rootlets were evident in the top of the highest peat layer.

Section 5.4.1 : Adventurers' Land-2

Due to the sampling difficulties only the bottom 50 cm. of the U4 core was considered undisturbed. This section included 20 cm. of presumed pre-Flandrian sands and gravels. Two organic layers were separated by a 5 cm.

clastic layer rich in diatoms. This sequence seemed undisturbed and pollen analysis was carried out at 2 cm. intervals to confirm this conclusion. Four diagrams are presented, figs. 5.28, 5.29, 5.30 and 5.31 and 4 Local Pollen Assemblage Zones have been recognised which show that the peat layers are quite different and not a result of disturbed sampling. Similarly diatom analysis showed that the two clastic layers have quite different assemblages.

A very noticeable feature of fig. 5.28, %AP+Group diagram, is the consistency of the curves for the major tree taxa. *Quercus*, *Alnus*, *Betula* and *Ulmus* show little variation while *Pinus*, *Tilia* and *Fraxinus* reveal barely significant changes. The whole diagram clearly falls in the Flandrian II chronozone and therefore the LPAZs are best characterized by changes in non-tree taxa and pollen concentration. The pollen data are given in appendix IV and the herbaceous and aquatic classes are shown in table 5.12.

TABLE 5.12 : AL2 herbaceous and aquatic classes (8 levels)

Class 1	Rosaceae *Taraxacum*-type	1:0.1% 1.1.0%	*Rumex*	1:0.1%
Class 2	*Caltha* *Ranunculus*	3:0.6% 3:1.0%	*Cladium*	1:0.3%
Class 3	*Artemisia* *Polygonum*	3:0.2% 4:1.3%	*Cirsium*-type *Senecio*-type	1:1.0% 1:1.5%
Class 4	*Plantago maritima*	2:0.5%	*Spergularia*	1:0.3%
Aquatics	*Lemna* *Nuphar* *Potamageton*	6:31.5% 1:0.2% 3:1.9%	*Myriophyllum spic.* *Nymphaea* *Typha angustifolia*-type	1:1.0% 1:0.6% 6:4.7%

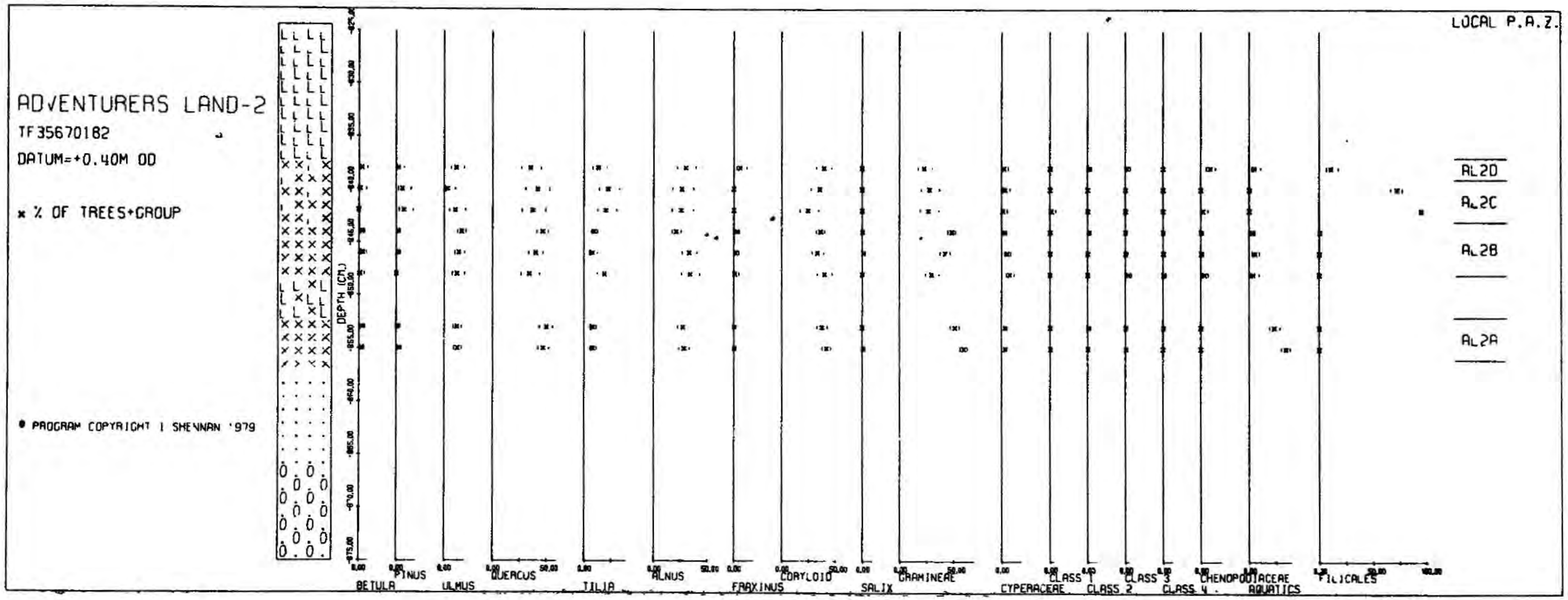


Figure 5.28 : AL2 %Trees + Group pollen diagram. The results of 3 radiocarbon assays are shown in fig. 5.31.

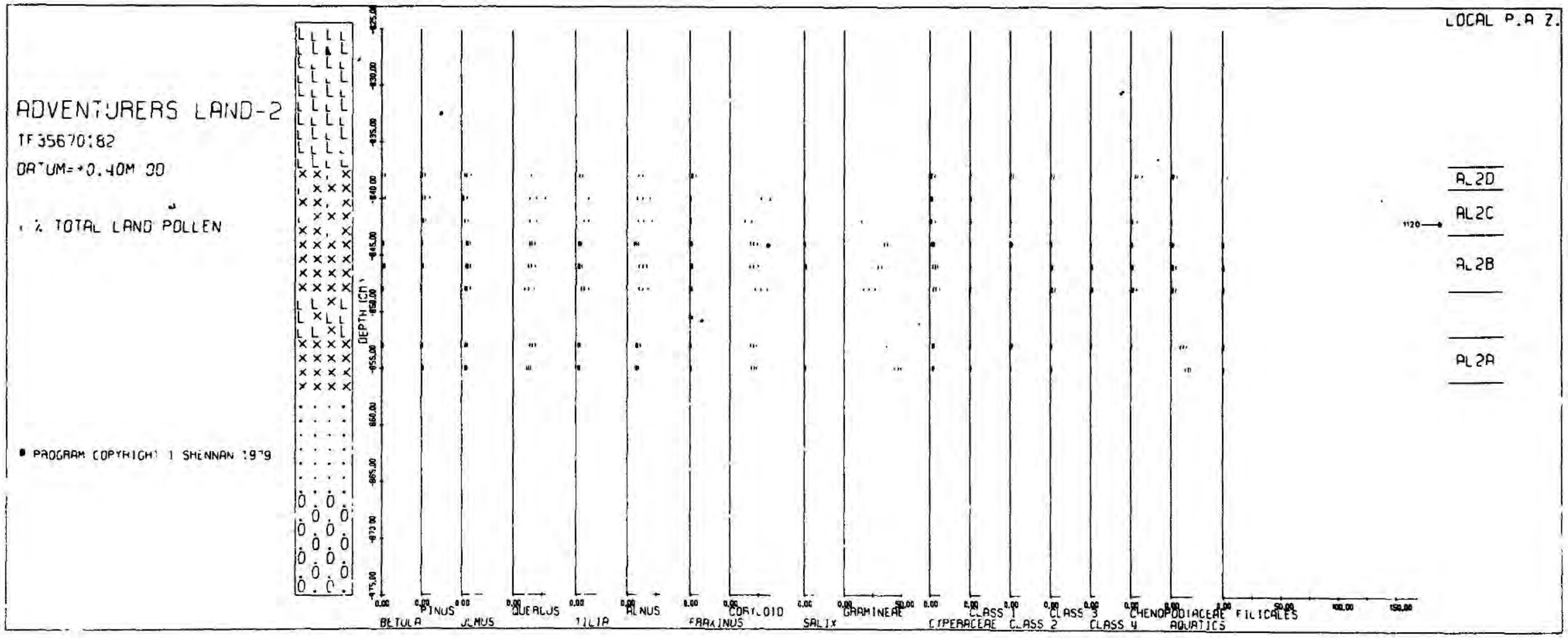


Figure 5.29 : AL2 %Total Land Pollen diagram. The results of 3 radiocarbon assays are shown in fig. 5.31.

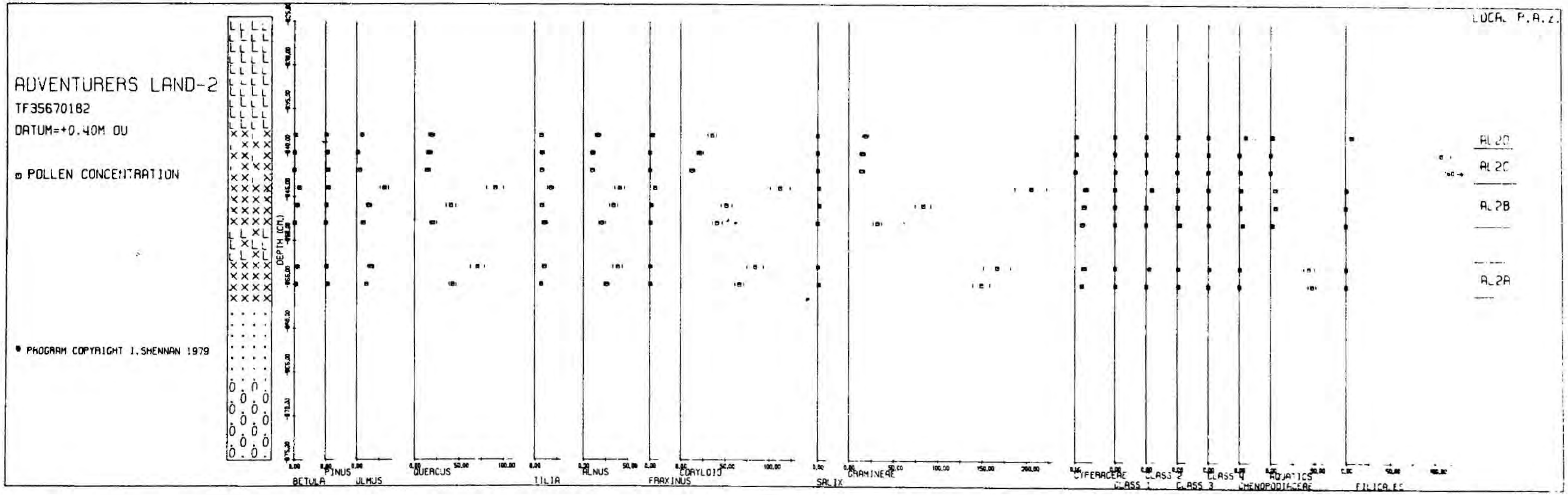


Figure 5.30 AL2 Pollen Concentration (grains x 1000/cc) diagram. The results of 3 radiocarbon assays are shown in fig. 5.31.

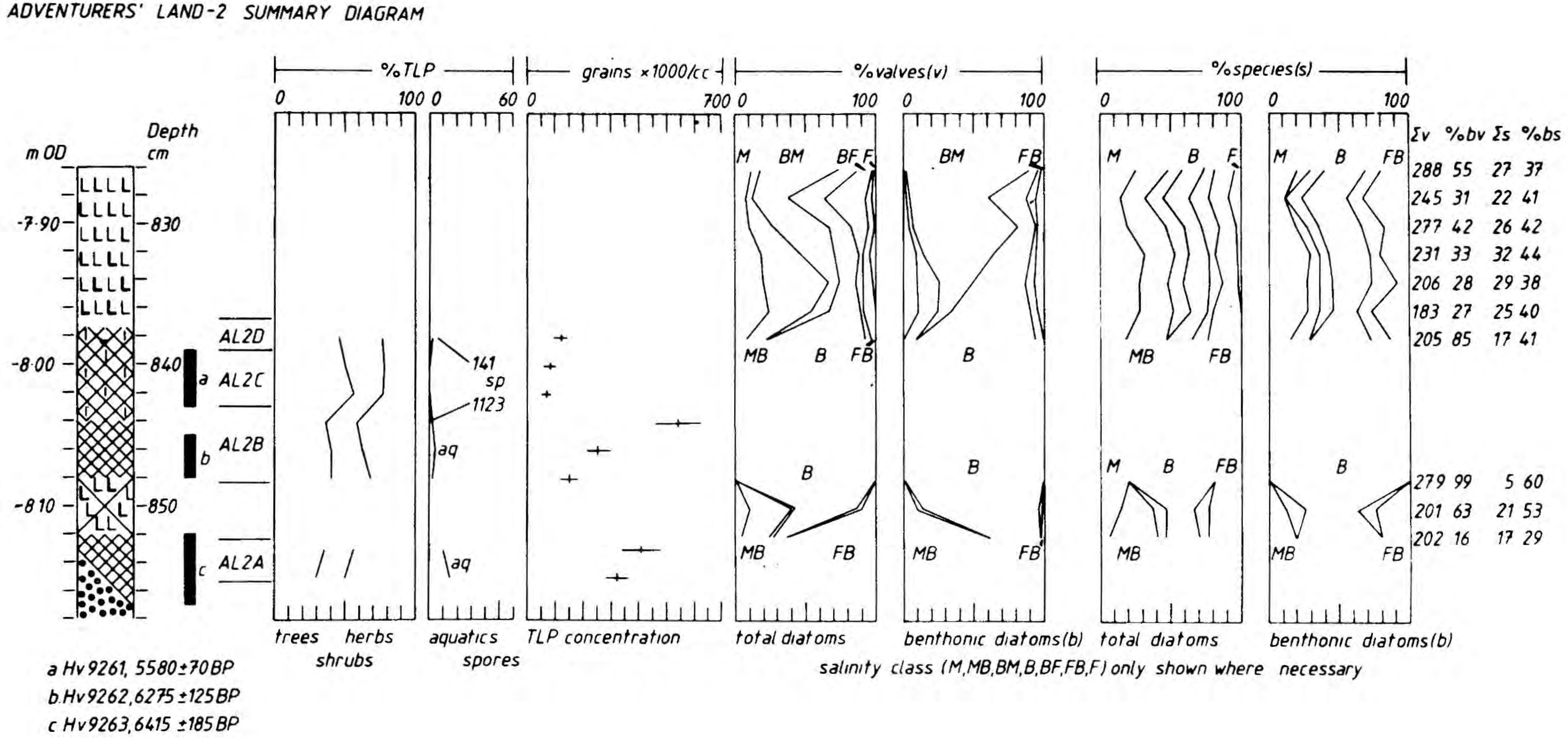


Figure 5.31 : AL2 summary diagram.

LPAZ	Depth	Description
AL2A	855 to 853 cm.	The zone is characterised by high aquatic frequencies, noticeably *Lemna* and *Typha angustifolia*-type. Gramineae account for over 40% TLP. Total Land Pollen concentration is high, 318-410 x 10^3 grains/cc.
AL2B	848 to 844 cm.	AL2B is very similar to AL2A except that aquatic percentages and concentrations are much lower while the percentages of Cyperaceae, both %AP + Herbs and %TLP, are higher, although they decline through the zone. Total Land Pollen concentration increases through the zone from 149 to 537 x 10^3 grains/cc. Gramineae show the largest increase in concentration and therefore also show an increase as both %AP+Herbs and %TLP. Chenopodiaceae, Class 4 and Class 3 herbs, e.g. *Polygonum*, *Plantago* *maritima*, *Senecio*-type, are more frequent than in AL2A and decline from maxima at the opening of the zone. Arboreal pollen is constant at *c*.40%TLP.
AL2C	842 to 840 cm.	The zone is totally dominated by high proportions and concentrations of Filicales spores. Pollen preservation

is generally poor, even the Filicales spores are corroded. Aquatics are totally absent and most pollen types show a significant decrease in concentration from the subjacent layer, particularly Gramineae. With Cyperaceae almost disappearing and only 3 other herb pollen grains counted arboreal pollen types show a relative increase as %TLP, collectively to 56%TLP. Pinus and Tilia are more frequent than in AL2B, 7%cf. 2% AP and 20% cf 9%AP respectively. Due to the low pollen concentration and accordingly smaller pollen sums involved the 95% confidence bands in AL2C are broader and therefore the significant changes are not so numerous as might have been expected.

AL2D 838 cm. The zone is defined by significant increases in the curves for Chenopodiaceae, to 8% AP+herbs, and aquatics, to 2% AP+aquatics, both of which were absent in AL2C.

Eighteen samples were prepared for diatom analysis. They were taken at 2 cm. intervals from 826 to 860 cm. Two samples from the basal sand contained no diatom frustules or fragments. Similarly 5 samples from the organic layers contained no fragments at all. However the sample from 846, at the base of the gyttja layer contained a few fragments, but not possible to count. The sample from the top of the organic layer, stratum 6, at 838 cm, immediately below the contact to overlying clasic deposits, contained ample whole diatom frustules to count. 9 samples from the two clastic layers, G1 and the lower part of G2, all contained diatoms and the spectra are shown in fig. 5.31.

Stratum G1, 852 to 848 cm, revealed marked salinity changes. The lowest level, 852 cm, shows a very low proportion of benthonic diatoms, 16% valves, 29% species, and a spectrum dominated by the Fresh-Brackish forms Fragilaria brevistriata and Opephora martyii. However the %benthonic valves and two species spectra show a predominance of more brackish forms. The small benthonic group is dominated by Diploneis didyma. The other two samples from G1 are dominated by the benthonic Brackish diatom Campylodiscus echeneis, reaching 97% of total valves.

The M-B-F diagrams for G2, 836 to 826 cm, appear to show different salinity changes, dependent on the method of calculation used. The proportion of benthonic valves falls from 85% at the contact immediately to 27% and then fluctuates to reach 55% at 826 cm. The % valves and % benthonic valves show large changes in M-B-F ratios. However in comparison the % benthonic species remains relatively constant, 37 to 44%, and the two diagrams based on species are similarly consistent.

In terms of the proportion of valves brackish and marine forms dominate. Melosira sulcata is important throughout while *Diploneis interrupta* is dominant at 838 cm. *Nitzschia navicularis*, Brackish and benthonic, *Synedra tabulata*, Brackish-Marine epiphytic, and the 3 Marine-Brackish epiphytes *Cocconeis scutellum*, *Actinoptychus undulatus* and *Diploneis smithii* are the most frequent forms up to 832 cm, while above this level *Nitzschia punctata*, Brackish-Marine benthonic, and *Rhopalodia gibberula*, a Brackish epiphyte, are more frequent. Diatoms favouring low salinities are infrequent throughout G2. While the % valves and % benthonic valves show large changes, due to different forms becoming dominant the species diagrams are more constant, but show a broad relative agreement of brackish forms being replaced by slightly more marine types with some fluctuation towards the top of the sampled section.

Therefore detailed pollen and diatom analysis has shown that the lowest 50 cm. of an otherwise unsatisfactory core are undisturbed and record two organic layers and two clastic layers, each with individually distinguishable microfossil floras. Three samples were submitted for ^{14}C analysis to record the absolute age limits of the organic layers sampled. The three samples are:-

Hv 9261 AL2 : 839-843 cm, -7.99 to -8.03 m.OD : 5580±70 BP
Hv 9262 AL2 : 845-848 cm, -8.05 to -8.08 m.OD : 6275±125 BP
HV 9263 AL2 : 852-857 cm, -8.12 to -8.17 m.OD : 6415±185 BP

Section 5.4.2 : Adventurers' Land-4

Adventurers' Land-4 is situated approximately 10 m. south of AL2. The stratigraphy has already been described. Pollen analysis has been carried out on 13 of 15 prepared samples, the basic data is given in Appendix IV, and the herbaceous and aquatic classes are shown in Table 5.13.

TABLE 5.13 : AL4 herbaceous and aquatics classes (13 levels)

Class 1	*Plantago lanceolata*	2:2.5%TLP	*Pl.major/media*	1:0.4%
	Taraxacum-type	2:8.1%TLP		
Class 2	*Caltha*	3:0.6%	*Filipendula*	1:0.3%
	Ranunculus	8:2.0%	Rubiaceae	5:20.2%
	Valeriana	1:0.2%		
Class 3	*Artemisia*	1:2.7%TLP	*Cirsium*-type	2:0.6%
	Cruciferae	1:0.6%	*Matricaria*-type	1:0.4%
	Polygonum	2:0.3%	*Senecio*-type	5:17.5%TLP
	Spergula	1:0.5%	Umbelliferae	7:5.0%
Aquatic	*Hydrocotyle*	1:1.3%	*Lemna*	9:30.0%
	Typha angustifolia-type	13:95.0%	*T.latifolia*	4:4.2%

NB. Where the maximum value falls in the samples 108-104 where ΣAP is very low, and the levels not shown on fig. 5.30, the value is given as %TLP.

As was the case with CW7 the uppermost peat layer at AL4 was found to contain very few arboreal pollen grains and therefore the two levels from this peat layer are not shown on fig. 5.32. Two samples, 826 and 462 cm, were found to contain black particles which obscured the pollen grains which prevented counting. They were reprepared but the black particles were again present. The counted levels are shown in figs. 5.32, 5.33, 5.34 and 5.35 and 5 LPAZs have been recognized.

LPAZ	Depth	Description
AL4A	824 to 818 cm.	*Quercus* accounts for 50% AP at the base of the zone and declines to 88% at 818 cm. In a complementary fashion *Alnus* increases 24 to 31%, *Ulmus* 4 to 13%, Fraximus 0 to 2%, while *Tilia* falls and then rises, 13 to 5 to 11% AP. Gramineae rises to 54% TLP and then falls to 15% TLP with a complementary rise of most arboreal types as %TLP. Σ AP rises from 25 to 43% TLP. *Senecio*-type and Chenopodiaceae are important in the lowest level while the latter only occur in low frequencies at 818 cm. Aquatics and Class 2 herbs, particularly *Ranunculus*, are consistently present and Cyperaceae rise at the end of the zone. TLP concentration varies from 190 x 10^3 grains/cc at the base to 390 x 10^3 grains/cc at the top, in the transition to predominantly inorganic sedimentation.
AL4B	730 to 726 cm.	Cyperaceae, up to 26% TLP, and Gramineae 22% TLP dominate the base of the zone. All of the thermophilous arboreal species are present, except *Fagus*, with *Ulmus* up to 19% AP. Total land pollen

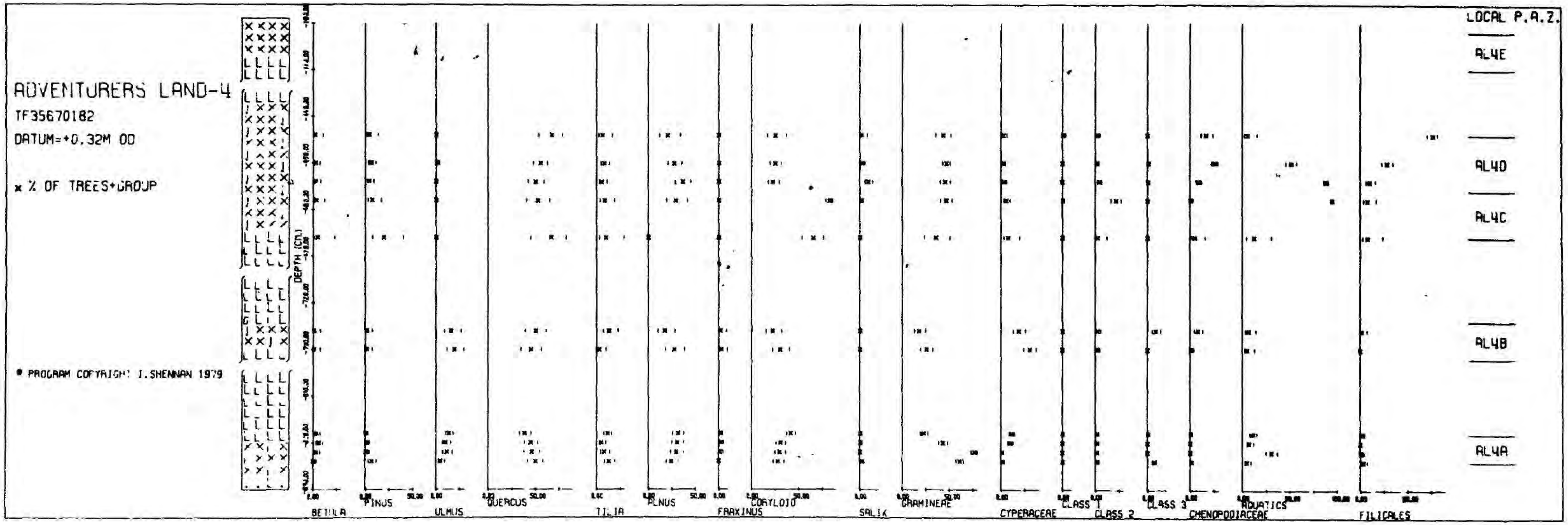


Figure 5.32 : AL4 %Trees + Group pollen diagram. The results of 3 radiocarbon assays are given in fig. 5.35. Samples from 104-108 cm. are not shown due to very low tree pollen sums.

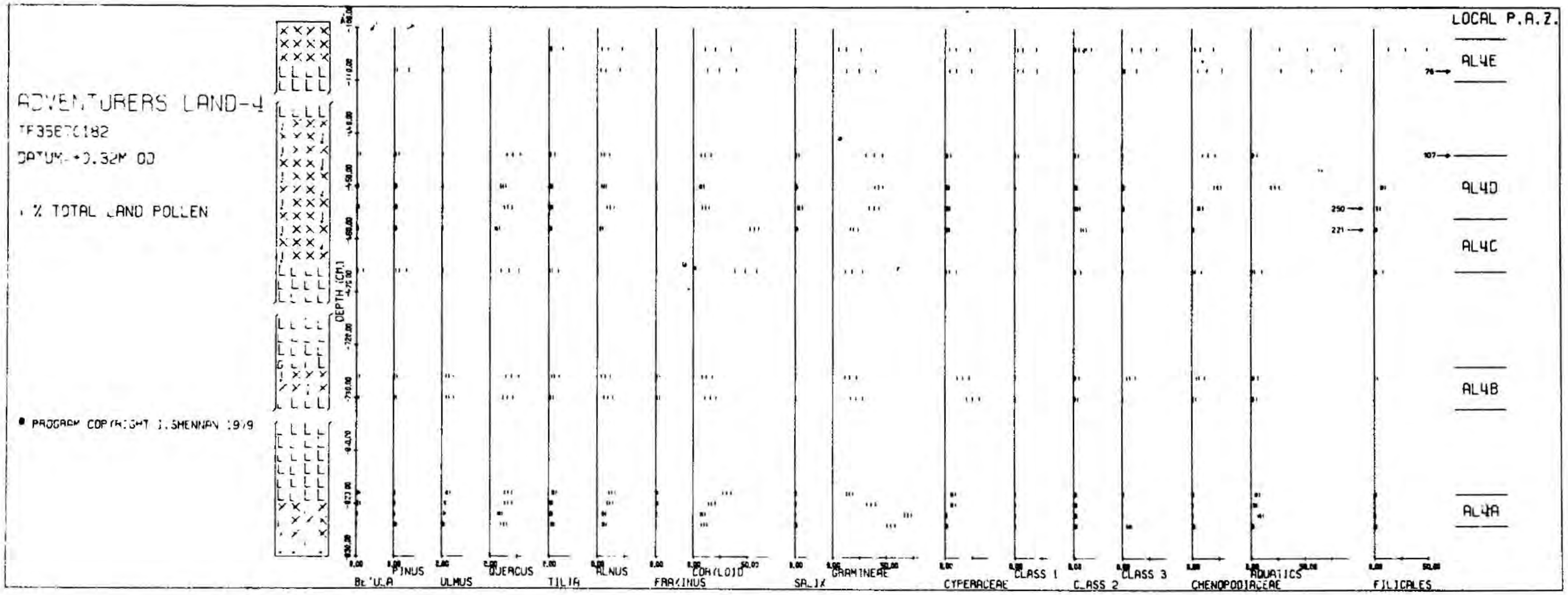


Figure 5.33 AL4 Total Land Pollen diagram. The results of 3 radiocarbon assays are given in fig. 5.35.

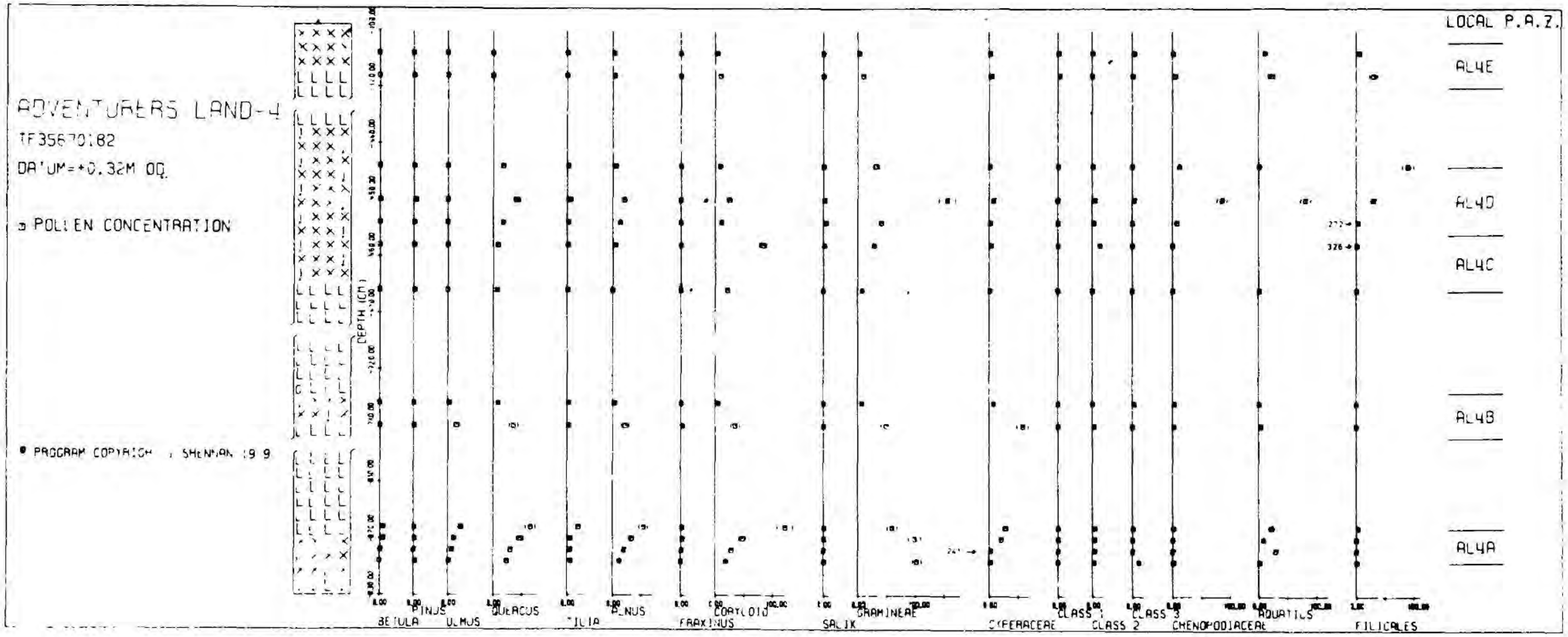


Figure 5.34 : AL4 Pollen Concentration (grains x 1000/cc) diagram. The results of 3 radiocarbon assays are given in fig. 5.35.

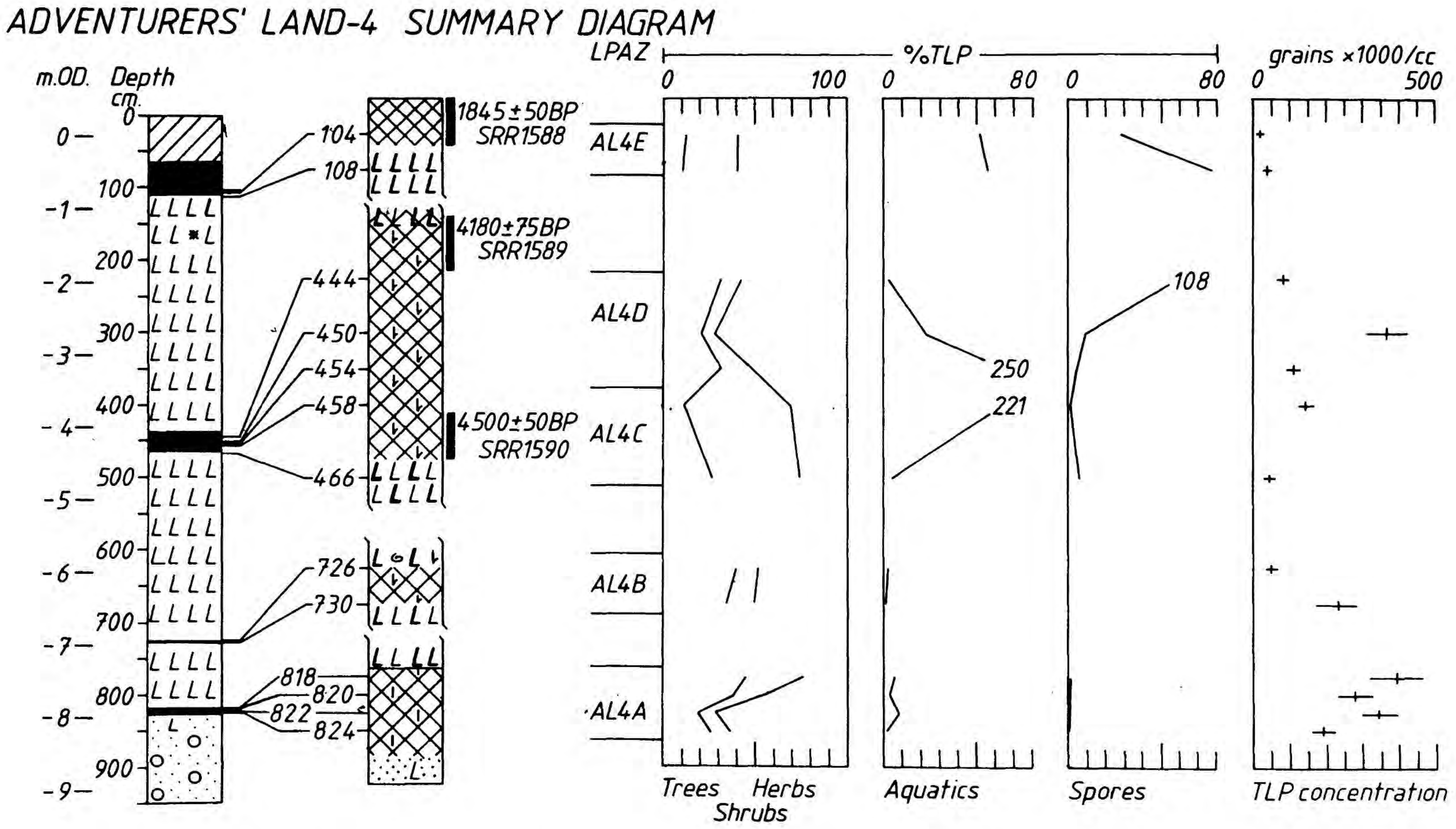


Figure 5.35 : AL4 summary diagram. Organic layers are shown by black shading.

concentration falls from 228 x 10^3 to 47 x 10^3 grains/cc with only Chenopodiaceae and *Senecio*-type increasing in concentration through the zone, therefore showing increased percentages.

AL4C 466 to 458 cm. The zone is characterised by the dominance of Coryloid pollen, 48 to 57% TLP. For many other taxa the zone is one of significant change, Alnus 0 to 29% AP, Pinus 19 to 7% AP, Chenopodiaceae 5 to <1% AP+herbs, Rubiaceae 0 to 20% AP+herbs and aquatics 13 to 95% AP+aquatics, the peak being mainly Typha angustifolia-type. *Quercus* dominates the arboreal pollen, with no *Ulmus*. AP falls to 10% TLP. Total land pollen concentration rises from 45 x 10^3 to 148 x 10^3 grains/cc.

AL4D 454 to 444 cm. *Quercus* continues as the dominant tree pollen although Alnus rises to 37% AP. Coryloid now <11% TLP. Gramineae are constant at 45% AP+herbs, as in AL4C, but have increased in %TLP as herbs dominate, 51 to 71% TLP, due to the demise of Coryloid frequencies. Chenopodiaceae pollen is high throughout, up to 25% AP+herbs, while aquatics and Rubiaceae decline from the peak established at the end of AL4C, Filicales rise through the zone to 77% AP+Spores. TLP concentration rises to a peak at 450 cm, 366 x 10^3 grains/cc, mainly due to Gramineae and Chenopodiaceae concentrations, although most arboreal taxa show concentration maxima for AL4C and AL4D at the same level. A single *Fagus* was seen at 454 cm.

AL4E 108 to 104 cm. Total land pollen concentration is low, 40 x 10^3 and 21 x 10^3 grains/cc, and the spectra are dominated by aquatics and Filicales. The low TLP sum, 40, is clearly reflected by the broad 95% confidence bands. Chenopodiaceae, *Taraxacum*-type, *Senecio*-type, Umbelliferae, *Plantago lanceolata* and *Artemisia* occur in low concentrations, but are reflected by quite high percentages. Pollen preservation was very poor with many disformed grains. Unidentifiable grains would be represented as 40% TLP, calculated outside the sum.

Further pollen analysis was not carried out for the highest peat bed due to the low and poor pollen content and the fact that the overlying inorganic sediments, ?G5, recorded by Godwin and Clifford (1938) were not sampled because they were disturbed.

5 samples have been submitted for ^{14}C analysis. Results are not available for all of the samples.

SRR 1588	1845±50BP	AL4	99 to 105 cm.
SRR 1589	4180±75BP	AL4	437 to 443 cm.
SRR 1590	4500±50BP	AL4	459 to 464 cm.
Not yet submitted		AL4	726 to 730 cm.
Hv		AL4	819 to 823 cm.
Hv		AL4	823 to 827 cm.

To summarize the data from the analysis of AL2 and AL4 5 organic and 4 inorganic horizons have been recorded and partially analysed for their microfossil content. The earliest, and lowest, organic deposits have been dated 6415 ± 185BP and the peat layer at -4.32 m.OD in AL4 is the lowest occurrence of post-<u>Ulmus</u> decline organic sedimentation. Diatom analyses of AL2 show the basal clastic deposits to be marine or brackish in origin.

Particle-size, diatom, pollen, stratigraphic, and ^{14}C analyses have been used at 4 sites, Freiston Marsh, Bourne Fen, Cowbit Wash, and Adventurers' Land, to provide data on the Flandrian sequences of the Fenland. Interpretation of these data and correlation within the Fenland sequences follow in chapter 6.

CHAPTER SIX

The analysis of transgressive and regressive overlaps

The data described in the preceding chapter permit an evaluation of the changes in early coastal environments in the Fenland between 6400-2600 BP, relating the changes in sediment to water-table movements, and enable existing models of stratigraphic and microfossil change at the salt marsh-freshwater fen transition to be modified. The chronology of sea-level and environmental change is described in chapter seven.

Chapter six is divided into 8 parts :

6.1 : Existing models for the interpretation of transgressive and regressive overlaps.
    6.1.1 : The Godwin model - arboreal pollen as indicators of water table mevements.
    6.1.2 : Tooley - evidence for fluctuating sea-levels.
    6.1.3 : Kidson and Heyworth - evidence for continuously rising sea-levels.

6.2 : Interpretation of the Bourne Fen data in comparison to the existing models.
    6.2.1 : Regional significance.
    6.2.2 : BF10
    6.2.3 : BFP1
    6.2.4 : BFP2
    6.2.5 : Correlation of the Bourne Fen sites.

6.3 : Cowbit Wash
    6.3.1 : Regional significance.
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6.4 : Adventurers' Land.

    6.4.1 : Regional significance.
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6.5 : Estimation of the altitude, age and meaning of transgressive and regressive overlaps.

    6.5.1 : Measurement of the present altitude.
    6.5.2 : Estimate of the original altitude.
    6.5.3 : Indicative meaning of the sample.
    6.5.4 : Age of the sample.

6.6 : Lithologic changes and sea-level movements.

6.7 : Models of the salt marsh-freshwater fen transition.

    6.7.1 : Time-stratigraphic model.
    6.7.2 : Pollen content model.

6.8 : Conclusions

Part 6.1 : Existing models for the interpretation of transgressive and regressive overlaps.

The interpretation of transgressive and regressive overlaps can be related to three informal models. Each of these models is discussed in a separate section.

Section 6.1.1: The Godwin model - arboreal pollen as indicators of water-table movements.

Whereas pollen analysis is widely used in sea-level studies to assess changes in local environment and as a corroboration for ^{14}C data (e.g. Tooley 1978a, b and section 6.1.2 below) it is not always appreciated that in favourable circumstances the arboreal pollen types can reveal changes in local conditions complementary to the non-arboreal pollen changes.

It has been noted for many years that the interpretation of pollen diagrams from coastal sites is very difficult due to the high percentages of Alnus that are generally encountered in deposits of Zone V11a and later (Godwin 1940a, b, Janssen 1959) and therefore many Fenland pollen diagrams appear to be best employed for studying local vegetational changes. Even so there is a complexity in their interpretation.

Godwin (1940a, 1978, Godwin and Clifford 1938) has used the fluctuations of the Alnus and Quercus pollen curves to explain phases of wetness and dryness in fen woods. On the one hand Godwin (1940a, p.243) explains that

> "In the dry phases fen woods developed, and in the wet ones [transgressions] they were destroyed. The dry periods show a marked local rise of alder pollen. In the wet periods a fall in the alder pollen indicates destruction of the fen woods, and then oak pollen from the upland rises in complementary fashion."

While on the other hand he states (Godwin and Clifford 1938, p.385)

> "The pollen drifts from dominance of alder to dominance of oak...replacement of alder scrub by [local] fen oak woods."

Therefore it appears that a replacement of Alnus pollen by Quercus pollen can represent either increasing relative wetness or dryness. Firstly when alder carr is replaced by reedswamp, e.g. prior to a transgression, it is a period of increasing relative wetness and the Alnus contribution to the arboreal pollen rain is reduced, therefore revealing an increase in the regional component, dominated in most Fenland diagrams by Quercus. However when peat growth is in excess of the rise in the water-table, i.e. a relative increase in dryness, waterlogging becomes more restricted and may result in the extension of other tree species, e.g. Quercus and also Pinus, onto the bog to compete with the Alnus, Salix and probably Betula (Godwin 1978). Therefore Quercus pollen may increase in relative frequency and Alnus decrease due to competition. Furthermore Godwin argues that the development of a fen oak wood is usually accompanied by macrofossil remains of oak wood, poor pollen preservation, pollen often too sparse to count, and a rise in the frequency of Filicales spores (Godwin 1978, Godwin and Clifford 1938).

Godwin's interpretation of the inverse relationship between the Alnus and Quercus curves is supported by Iversen (1960) who noted a clear negative correlation between Alnus and Quercus pollen during the transition from Phragmites reed swamp to alder carr to oak forest following the regression of the sea in Sub-boreal time at Lundergard Moss.

The fluctuations of the arboreal pollen types complement the rise and fall of non-arboreal pollen types, especially the Chenopodiaceae, and Godwin (1940a) relates the inferred change from Phragmites freshwater peat to salt marsh, or vice versa, as occurring at c. MHWST with fenwood development at a slightly higher altitude. However, Godwin pointed out that the water level controlling fenwood growth is dependent on the distance to the sea since the tidal influence will vary up-channel, and away from direct tidal influence it may drop to MSL (or MTL). This latter value is the one given for the initiation of peat growth on a sloping Pleistocene sand surface (Jelgersma 1979 cf. 1961, van de Plassche 1979).

Therefore the fluctuations of the Alnus and Quercus curves and the non-arboreal pollen types noted in chapter five may be related to this informal model which for convenient future reference is attributed to Godwin. This assessment is presented in parts 6.2 - 6.4.

Section 6.1.2 : Tooley - evidence for fluctuating sea-levels.

Tooley (1978b, 1979) has presented mechanical, chemical and micropalaeontological analyses from Downholland Moss to illustrate the changes of water quality and water depth at the transgressive and regressive overlaps. He summarized (Tooley 1979 p.504)

> "All the palaeoenvironmental indicators point to an initially increasing and then decreasing marine influence in the minerogenic layers and to a limnic-telmatic-terrestrial-telmatic-limnic cycle in the biogenic layers. The conclusion is difficult to avoid that these changes in water quality and water depth were a consequence of actual changes in the sea-level surface."

Tooley also suggests that the transgressive and regressive overlaps indicate the change of processes at c.MHWST, and each intercalated peat layer should be dated by two assays, one for each overlap.

Section 6.1.3 : Kidson and Heyworth - evidence for continuously rising sea-levels.

Kidson and Heyworth (1973, 1979) offer a quite different interpretation of transgressive and regressive overlaps. They maintain that the intercalated organic and clastic layers are the result of a continuously rising sea-level characterised by periods of rapid sea-level rise and periods of slow sea-level rise. Associated with these periods the gradual change in the relative sedimentation rates of the clastic or organic deposits will determine the type of overlap developed. They also suggest that storm surges, the breaching of coastal barriers and other normal coastal processes adequately explain the stratigraphic and micropalaeontological evidence without invoking positive and negative movements in the sea-level surface.

Furthermore they have criticised the technique of dating the transgressive and regressive contacts if they are not characterised by woody peat, arguing that only the latter material is suitable material for dating, being formed at a more constant tide level than other commonly dated materials (Kidson and Heyworth 1979). Originally they suggested that such formations occurred at _c_.MHWNT to MHWST (Kidson and Heyworth 1973, 1978). However they now conclude that the lower limit of trees is midway between MHWST and HAT for the regressive overlap, or periods of slow sea-level rise, and just below MHWST for the transgressive overlap, or periods of rapid rise in sea-level (Kidson and Heyworth 1979). This point relating to a different indicative meaning (cf. van de Plassche 1977) for the transgressive and regressive overlaps should also be applied to other dated materials if it is assumed to be correct.

The data from Adventurers' Land, Cowbit Wash, and Bourne Fen are used to test the major contentions between the informal models of Tooley and Kidson and

Heyworth, i.e. whether a fall in sea-level is in evidence or whether local phenomena relating to storm surges and normal coastal change during a period of continuously rising sea-level offer an adequate explanation.

Part 6.2 : Interpretation of the Bourne Fen data in comparison to the existing models

Section 6.2.1 : Regional significance

The X4 sequence was recorded in a section over 2 km. long. Cleaned dyke sections and borehole records revealed the same sequence c.3 km. further east, to Tongue End, c.2 km. north into Bourne North Fen (Smith 1970) and c.1 km south into Bourne South Fen. Lithologically the sequence appears to correlate with the Southern Fenlands but the timing of the deposition of the clastic deposits may differ (Godwin 1940a, Godwin and Vishnu-Mittre 1975). The lower peat and clastic deposits were recorded further to the north and south but the surface peat has been removed due to wastage and is only preserved in favourable locations.

Section 6.2.2 : BF10

The pollen diagrams from BF10 (figs. 5.9, 5.10, 5.11) illustrate the negative correlation between the Quercus and Alnus curves as discussed in section 6.1.1.

A rise in the freshwater table is inferred from the destruction of the forest species, which had grown rooted in the pre-Flandrian deposits of Bourne Fen, due to the initiation of peat growth. No diatoms were found in either the lowest peat or the pre-Flandrian deposits. The high Alnus peak in BF10A suggests an early development of alder carr but its regional significance is unclear.

LPAZ BF10B covers a large part of the diagram (fig. 5.9) and the interrelationship of the Alnus and Quercus curves is envisaged as the result of local competition and pollen production since there are no significant fluctuations in the curves of the other regional forest species, e.g. Tilia and Ulmus, as might be expected if the destruction of alder carr was taking place. The presence of wood macrofossils and abundant Filicales spores would indicate the development of locally drier fen oak woods but the fluctuating aquatic curve still suggests waterlogging. There appears to be a delicate balance between peat growth, alder carr/fen oak wood stability and freshwater-table rise caused by the approaching marine conditions.

The rise in aquatic pollen frequencies at 275 to 245 cm. must be divided into two parts. From 275 to 265 cm. Potamogeton dominates while from 260 to 245 cm. firstly Lemna and then Typha latifolia pollen is important. This is interpreted as a change from small shallow pools to reedswamp and is corroborated by the significant rise in the Gramineae curve at 260 cm. which would include Phragmites pollen, the rhizomes of which were also recorded at that level.

If this general waterlogging was to affect any oak present before alder then once the lower threshold was reached a gradual rise in water level would reduce the arboreal pollen spectra quite drastically, e.g. at the BF10B/C boundary. Alnus pollen would show a peak (%AP), due to the preceding decline of oak in the fenwood, but the decline of AP as %TLP suggests that as the water level continued to rise the alder carr was destroyed and replaced by reedswamp. Therefore, the regional component of Quercus pollen is expressed as a relative rise (%AP). The rapid change of the Alnus/Quercus curves may be exaggerated due to the changing pollen productivity of individual plants as the growth and flowering conditions changed.

The rising water table is clearly connected to the rise in tide-level evidenced by the deposition of the silt and clay between 240-210 cm. The Chenopodiaceae curve rises at 250 cm. and Plantago maritima and Artemisia pollen were also identified.

The regressive contact, coinciding with BF10D, is dominated by Gramineae and aquatic pollen with a low proportion of arboreal pollen. The higher proportion of tree species other than Alnus and Quercus in the arboreal spectra indicates that these woody fen taxa had not yet extended over the site. Large trunks of trees were occasionally seen in the dyke exposures of the surface peat but the development to fenwood was not revealed in the pollen record. BF10E reveals the start of increased pollen corrosion.

Finally the pollen diagram from BF10 shows the whole sequence to be post-Ulmus decline, Ulmus is never > 5% AP and often < 1%AP. It has not been possible to recognize

Zone VII-VIII (Godwin and Vishnu-Mittre 1975).

In conclusion the BF10 pollen diagrams are interpreted as revealing a rising water table during which time alder and oak fenwoods developed at an equal rate since no periods of destruction and regeneration are noted prior to the development of reedswamp communities and then marine clastic sedimentation. The regressive overlap is very similar to a reversal of the transgressive sequence and there is some evidence for the return to fen wood conditions.

Section 6.2.3 : BFP1

BFP1 (figs. 5.13 to 5.16) is close to BF10 (c.100 m) and the pollen analyses show broad similarities but also important local changes. The peak in the *Alnus* curve in BFP1B appears to correlate with that of BF10C. However in the former the aquatics frequencies are lower than would be expected. But the isolated peak of *Sphagnum* spores at 75 cm, the same level as the highest recorded macrofossil wood remains, may represent a significant difference between local conditions at BFP1 and BF10. Godwin (1978) has reported that in many places in the alder-birch carr at Calthorpe Broad, Norfolk, there was a discontinuous growth of a carpet of *Sphagnum* moss, showing a tendency for the acidification of fenwoods. However, conditions at BFP1 were not suitable for the continued succession to raised bog due to the rising water table and alder carr is strongly represented in BFP1B.

The complementary curves for *Alnus* and *Quercus* noted in BF10 are also seen in BFP1A and BFP1B. However the pollen concentration diagram (fig. 5.15) shows that the fluctuations are due to changes in Alnus concentrations whereas Quercus is quite constant. The two sites show consistent changes in environment during the approach of marine conditions. With only localised differences, as would be expected if the comparison with Calthorpe Broad is valid, both sites show a gradual rise of water table and the replacement of Cyperaceae pollen by Gramineae, which would include Phragmites pollen.

The fall in the Alnus curve is rapid and coincides with rising aquatics, Gramineae and Chenopodiaceae which clearly represent the approaching salt marsh conditions. The stratigraphy, loss on ignition curve, and the pollen spectra all reflect a relatively rapid transgressive episode with constant conditions during the period of predominant inorganic deposition up to 50 cm. (depth below pit datum), and a gradual regressive phase. The predominantly inorganic deposits show a more regional pollen spectra, with all the major tree species represented while from 50 cm. upwards organic accumulation increases, although the proximity to salt marsh or tidal creeks is testified by high Chenopodiaceae concentrations.

The regressive sequence shows unequivocal evidence for the replacement of highly inorganic sedimentation by biogenic sedimentation and an associated lessening of the saltwater influence. The minimum in the Alnus curve at the base of BFP1D may tentatively represent the maximum recession of the alder carr at more landward locations and the increase through BFP1D a result of its migration back onto the fen. The development of freshwater fen is evident from continually rising Gramineae percentages followed, in sequence, by rises in Cyperaceae, Lemna, and Typha angustifolia. Apparent pollen corrosion in BFP1E precludes any further environmental interpretation.

Section 6.2.4 : BFP2

This site (figs. 5.18 to 5.21) is the most seaward of the three Bourne Fen sites studied and LPAZ BFP2A represents the reedswamp community prior to the transgressive clastic deposits. Typically the Gramineae, Cyperaceae, Typha latifolia and Filicales curves show high frequencies while AP has a maximum for the whole diagram of 36% TLP. The more regional nature,cf.BFP1 and BF10, of all the tree components is evidenced by relatively low Alnus frequencies, never reaching 50%AP, and the lack of great locally-induced fluctuations in the tree pollen curves. The transition to BFP2B, coinciding with stratum 2, closely follows Tooley's model (section 6.1.2); the Cyperaceae curve is replaced by the Gramineae curve in the percentage diagrams, and a fall in the frequency of aquatic pollen and a rise in the pollen of coastal species also conform to the model.

The clastic horizon is typified by constant and low tree pollen concentrations and %TLP, with the major changes in the pollen spectra for the Gramineae, Chenopodiaceae and Triglochin of the local salt marsh environment.

The diatom spectra from BFP2 suggest that the clastic deposits were laid down in a low energy, high tidal sedimentation area, with a strong brackish-marine influence rather than freshwater input, reached by the highest tides. This is very similar to the results of the diatom and foraminiferal analyses from the Green Dyke section (Godwin and Clifford 1938) but any suggestion that the marine sediment was laid down by storm tides is not borne out by the results of the diatom and particle size distributions; the predominance of clay size particles and no sand size fraction suggests the absence of a high wave energy environment. The diatoms do not allow a fine distinction of changes in water salinity or depth due to their absence across the transitions to the peat although the pollen analyses reveal the vegetational successions across these lithologic boundaries.

The regressive overlap at BFP2 reveals, in the same way as BFP1 and BF10, the transition from saltmarsh through coastal reedswamp to freshwater fen. This transition occurs over a narrower zone in BFP2 than in BFP1. The increased pollen concentration in BFP2C may reflect a change in pollen sedimentary conditions from BFP2B. The source of the pollen in both the clastic and organic horizons is not known in detail but certain factors are apparent. It may be suggested at this stage that there are three major components; pollen from plants growing at the site, airborne pollen, and water transported, redeposited pollen. It is difficult to distinguish between these in the pollen sum. Local pollen is likely to be more important in the organic deposits due to the restricted movement of water while the airborne and water transported pollen may dominate in the clastic horizon. The airborne pollen source is evidenced by the distance decay effect, for example the differences of the *Alnus* and *Quercus* percentages and concentrations between BFP1 and BFP2. Reworking by water may be suggested by the increased *Pinus* frequencies in BFP2B due to its bouyancy. The source of the pollen rain and its path to the sampling site is an important consideration in the development of the model considered in part 6.7.

Section 6.2.5 : Correlation of the Bourne Fen sites

The correlation of the 3 sites, BF10, BFP1 and BFP2, reveals the problems of the different methods used for stratigraphic correlation and the need to differentiate between local and regional environmental changes.

Lithostratigraphic correlation of the sites is simple because they all show an X4 type sequence; a clastic horizon, between two organic sequences, at similar altitudes. However biostratigraphic and chronostratigraphic correlation is more difficult, especially in correlating BFP2 with the other 2 sites. The chronological validity of the lithostratigraphic correlation depends on the scale of the investigated area since facies which follow immediately in time, or in a profile without a sedimentary hiatus, can only have formed side by side in space. Therefore lithostratigraphic units will only occasionally correlate with each other in time. This is the problem with Tooley's use of the term transgression (see part 1.2). Similarly the biostratigraphic units will not correlate exactly in time. The biostratigraphic units are the LPAZs, each initially defined according to the significant changes in the pollen spectra for that diagram, and therefore not related to preconceived ideas of a general model. Furthermore the LPAZ boundaries do not reveal the same environmental changes for each site. The environmental changes at each site were a continuous process and the boundaries purely reflect a point of rapid change in one, two or more dependent variables. The boundaries should not be expected to, and indeed do not, always reflect equivalent environmental changes at each site. The definition of the zones is a reflection of the relative position of the site to the maxima of marine inundation, at that time, and the regional forest, thus being based on both regional and local changes.

As sites pass along the ecological gradient the recorded environmental changes at one site will be recorded by an equivalent, but different, change at another site. For example the change from coastal reedswamp to highest saltmarsh at BFP2 may be registered, at the same point in time but at a different point on the ecological gradient, at BFP1 by a change in the fen wood or fen carr towards a sedge fen community. The limitations of ^{14}C analyses preclude an accurate assessment of the rate of change for these ecological successions.

Fig. 6.1 is an attempt to relate the LPAZs for each site, which were defined purely on within-site variations, to a common ecological succession, each then identifiable to a point in relative time for a different point in space.

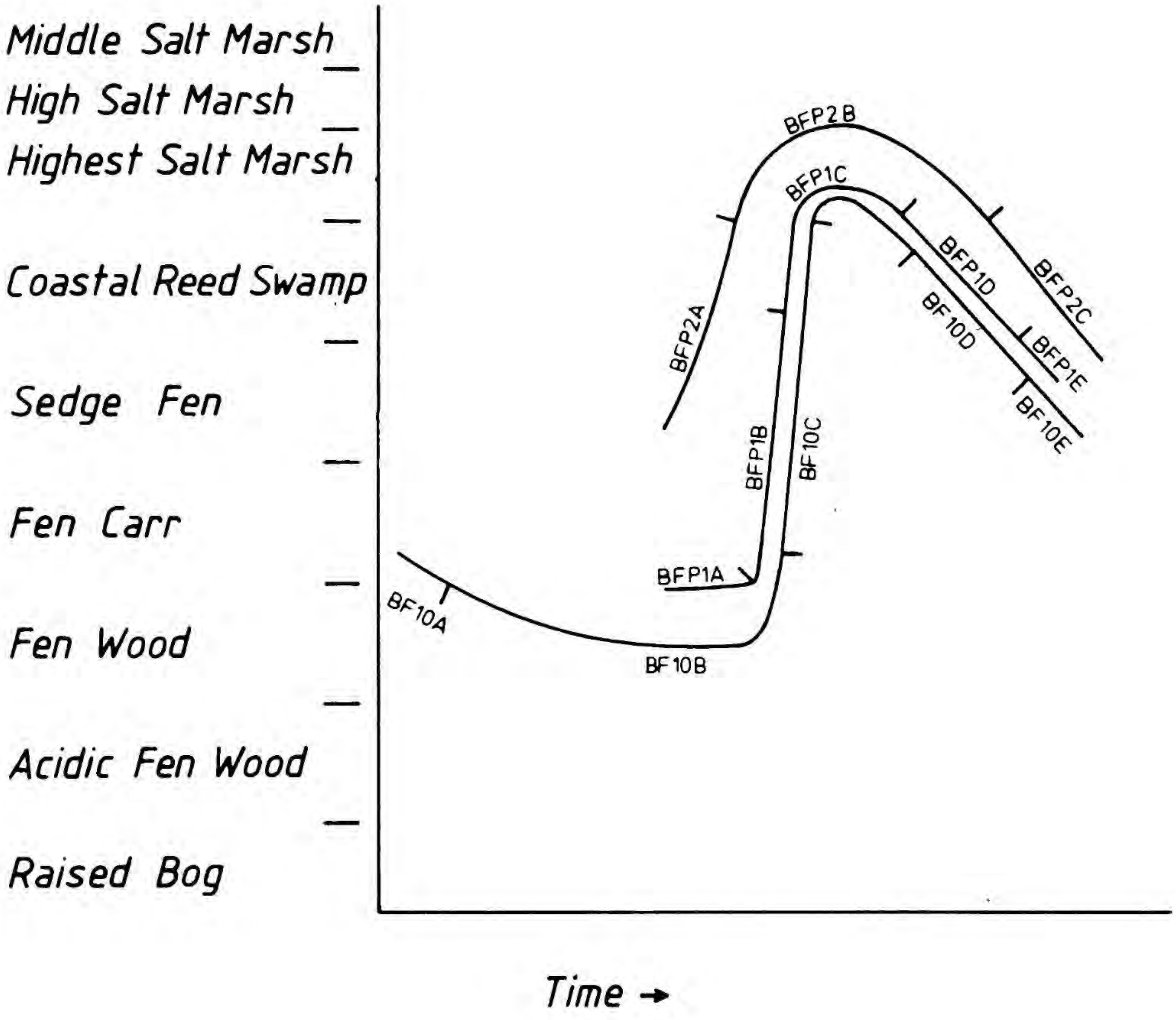


Figure 6.1 : Biostratigraphic and chronostratigraphic correlation of the Bourne Fen sites. The LPAZs for each site are related to a generalized ecological succession and relative time scale. No reference is made to the ^{14}C data.

No reference is made to the limited ^{14}C data from Bourne Fen. Therefore LPAZ BFP2B is biostratigraphically correlated with the top of BFP1C yet may be chronostratigraphically equivalent to the end of BFP1A, all of BFP1B, BFP1C and the beginning of BFP1D.

Therefore LPAZs appear to be best employed in this situation for evaluating local environmental changes. These local changes can then be incorporated in any model of proposed changes of regional importance. Only when the local effects have been identified can a comparison be made with RPAZs and the chronozone system be used to verify ^{14}C date.

Part 6.3 : Cowbit Wash

Cowbit Wash was analysed in less detail than Bourne Fen and at this stage it is sufficient to analyse the extent and nature of the intercalated organic and inorganic deposits.

Section 6.3.1 : Regional significance

Three periods of marine sedimentation and a surface inorganic deposit of freshwater origin were noted in part 5.3. The lowest marine layer was very thin, from -5.90 to -5.87 m.OD., in CW7 and was only recorded in one other borehole, SP-2, by the Institute of Geological Sciences. However from Broadgate Farm Smith (1970) reported a grey slightly silty clay with Hydrobia ulvae and H.ventrosa from -5.97 to -7.52 m.OD, below a compressed peat and overlying a shelly organic mud. This silty clay could possibly be an eastward extension of the lowest clastic horizon at CW7.

Other borehole data from the Spalding-Cowbit Wash area allow further analysis (fig. 6.2). The records are from engineers' logs and were sometimes bulk disturbed samples and therefore the boundaries of the layers should perhaps be estimates, ±25 cm, and thin alternations of different sediment types should not be expected, cf. CW7.

The sites from Spalding which show 2 peat layers (WD7, 8, 9, 11 and 12) are between 3.2 and 4.4 km. from CW7 in a general seaward direction. The intercalated peat layer, also recorded at NC1, may be equivalent to the peat recorded at -3.33 to -3.31 m.OD at CW7, but with altitudes ranging up to -1.75 m.OD (table 5.10), if there is a seaward slope of the deposits as recorded in Bourne Fen (part 5.2) due to either consolidation of the sediments or changes in the altitude of the sedimentary environments through time, of which a fall in sea-level would be one factor. However an equally valid argument can be made that the intercalated peat layer at Spalding may be related to the peat from -5.87 to -5.14 m OD. at CW7. This problem cannot be resolved without further sampling, and with reliable coring equipment, in the Spalding area where organic deposits have been recorded to c.-8.5 m.OD.

The peat layer at WD10 appears anomalous but may be the equivalent to the second intercalated peat from CW7 if the lower peats at Spalding are correlated with the lowest intercalated peat at CW7.

The highest peat at CW7, also recorded at CW1 and

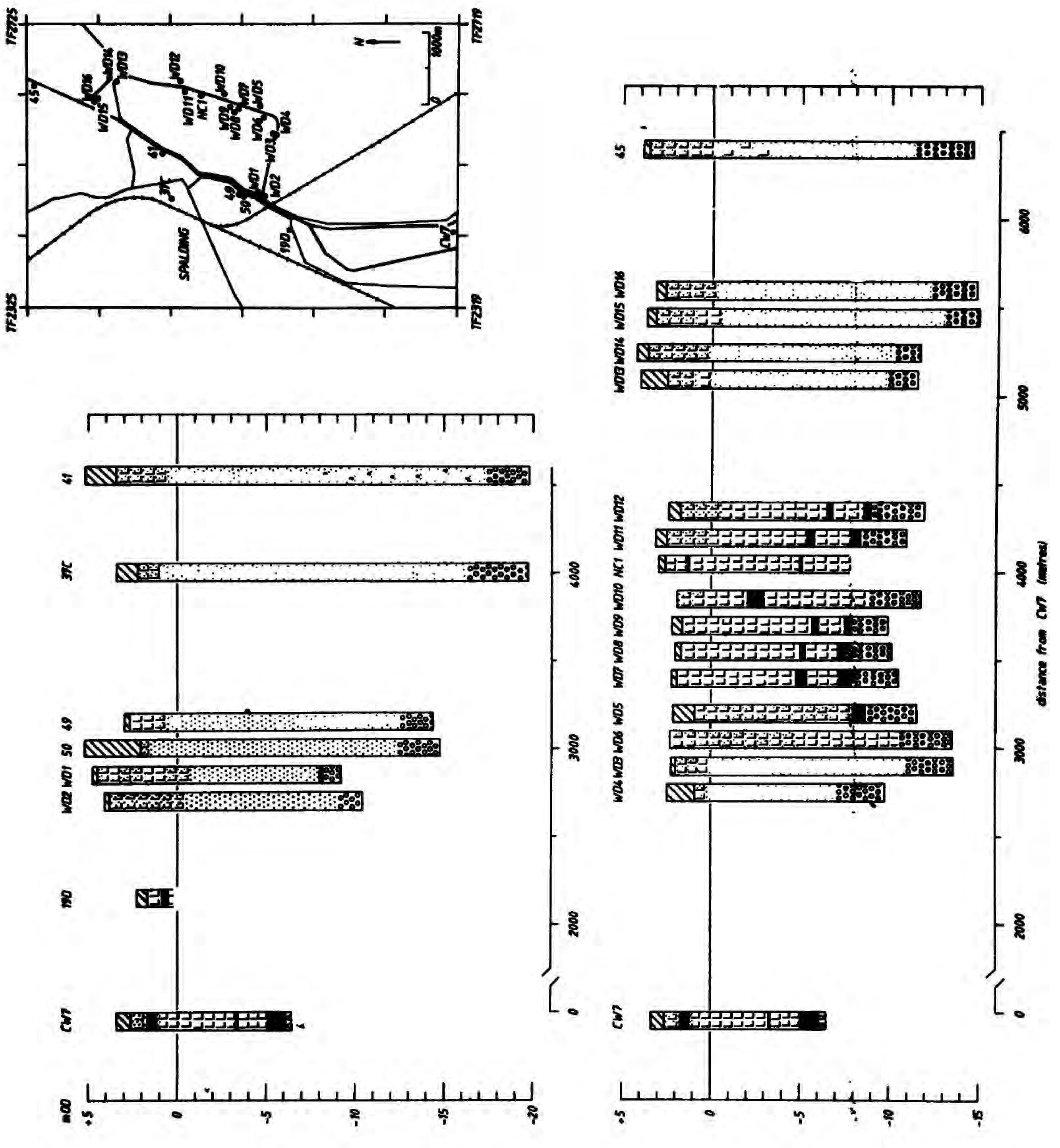


Figure 6.2 : Borehole data from the Spalding - Cowbit Wash area extracted from engineers' logs. The stratigraphy is generalised, showing peat (black shading), sand, silt/clay, shells and basal gravel.

CW3, appears to correlate with those at 19D and NC1 (fig.6.3) and also NC2 (Smith 1970).

Broad conclusions may be made relating to the nature of the inorganic horizons at Spalding and Cowbit Wash. Those at Spalding are generally coarser than at CW7, being either sand or sandy silts, apart from the group between WD7 and WD12 along the eastern side (fig. 6.3). The coarser sediments coincide with the boreholes showing no intercalated peat (WD1, WD5), no basal peat (WD2, 50, 49, 37C, 41, WD4, WD3, WD6, WD13, WD14, WD15, WD16, 45) and the deeper sequences to a gravel layer taken as the base of the Flandrian sequence (especially 37C and 41). These coarser and deeper sediments appear to represent an early channel or estuary of what is now the embanked River Welland. A detailed survey of the Spalding area is necessary to trace the extent of the coarse and fine sequences and their relationship to the transgressive and regressive overlaps.

Section 6.3.2 : Inferred palaeoenvironments

Diatom analyses from CW7 have shown that there were 3 periods of marine sedimentation at that site. Such data are not available for any of the Spalding boreholes except for NC1 and from the site of Romano-British finds close to NC1 where Smith (1970) reports the results of foraminifera analysis. Sample D was from directly below the Romano-British finds at approximately the same altitude as the highest peat at NC1. Sample A was from the surface silts above the same peat bed while B came from the middle of the clastic layer between the two peats in NC1 and sample C was from below the lower peat. Sample A was of clearly estuarine aspect, with a strongly marked marine element, with numerous species intolerent of admixed fresh water. Samples B, C, and D are of more brackish water habitats, showing much lower numbers of species (no more than 20, cf. 50 for sample A). Sample D appeared to have slightly better access to the sea than the restricted brackish water habitats of B and C (Smith 1970).

The results of the foraminifera analysis provide interesting comparison with the diatoms of CW7 (part 5.3). The correlation of the layers below the highest peat at NC1 and CW7 is enhanced by the microfossil analysis. The diatom samples revealed a low energy brackish/marine environment with some variation in aspect to open or estuarine waters and therefore some mixing with fresher water. This is in good agreement with the foraminiferal analyses. However the diatom analysis of the sandy silt above the highest peat at CW7 revealed a freshwater environment quite different to the estuarine surface silts at NC1. The age of the surface silts at CW7 are not known but may be very recent, deposited during the flooding of the Welland washlands during periods of high river discharge.

The organic layers at CW7 were analysed for their pollen content (figs. 5.23 to 5.26) to corroborate the ^{14}C data and to reveal any unconformities in the changes from semi-terrestrial to clastic sedimentation.

It was noted in part 5.3 that the oldest organic deposit at CW7 accumulated in pollen Zone VIIa, c.7000-5000 BP.

No *Ulmus* decline could be defined apart from an overall decline from CW7B to CW7D. An age of *c*.5000BP might be expected for late CW7C or CW7D.

The *Alnus* and *Quercus* curves in LPAZs CW7A to CW7C closely follow Godwin's model for a rise and fall of water table; *Quercus*, along with other tree types, rises immediately prior to clastic sedimentation as *Alnus* frequencies fall, with a reversal of trends at the regressive overlap. The Gramineae, Cyperaceae, and *Typha angustifolia* curves show the expected trends while the fluctuating Chenopodiaceae curve reveals close proximity to a coastal environment through the time interval of these LPAZs. An uninterrupted transgressive and regressive cycle is evident.

The humified wood peat from 860-900 cm. contains no pollen, apart from some Filicales, but this also fits in with Godwins model for the development of relatively drier fen oak woods. Therefore there is good evidence of a fall in watertable prior to the rise subsequent to the next transgression sediments.

The transgressive contact to the second clastic layer is transitional with no unconformity. *Alnus* is replaced by *Quercus*, *Salix* falls, Gramineae and Chenopodiaceae rise and *Typha angustifolia* and the other aquatics decrease.

The third organic layer is very poorly represented at CW7 but is recorded in other boreholes (table 5.10) and dated at Sp-1 by the Institute of Geological Sciences (table 3.1). A short interruption of clastic sedimentation at the salt marsh-freshwater fen transition is represented by the pollen analyses at CW7.

The transition to the highest organic layer appears gradual in the stratigraphy and this is confirmed by pollen analysis. Tree pollen are virtually absent, with the pollen spectra dominated by freshwater fen pollen types, with Chenopodiaceae at the lower boundary.

Therefore pollen and stratigraphic analyses confirm that all of the transgressive and regressive overlaps at CW7 are transitional. The stratigraphic boundary to the surface silts was sharper and since they were shown to be of freshwater origin this is the only contact unsuitable for dating as a sea-level index point. Particle-size analyses (table 5.9) revealed a dominance of clay and silt size particles indicating a low energy depositional environment and the models of both Godwin and Tooley can be used to explain the pollen and stratigraphic changes identified in CW7. Whereas local environmental changes have been compared between Cowbit Wash and Bourne Fen, by reference to the models described in part 6.1, no lithostratigraphic or chronostratigraphic correlation has been attempted due to the lack of borehole evidence in the area between the sites and the absence of ^{14}C data from CW7.

Part 6.4 : Adventurers' Land

Section 6.4.1 : Regional significance

The extent of the intercalated peats and clays recorded at Adventurers' Land was discussed briefly in part 5.4. The 2 new boreholes, AL2 and AL4, can be compared to 3 sections reported by Godwin and Clifford (1938).

Firstly a 15 km. west to east section along the River Nene from the Dog-in-a-Doublet Sluice to Guyhirn railway bridge and continued to Pear Tree Hill (Godwin and Clifford 1938, fig.27) revealed a thickening Flandrian sequence towards Guyhirn with up to 5 peat layers. Only 10 borehole records were used in this section but there is remarkable agreement with AL2 and AL4 (fig. 5.27) in the Cross Guns Public House-B and Bankhouse Farm-G area. The organic layer at c.-4 m.OD is not present at Guyhirn Bridge while the peat layers below that level at Adventurers' Land are recorded at lower levels, down to c.-10.5 m.OD. The correlation of these peat layers must remain relatively uncertain until more detailed sampling is possible.

A second section from the Pigwater at Yaxley, and along the Twenty Foot River to Guyhirn Railway Bridge and then to Wisbech Bridge (Godwin and Clifford 1938 figs. 21 & 26) revealed a less complex sedimentation sequence. From the south-west and along the Twenty Foot River to Guyhirn only one clastic layer was recorded (an X4 sequence). The lowest intercalations of clastic sediments in the Y2/Y4 sequences of Adventurers' Land have been excluded from the area running south-west from Guyhirn towards Whittlesey Mere, between the "islands" of Whittlesey to the north and March and Ramsey to the south (Godwin & Clifford 1938 figs. 21 & 22).

The deepened valley form containing the Flandrian deposits below -4 m.OD in Adventurers' Land is confirmed by the third section from Bankhouse Farm-G to the Old River

Nene 3 km. west of Guyhirn (Godwin and Clifford 1938 fig. 30). The base of the Flandrian sequence falls rapidly from -4.5 m.OD just north of the Twenty Foot River to -6m.OD at Moreton's Leam to -8.3 m.OD at Bankhouse Farm-G (fig. 5.27).

Further evidence from Adventurers' Land from borehole records from Monk & Co.Ltd. show that the valley rises northwards to within 2.3 m. of the ground surface in c. 1.2 km. (fig. 5.27). Therefore with the evidence presently available the Flandrian sequence below -4.0 m.OD at Adventurers' Land is confined to a WSW-ENE running valley deepening towards Guyhirn. The continuation of the valley towards Wisbech where the Flandrian sequence extends to -17 m.OD is not clear since valley forms have only been suggested in a section and not with a grid sampling survey.

Therefore although limited in area the deeper Flandrian sequence at Adventurers' Land may be particularly favourable for recording the earlier sea-level movements. The relationship of the deposits to a marine environment therefore must be assessed.

Section 6.4.2 : Inferred palaeoenvironments

Only the two lowest recorded clastic layers, G1 and G2, have been analysed for their diatom content (Part 5.4). G1 showed a change from a spectrum dominated by epiphytic fresh-brackish forms to a benthonic brackish community dominated by the form Campylodiscus echeneis. The basal 10 cm. of G2, no other samples being analysed, showed no conclusive salinity change, only a slight increase in marine forms compared to brackish forms. Freshwater types were generally absent.

Since no diatoms were present in the organic layers pollen analysis and stratigraphic analysis must be used to identify the nature of change at the sedimentary boundaries.

At AL-2 the Quercus and Alnus curves show very little change, Ulmus values are above 10% except at 840 cm, and cannot be used in the same way as at Bourne Fen to identify changes in water level. The onset of the transgression Gl is only evidenced by a falling aquatics curve and just one Chenopodiaceae and two Plantago maritima pollen grains. There is a trace of sand in both the subjacent dark brown gyttja and in the clayey silt (Gl), and the boundary between the two layers is recorded as lim.1. The regression overlap to the overlying dark brown gyttja shows a receding marine influence; falling Chenopodiaceae and Class 4 herb curves, with an insignificant rise and then fall of aquatics' pollen. Therefore while the evidence for the gradual removal of marine conditions, or specifically brackish as shown by the diatom analyses, appears conclusive the nature of the transgression overlap is more problematic. The diatoms in the lowest level show a more fresh-brackish spectrum than any other analysed, including those from Bourne Fen, Cowbit Wash and Freiston Marsh, there is some sand in both the organic and clastic deposits adjacent to the boundary, and the pollen indicators of salt marsh communities are poor. Therefore the transgressive contact to Gl is the least reliable sea-level index point evaluated so far in this chapter. There appears to have been slight erosion of the transgressive contact in a slightly higher energy, fresh-brackish environment. Further analysis of this clastic layer which has been recorded at lower altitudes (Godwin and Clifford 1938) would be desirable.

The transgressive contact to G2 is represented by Chenopodiaceae at 8.4% (AP + herbs) although the aquatics and Class 2 herbs show a similar rise from the previous level. This may be a result of quite rapid, but transitional, changes from the period covered by AL2C, which indicated a drying out of the fen and possible break in peat accumulation. This was interpreted from the absence of aquatic and Class 2 herbs in AL2C, changes in pollen concentration, the dominance of Filicales spores and abundance of corroded pollen in agreement with Godwin's model. The age difference between the top and bottom of the peat layer was 5580 ± 70 to 6275 ± 125BP and corroborates the interpretation of either very slow peat accumulation or a break in peat accumulation. The very sandy nature of the pre-Flandrian deposits at this site may have made it particularly suitable for recording fluctuations in the water table, possibly equivalent to the donken sites described as favourable locations for sea-level index points by Jelgersma (1961) and van de Plassche (1979). The close proximity of these sandy deposits may also account for the presence of sand at the transgressive overlap of G1 and the fresh-brackish diatom spectrum may have been the result of enriched fresh water seepage through the sand. Such an effect would only be possible before peat accumulation became too thick to reduce the seepage of fresh water.

The peat layer between G1 and G2 at AL2 is correlated with the basal peat at AL4. Pollen analysis of the basal peat at AL4 does not indicate whether it developed synchronously with only the upper peat revealed in AL2 or with the clastic sediment G1 and the basal peat as well. Noticeably there is no equivalent pollen zone to AL2C. The sample from 818 cm., 1 cm. below a quite sharp boundary (lim. 2) to the overlying silty clay, contains only 2 Chenopodiaceae (0.5% AP + herbs) and 2 Spergula-type grains as indicators of approaching marine conditions. Gramineae pollen have decreased, Cyperaceae have increased and aquatics are consistent. Comparison with Bourne Fen would suggest that the sequence to salt marsh conditions is not complete, with an expected fall in Cyperaceae and aquatics and a rise in Gramineae to follow, and therefore slight erosion of this contact may have occurred. This conclusion is supported by the balls of reworked peat, with shells and shell fragments, in the lowest 20 cm. of the clastic layer G2 at AL4.

This transgression came to an end at AL4 at -6.96 m.OD with a compressed monocot. gyttja with Phragmites, some inorganic fraction and shell fragments. The proximity to the salt marsh-fresh water fen transition is evidenced by the Chenopodiaceae, Gramineae and aquatics record. With similar estimates to the basal peat in AL4 the Ulmus curve is up to 19% AP indicating a Zone VIIa age to both peat horizons. No sedimentary hiatus or erosion on the transgression overlap is apparent.

The third peat layer at AL4 at -4.32 to -4.06 m.OD (464-438 cm.) is correlated with an intercalated peat layer at a similar altitude at Bankhouse Farm-G. This is further correlated by Godwin and Clifford (1938) to an intercalated peat at Cross Guns Public House-B and the basal peat in the

Woodwalton-Guyhirn and Yaxley-Wisbech sections. Even though it was not possible to count the sample from 462 cm. the change from inorganic sedimentation, sample 466 cm., to organic sedimentation, sampled at 458 cm., revealed a change in the pollen spectra within LPAZ AL4C. Separated from AL4D solely on the great difference in the Coryloid curve AL4C represents the replacement of salt marsh sedimentation by freshwater fen, indicated by a decline in the Chenopodiaceae curve and a rise in the aquatics curve, totally Typha angustifolia-type, and Class 2 herbs, mainly Rubiaceae. AL4D represents a reversal towards a salt marsh environment with high Chenopodiaceae but still very high aquatics. The rather constant tree curves, apart from the absence of Alnus at 466 cm., and the large changes of the herbs and aquatics percentages and concentrations suggest localised changes close to the saltmarsh-freshwater fen transition.

The absence of Ulmus pollen indicates a post-5000 BP age for this peat layer. This is borne out by the two ^{14}C assays, 4500 ± 50 BP (SRR 1589) for the regressive contact, and 4180 ± 75 BP (SRR 1589) for the transgressive contact. The latter contact is represented by a mixed layer of flames of peat and clay. Slight erosion is suggested but the proximity to a salt marsh environment is evidenced by the pollen spectra. However it is not possible to say, using available data, if there was a time lapse prior to clastic sedimentation.

The base of the highest organic layer, -0.73 to -0.56 m.OD, revealed a fall in Chenopodiaceae, high aquatic values, very low tree pollen frequencies and the occurrence of herbs of disturbed habitats : Senecio-type, Taraxacum-type, Umbelliferae, and Plantago lanceolata. This final regression overlap at AL4 seems transitional and yielded a ^{14}C age of 1845 ± 50 BP (SRR 1588).

It has been seen that models relating changes in the pollen spectra to water level changes are applicable to basal peats, intercalated peats, and surface peats. Changes in the arboreal types may reflect water level changes during the totally freshwater stages while non-arboreal pollen changes are particularly good indicators of the change to saltmarsh conditions and vice-versa. Therefore the models of Godwin, Tooley, and Kidson and Heyworth are combined in part 6.7.

Part 6.5 : Estimation of the altitude, age, and meaning of transgressive and regressive overlaps.

A sea-level index point on a time/depth diagram is dependent on the assessment of the following criteria, each discussed in a separate section :

Section 6.5.1 : measurement of the present altitude.
Section 6.5.2 : estimate of the original altitude.
Section 6.5.3 : indicative meaning of the sample.
Section 6.5.4 : age of the sample.

Section 6.5.1 : Measurement of the present altitude

Errors may arise at three stages of measurement ing the measurement of depth, e.g. in a borehole, during levelling of the site to an Ordnance Survey benchmark, and finally with the assessment of the benchmark's accuracy to OD Newlyn.

The measurement of depth will vary greatly depending on the situation of the sample, e.g. free face exposure or a vibrocore sample from the offshore zone. In the present study careful fieldwork should allow an accuracy of ±1 cm. for hand coring equipment. This however assumes that the borer was exactly perpendicular to the zero plane of the country. This assumption may not be valid and the real depth may be given by $D_m.\text{Cos}\phi$ where D_m is the measured depth and ϕ the mean angle between the borer and the vertical plane. The error is therefore depth dependent and unidirectional, equal to c.0.4 cm/m. where $\phi = 5^\circ$ and 1.5 cm/m where $\phi = 10^\circ$, the real depth always being less than the measured depth.

This only applies to hand coring techniques. For commercial boreholes while the core is more likely to be vertical the measurement of depth is much less reliable. Observation of techniques in the field suggest a rough estimate of ±5 cm. for undisturbed U-4 techniques and perhaps ± 25 cm. for disturbed bulk samples.

Further depth measurement error is equipment-dependent. Piston corers may reveal some compaction of sediment on extrusion and less than 100% sample retrieval. Estimates of these equipment-sample errors can always be made. The error is unidirectional if the sample is extruded from the same end of the chamber through which it was sampled; the measured depth always being greater than the real depth. Within the present research only one metre-unit of sediment was affected by such error, but this unit was totally organic and therefore none of the transgressive/regressive overlaps is affected.

Such problems do not occur with the Russian-type sampler, however the poor quality of samples from the Duits-gouge sampler has already been noted in part 5.3. The depth error is estimated as up to +20 cm. for the Cowbit Wash sequence, i.e. it is unidirectional, but it is sediment-dependent and limited to within—1 m. sample-lengths. It was noted that the Duits-gouge sampler was in good agreement with the Russian sampler in the predominantly organic sequences in Bourne Fen. Furthermore the Duits-gouge sampler has not been used to provide samples for ^{14}C-dating.

Within the present study the levelling of the site to a benchmark was given an accuracy of ± 2 cm. in part 4.2 for the longest transect. However for Adventurers' Land the benchmark was so close that no levelling error need be considered.

The importance of the final error in the measurement of the present altitude of the sample is scale-dependent. This error is the assumed accuracy of the Ordnance Survey benchmark. Since the accuracy of levelling is dependent on the length of the survey line from Newlyn, and varies for the order of benchmark and levelling (Allan et al. 1975), it can be assumed that within 0.5 km. benchmarks are accurate to ±0.01 m. relative to each other but for inter-regional comparison more error is involved. This is estimated at ±0.15 m. for England and Wales and ±0.20 m. for Scotland relative to O.D. Newlyn (Eady 1976).

Furthermore the accuracy of the measured altitude of a stratigraphic boundary is dependent on the sampling density, i.e. the number of boreholes. Any stratigraphic boundary can be viewed as a terrain surface and therefore to get an accurate assessment of the surface the sampling density must be matched with the local terrain roughness (Makarovic 1973). The analysis of the stratigraphic boundaries in Bourne Fen, part 5.2., gives an indication of the land terrain roughness, i.e. the undulations of stratigraphic boundaries over short distances.

It was argued that the mean and standard deviation of the altitude of transgressive and regressive contacts should not be used to describe such sedimentary boundaries (cf. Tooley 1978a). The data for Bourne Fen, table 5.2 show quite different values dependent on the data set, (i.e. scale) used, and a linear regression solution showed that the altitude of the boundaries were highly correlated with distance for a section c.2 km. in length. The use of the mean and standard deviation can also be rejected on hypothetical grounds since the basic assumption is of a horizontal surface, therefore precluding the well-documented tapering of marine sediments landwards and semi-terrestrial sediments seawards. However the mean and standard deviation are useful to describe the altitude of a contact where it is assumed horizontal.

The altitudinal range for the transgressive contact was measured as 13 cm. in BFP1 and 11 cm. in BFP2, and the regressive contact as 8 cm. and 13 cm. respectively, while the standard deviation ($\hat{\sigma}$) for T and R for subset 1, table 5.2, was ±0.15 and ±0.14 m. Furthermore a regional slope to the east was indicated by the linear regression solutions yet the BFP1 and BFP2 sections both show a slope within the pits to the west. These indicate the terrain roughness, which may be related to a local dendritic pattern on the former marsh superimposed on a regional slope.

Therefore the accuracy of each borehole as an estimate of the contact's altitude is proportional to the sampling density. If a single borehole was to represent an area the size of one of the pits the error, total range, would be *c.* ±6 cm., while a single borehole assumed to represent the area 180 x 30 m. the standard deviation ($\hat{\sigma}$) given by 13 estimates was up to ±14 cm. This gives 95% confidence limits of *c.* ±0.30 m. These assume a horizontal surface for the area covered.

The estimated errors affecting the measured altitude of stratigraphic boundaries are shown in table 6.1.

Table 6.1 : Errors affecting the measured altitude of stratigraphic boundaries (present study)

identification of boundary		±0.01 m.
measurement of depth - handcoring		±0.01 m.
" " - commercial U4		±0.05 m.
" " - commercial disturbed		±0.25 m.
compaction & extrusion of piston cores		-0.06 m.
Duits gouge (not for ^{14}C samples)		-0.20 m.
angle of borehole	up to	+0.04 m.
levelling to nearest benchmark	up to	±0.02 m.
accuracy of benchmark to OD		±0.15 m.
sampling density - pit size	*c.*	±0.06 m.
" " - 180 x 30 m.	*c.*	±0.14 m. ($\hat{\sigma}$) 95% limits = ±0.30 m.

Section 6.5.2 : Estimate of the original altitude

The majority of the materials dated in the Fenland for use as sea-level index points are not presently at the altitude at which they were deposited : consolidation of the underlying peats, clays and silts is an important factor. There appears no satisfactory method of allowing for consolidation even though van de Plassche and Preuss state explicitly (1978 p.3)

> "Relative sea-level curves based upon index points that have been subject to compaction for which no reliable correction can be applied, are of very little use to the Sea-Level Project".

However this criterion may lead to a bias of the data base subject to the theoretical observation that dates from peats on the unconsolidated pre-Flandrian sands and gravels are the most suitable material for sea-level index points.

Two methods of allowing for consolidation of sediments have been employed in sea-level studies. Either to use dated samples not subject to consolidation (e.g. Jelgersma 1961, 1979, van de Plassche 1979) or to compute a correction factor (Kidson and Heyworth 1973).

The assumptions behind the dating of peats resting on pre-Flandrian sands have been more strictly adhered to since Jelgersma's early statements (Jelgersma 1961), and the term basis peat has been suggested where careful study of the stratigraphy, the regional slope and nature of the pre-Flandrian sediments, and pollen analysis of the peat has revealed those samples which reflect the general rise of the watertable and therefore sea-level (van de Plassche 1977).

However the fundamental argument against using solely the basis peat is that the relationship of peat growth to sea-level may not theoretically allow for falls in sea-level. Indeed Jelgersma (1979 p.243) states that

> "only the points located in the lowest places for a given age represent a ground-water table that coincide with sea-level. In this way a smooth curve is obtained. All aberrations must be considered as errors and not as fluctuations of sea-level."

This is quite irrational. It would mean that the indicative meaning (see section 6.5.3) of a sample and its reliability is age-dependent and furthermore it ignores stratigraphic changes.

A better approach is that adopted by van de Plassche (1979) who uses a close and regular sampling interval to reveal any variations in the speed of the local water level rise. Even so, existing fen vegetation and peat will act as a reservoir and only when a fall in water-table is sufficient to overcome this local effect will peat growth cease. Therefore if the analysis of many ^{14}C dates (van de Plassche 1979) does reveal periods of reduced peat growth then an important water-level fluctuation is probably recorded. However the complex relationship between local and regional water-tables, river discharge, and sea-level, especially with a coastline that shows great horizontal movements, means a possible change in the indicative meaning of basis peat samples as indicated by Godwin (1940a). When detailed analysis of basis peats is completed (van de Plassche 1979) it will be most interesting to compare the periods of most rapid and reduced peat growth to the timing of the deposition of clastic sediments. For the present, however, the dating of basis peats is believed to produce a biased sample.

The second method used to allow for consolidation is to compute a correction factor for each sample. Kidson and Heyworth (1973 p.578) state:-

> "The precision with which the effects of compaction can be estimated varies with the type of sediment. The behaviour of clays under applied overburden pressures is fairly well understood. Peats, however, are of such varied types and undergo such complicated changes during humification, that figures can only be approximate. The height of each dated peat before compaction has been calculated, following the method of Skempton (1970)."

However the discussion of the original paper (Skempton 1970 p.410) clearly states that

> "clays with a high carbonate or organic content had been excluded from the paper as the rather fragmentary information on such sediments suggested that they behaved in a manner quantitatively different from the commonly occurring inorganic clays."

The former is exactly the type of sequence to which Kidson and Heyworth applied the correction factors. Furthermore they showed no actual examples of how they calculated the correction factor nor how they dealt with the consolidation of peat layers. Even though they said that the results must be approximate no indication of an error margin was given. Until further empirical studies are carried out such correction factors should not be applied.

A different approach which may prove useful when more data are available is the multivariate analysis of data sets similar to the Bourne Fen data for which exploratory statistical analyses were carried out in part 5.2.

It was acknowledged that sufficient data were not available to draw any firm conclusions but certain relationships were apparent. The seaward slopes, 0.45 m/km. for the regressive contact and 0.87m/km. for the transgressive contact, were calculated from a non-random data set and other relationships could be investigated with further analysis. For example, the changes in the altitude of the pre-Flandrian surface in the region of 27a-P1 (figs. 5.6 and 5.7) is much greater than for T and R while the slopes of T,B and R with distance, table 5.3, for set 1 are all greater than for sets 2 and 3. The difference is greatest for B but the difference for T and R may be an effect of consolidation. However a figure such as 90%, the maximum value suggested by Jelgersma (1961) is not likely. Furthermore fig. 5.7 shows an increase in the altitude of the pre-Flandrian surface between 1400 and 2000 m. from BF16. The slope of the transgressive and regressive contacts for the 3 points given does not reflect the c.1 m. change in B. The further development of this type of inquiry is awaited.

Consolidation remains a problem in the estimation of the accuracy of sea-level indicators. No satisfactory method of correction is available. Multivariate analysis of large data sets is suggested, for problems of scale can then be analysed by subdivision into smaller data sets. Regional slopes, in three dimensions by trendsurface analysis, can be calculated for the various surfaces and residuals plotted. It might then be hypothesized that positive residuals in the pre-Flandrian surface should correlate with positive residuals in the transgressive and regressive contacts if consolidation is an important consideration. This type of analysis has the advantage over linear regression, since it was assumed for Bourne Fen that the line of the section followed the regional seaward drainage pattern whereas a dendritic palaeodrainage pattern is more likely.

Overall it is clear that larger data sets should be encouraged to be used rather than the detailed analysis of special boreholes which is the situation that predominates at the moment. It would be very interesting to apply the correction factors as outlined by Kidson and Heyworth (1973) to a large data set to see whole stratigraphic sections prior to consolidation are represented (cf. Godwin and Vishnu-Mittre 1975 fig. 22). Large data sets could then be used in the development of computer simulation models of sequence development in an attempt to overcome the apparent impasse concerning the problem of consolidation.

Finally the consideration of the time factor must be included in the assessment of consolidation. To ley (1978a) has noted, from a paper by MacFarlane, that the primary consolidation of the peat, which can account for 50% of total consolidation, occurs extremely rapidly when a load is applied. Therefore a uniform correction factor cannot be applied proportionally through a single core for separate transgressive and regressive overlaps since the lowest sediments in the core will have completed much more of their total consolidation. The effects of consolidation of peat by the overburden of a further 1 m. of overlying peat is not known. Is there sufficient time for primary consolidation to be completed? Similarly is the overburden of the sediment and waterbody during clastic sedimentation sufficient to account for primary consolidation or even part of secondary consolidation? A further consideration is the effect of the removal of overburden,causing the occurrence of over-consolidated layers such as those recorded by Greensmith and Tucker (1973) in the outer Thames estuary.

Therefore for a more accurate assessment of consolidation it is suggested that many ^{14}C data from a small area would be necessary to consider the effect of time so that the rate of peat growth, vertically at different sites, could be compared with the initiation of peat growth up a sloping pre-Flandrian surface, and the altitude and extent of transgressive and regressive overlaps. These considerations are included in the development of a model in part 6.7.

For the present study no empirical consolidation correction factors have been applied since no reliable method for their calculation is available.

Section 6.5.3 : Indicative meaning

The indicative meaning of a dated sample is the relationship of the environment in which it accumulated to a reference tide-level (van de Plassche 1977). Since sea-level curves are seldom produced from a single type of dated material, and to allow for comparison between different areas, each sample is related to a reference tide-level. This tide-level may not be constant and therefore the interpretation of composite sea-level curves must take into account two factors; firstly the accuracy of the indicative range for the dated sample, and secondly the accuracy of the tide-level to which it is referenced. Whereas there is an obvious advantage in dating the same type of material for all points in a sea-level curve rigorous adherence to this principle may result in the omission of some suitable data.

Most of the Fenland ^{14}C dates, chapters 3 and 5, are on Phragmites peat/gyttja, monocot. peat, and woody detrital peat. Where possible any wood dated should be shown to be *in situ*.

There is a general lack of information on the contemporary relationships between sea-level, soil conditions, and the succession of coastal plant communities (Tooley 1978a). When this is extended to those communities which form peat the lack is even greater. The main reason is that sites where such relationships could exist have been utilized and extensively altered by man. Five examples can be cited which are barely the equivalent of hypothesized fossil sequences.

Tooley (1978a) describes a sandy *Phragmites* peat forming *c*.15 cm. below MHWST at the Alt Mouth. However the *Phragmites* utilize freshwater seepage from the sand dunes and together with the sandy nature of the peat do not present a typical sequence compared to the fossil ones.

On Loch Scridain (Gillham in Tooley 1978a) a mixed grass, sedge and rush community was recorded from 23 to 59 cm. above MHWST followed by a transition to a moorland community above a deep accumulation of peat. However it should be noted that this site at the head of a narrow sea loch may be subject to quite different hydrological and tidal conditions to the wide expanses of marsh envisaged for the fossil Fenland sequences.

Tooley (1978a) also mentions the example of Cold Spring Harbour, USA, where fen wood peat is seen to accumulate 80 cm. below spring tide level while a reedswamp peat occurs from 70 to 200 cm. below the same datum. These values are much lower than any other quoted levels and the local conditions really require accurate re-investigation since if they are typical values then the indicative meaning of certain dated materials will have to be revised.

Ranwell (1974) described the saltmarsh to tidal woodland transition in the Fal Estuary but the lack of an accurate tide-level relationship, unnatural hydrological conditions caused by an artificial causeway and bridge crossing the narrow estuary, and high river sediment loads due to kaolin workings within the catchment suggest that the vegetation levels and marsh development may not be particularly useful comparisons to fossil situations.

Kidson and Heyworth (1979) suggest that the best material for accurate ^{14}C dating of sea-level movements is submerged forest wood, usually oak. However Heyworth's (1978) adherence to inter-tidal 'submerged forest' peat is too restrictive and based on poorly tested theory. Firstly the restriction to such sites provides an extremely biased sample; where the present inter-tidal zone coincides with a location at which an earlier coastline crossed the line of the present one and is subsequently revealed as the result of favourable isostatic movements and coastal processes (Heyworth 1978 fig. 2). Secondly his explanation for the genesis of a relatively drier environment upon which the forest may grow; rapid and temporary inorganic deposition following the breaching of a coastal barrier or river bank, is hardly applicable as a model to explain the pollen, diatom and particle-size distribution records from Bourne Fen, Cowbit Wash, Adventurers' Land and Downholland Moss. But it must be said that submerged forests can be extremely good indicators of past sea-level movements if there is careful stratigraphic and microfossil analysis, as argued by Tooley (1979).

Kidson and Heyworth (1979) suggest that the oak trees at Roudsea Wood, Morecambe Bay, are of great significance as sea-level indicators. However they fail to mention a few important facts relating to the site. Firstly the saltmarsh is very narrow, <100 m. in some instances, it is in a narrow estuary, with a bridge and embankment constructed across the mouth in the nineteenth century and with the input of freshwater from the Windermere catchment the hydrological conditions cannot be representative of the palaeoenvironments of the Fenlands or Somerset Levels or south-west Lancashire. Furthermore the trees are often rooted in a shallow soil on solid rock with a few decimetres of organic silts and clays around their roots. Thus the present position of the oaks is more indicative of the basal forest of the Fenland rather than those found in intercalated peat horizons.

Therefore the question to be answered is whether any reliable estimate can be given for the range over which certain vegetation communities occur. Preuss (1979) gives the indicative range of Phragmites from a fossil swamp that produced peat accumulation as 70 cm. He does not state whether this is tide-dependent or not. Clearly, indicative ranges should be calculated, from several localities in different tidal environments, as a function of tidal parameters. However suitable present communities are rarely encountered in sufficient locations to allow site-dependent factors, e.g. estuary shape, tidal range, bedrock, freshwater input, to be assessed.

However the present use of indicative range (e.g. van de Plassche and Preuss 1978, Streif 1979b) may result in a greater error-box, for altitude, than is necessary. The rule that deposits found one above the other without an hiatus in a sequence must have formed in environments encountered side by side in space should be remembered. Therefore the transition from saltmarsh to freshwater fen does not have an indicative range equal to the range of the saltmarsh community or the freshwater fen community, whichever is dated, but the range of the transition from saltmarsh to freshwater fen. The altitudes from present localities where either of the components is absent will give spurious indicative ranges. The variation of altitudes of mature saltmarshes in Morecambe Bay (Tooley 1978a) does not represent the indicative range of the saltmarsh to freshwater fen transition. Therefore the level where pollen diatom, macrofossil and stratigraphic analysis reveal a change in sedimentary environment provides the best sample for ^{14}C dating. In this way the indicative range is reduced and tendencies of watertable movement can be evaluated. Dated samples from the middle of homogeneous peat layers are therefore less useful sea-level index points.

Kidson and Heyworth (1979) state that an alteration of ±10 cm. in altitude will alter the pattern of oak regeneration at the coast, therefore if it can be assumed that oak trees are ready to colonize the site as soon as is feasible, as should be evident from the pollen analysed, then the indicative range may be taken as 20 cm.

The indicative meaning of commonly dated materials is shown in table 6.2 along with the default values applied by the Hannover group for the evaluation of IGCP Project 61 sea-level data (Streif pers.comm.).

If the two sets of indicative meanings shown in table 6.2 are applied to model data it can be seen that the comparability of the curves is dependent on the tidal parameters. This is shown in fig. 6.3 and table 6.3. The stratigraphy shows a Y2 sequence with seven possible sea-level index points represented. Four model "curves" are calculated, using the alternative indicative meanings shown in table 6.2 for 2 sets of tidal data. Tidal data set 1 is "real", giving the mean values for 3 stations along the southern end of the Wash (Admiralty Tide Tables 1980) while tide data set 2 is a manipulation of set 1; relative to the same mean tide level the other parameters are given values 25% of the original. The calculation of the movement of MTL during the period of samples 1-7, assuming a constant tidal regime, is shown in table 6.3 and fig. 6.3. The coincidence of the two "curves" for data set 2 confirm that the default values used in the IGCP Project No. 61 result from present day

Table 6.2 : Indicative range and reference water level for commonly dated materials

Default values, IGCP Project 61 (Streif pers.comm)

	Indicative range	reference water level
Phragmites peat	70 cm	MHT + 18 cm
Sedge peat	40 cm	(b)MHT + 20 cm (est.)
Fenwood peat	80 cm	(a)MHT + 40 cm
Moss Peat (not in raised bog)	10 cm	(b)MHT + 20 cm (est.)
Puccinella grasses	40 cm	MHT ± 0 cm
Spartina grasses	30 cm	MHT - 30 cm

(a) only in coastal fen and level backswamps, otherwise groundwater table

(b) decreases with distance from open coast, approaches MSL in lagoons and coastal backswamp.

(est.) estimate only.

Proposed values (inferred from Godwin 1940a, Kidson and Heyworth 1979, van de Plassche 1979, Tooley 1979)

	Indicative range	reference water level
Phragmites or monocot.peat:		
- directly above saltmarsh	20 cm	((MHWST + HAT)/2)-20 cm
- " below " deposit	20 cm	MHWST-20 cm
- " above fen wood deposit	20 cm	MHWST-10 cm
- " below " "	20 cm	((MHWST+HAT)/2)-10 cm
- middle of layer	70 cm	infer from stratigraphy
Fen wood peat:		
- directly above *Phragmites* or salt marsh	20 cm	(MHWST+HAT/2)
" below *Phragmites* or salt marsh	20 cm	MHWST
Basis peat:	?80 cm	MTL to MHWST

Table 6.3 **Model data to compare indicative meanings**

Tidal data 1

HAT = 4.73
M^I = 4.27
MHWST = 3.80
MHT = 2.89
MHWNT = 1.97
MTL = 0.49
M^I = (HAT + MHWST)/2

Sample altitude

1 = 0.04
2 = 1.04
3 = 1.16
4 = 1.44
5 = 1.56
6 = 1.64
7 = 1.76

Tidal data 2

HAT = 1.55
M^I = 1.44
MHWST = 1.32
MHT = 1.10
MHWNT = 0.88
MTL = 0.49

Indicative meaning - set 1					Indicative meaning - set 2			
proposed - 1		IGCP -1		Sample	proposed - 2		IGCP - 1	
M_p	R	M_p	R		M_p	R	M_p	R
0.49 to 3.80	0.80	0.49 to 3.29	0.80	1	0.49 to 1.32	0.80	0.49 to 1.50	0.80
3.80	0.20	3.29	0.80	2	1.32	0.20	1.50	0.80
3.60	0.20	3.07	0.70	3	1.12	0.20	1.28	0.70
4.07	0.20	3.07	0.70	4	1.24	0.20	1.28	0.70
4.27	0.20	3.29	0.80	5	1.44	0.20	1.50	0.80
3.80	0.20	3.29	0.80	6	1.32	0.20	1.50	0.80
3.60	0.20	3.07	0.70	7	1.12	0.20	1.28	0.70

Calculated value of MTL					Calculated value of MTL			
proposed - 1		IGCP - 1			proposed - 2		IGCP - 2	
MTL	R	MTL	R	Sample	MTL	R	MTL	R
0.04 to -3.27	0.80	0.04 to -2.76	0.80	1	0.04 to -0.79	0.80	0.04 to -0.97	0.80
-2.27	0.20	-1.76	0.80	2	0.21	0.20	0.03	0.80
-1.95	0.20	-1.42	0.70	3	0.53	0.20	0.37	0.70
-2.14	0.20	-1.14	0.70	4	0.69	0.20	0.65	0.70
-2.22	0.20	-1.24	0.80	5	0.61	0.20	0.55	0.80
-1.67	0.20	-1.16	0.80	6	0.81	0.20	0.63	0.80
-1.35	0.20	-0.82	0.70	7	1.13	0.20	0.97	0.70

Mp: Mid-point
R : Indicative range

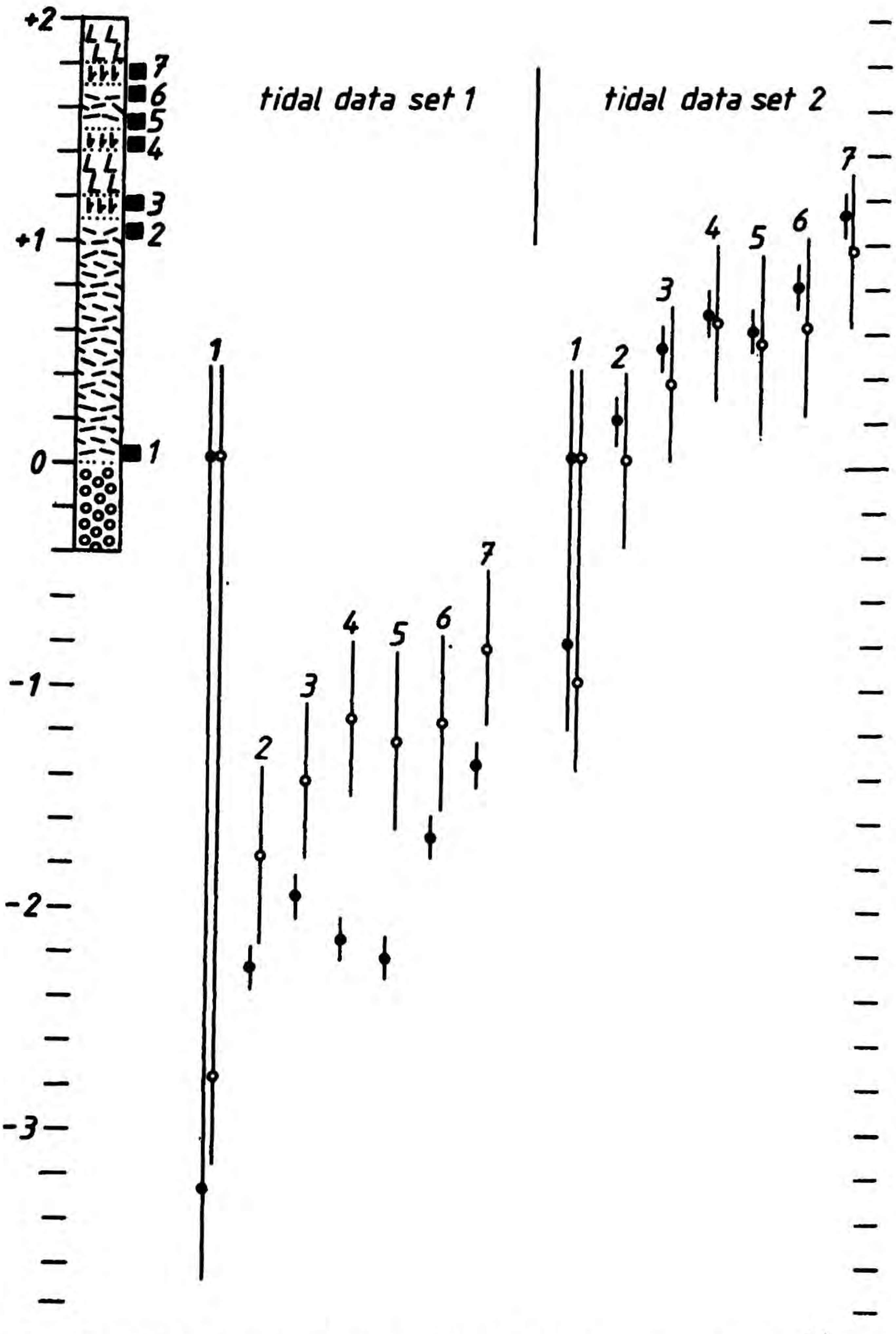


Figure 6.3 : Reconstruction of MTL using model data. Seven ^{14}C samples, of ages 1-7, are taken from the stratigraphic section shown. The inferred heights of MTl at points in time 1-7 are calculated for 2 sets of data (see text and tables 6.2, 6.3, 6.4) and 2 methods of assessing the indicative meaning of sea-level index points : IGCP values (open circles), proposed values (shaded circles). Close agreement for the low tidal range data and less agreement for high tidal range data suggests more research is necessary to relate indicative values to proportions of tide levels (eg. "proposed values") rather than constant differences (eg. IGCP values).

studies in zones of relatively small tidal range. The applicability of these default values to other areas is not proven and the evidence from the UK suggests that the alternative values shown in table 6.2 may be better (e.g. Godwin 1940a, Devoy 1979, Kidson and Heyworth 1979, Tooley 1979).

Fig. 6.3 also shows the care needed in assessing the tidal conditions at the time of deposition. The reliability of a sea-level index point must be considered in light of the following factors.

Ordnance Datum Newlyn does not represent mean tide level, in effect the same as "mean sea level" (Jardine 1975a), for the whole of the United Kingdom. The national datum was mean sea-level at Newlyn for the period 1915-21 but it is now 0.086 m. below mean sea-level at that location (Jardine 1976). Therefore it is necessary to know the accuracy of a local tide-level and its relationship to OD. This is important for height correlation between different coastal units and the relative coarseness of the Admiralty Tide Tables for particular estuarine situations should be noted (Kidson and Heyworth 1979). Everard (1979) states that annual mean sea-level tends to have a standard deviation of 2 or 3 cm. from the datum mean but this error is easily covered by the ±0.05 m. error in the Admiralty Tide Tables (1980) where the tide levels, relative to chart datum, are rounded off to the nearest 10 cm.

For comparison of fossil levels to the present the relationship of the reference tide-level used to OD must be assessed. The problem arises in which tide-recording station

Table 6.4 : Tide levels in the Wash

Levels relative to OD, in metres (source: Admiralty Tide Tables 1980)

	HAT*	M^1	MHWST	MHWNT	MTL	MLWNT	MLWST	LAT*
Hunstanton+	4.25	3.90	3.55	1.75	0.30	-1.25	-2.85	-3.65
Kings Lynn	4.77	4.32	3.87	2.07	0.67	-1.23	-2.03	-2.53
Wisbech Cut^x	5.20	4.70	4.20	2.30		-1.00		
Tabs Head	4.80	4.30	3.80	1.90	0.35	-1.30	-3.00	-3.90
Boston	4.63	4.18	3.73	1.93	0.43	-1.07	-2.87	-3.97
Skegness+	3.95	3.55	3.15	1.55	0.15	-1.25	-2.85	-3.75

* extrapolated values

\+ excluded from "inner Wash" values

^{x} incomplete data, excluded from further calculations

$M^1 = (HAT + MHWST)/2$

NB. original data, i.e. chart datum, given to ± 0.05

Mean values and correction factors (± 1 σ)

	all (5)	inner Wash (3)
HAT	4.48 ± 0.37	4.73 ± 0.24
M^1	4.05 ± 0.33	4.27 ± 0.08
MHWST	3.62 ± 0.29	3.80 ± 0.07
MHWNT	1.84 ± 0.20	1.97 ± 0.09
MTL	0.38 ± 0.19	0.49 ± 0.13
MLWNT	-1.22 ± 0.09	-1.20 ± 0.12
MLWST	-2.72 ± 0.39	-2.63 ± 0.55
LAT	-3.56 ± 0.59	-3.47 ± 0.79
M^1-MHWST	0.43 ± 0.06	0.47 ± 0.03
MHWST-MTL	3.24 ± 0.16	3.32 ± 0.13
M^1-MTL	3.67 ± 0.20	3.78 ± 0.15
HAT-M^1	0.43 ± 0.06	0.47 ± 0.03

should be used since many are situated some distance away from the open coast. The variability of the data is shown in table 6.4. The preferred levels for the Fenland sites are those calculated from the 3 "inner Wash" stations.

The total error involved from the tidal data is dependent on the nature of the study. For within-Fenland studies only the "correction factors" between different tide-levels are important. Similarly for correlation between regions, e.g. the Fenland, North-West England, Bristol Channel and Cardigan Bay, where the reference datum is a present tide-level the same "correction factors", calculated for each region, can be used, but if the relationship to OD is required then the mean value, and standard deviation, of the tide-level estimate must be used. For the Fenland data the standard deviation, for the tide data, to draw a curve of MHWST from the commonly dated materials - "proposed values" in table 6.2 - is ±0.03 m., table 6.4, or up to ±0.15 m. for a MTL curve. To relate the movement of MHWST to OD the additional error is given by a standard deviation ±0.07 m., or ±0.13 m. for MTL.

It is possible to ignore the "correction factor" error by indicating the reference tide-level of each data point on the sea-level curve (Streif 1979b) but this is considered less satisfactory in light of the comparisons between the "IGCP" and "proposed" indicative meanings in tables 6.2 and 6.3 and fig. 6.3.

All of the relationships to tidal conditions need not have remained constant through time and the understanding of palaeo-tidal changes is fundamental to the correlation of sea-level curves from different areas. The problem is highlighted by Tooley (1979 p.505):

> "The oscillating sea-level curve traces the change in mean high-water mark of spring tides in West Lancashire. From this curve, a mean sea-level or mean tide curve cannot be constructed assuming a constant tidal relationship since the present, contrary to former practice, because changes in palaeotidal amplitudes have not yet been established for this area."

Therefore if the present tidal conditions cannot be referred to earlier conditions, then no correlation of altitude can be made, either for a single curve consisting of index points referred to different tide-levels or for regional comparison. Therefore the evaluation of isostatic movement (e.g. Kidson and Heyworth 1978, Mörner 1976b) for areas with differing tidal conditions is dependent on the precept of constant palaeotidal relationships.
It is necessary to avoid a circular argument, but where a constant palaeotidal range is assumed and the corrected curve fits in with other independently established results then this may lend support to a theory of little or no change in tidal conditions. The whole problem of palaeo-tidal changes needs evaluating if detailed inter-regional altitudinal changes are to be studied, since the form of a local sea-level curve will vary if different tide-level indicators are used. Only in favourable sedimentary conditions has the palaeotidal range been evaluated (Roep _et al_. 1975) but the evidence is not totally convincing. However it has been claimed (Jelgersma in Streif 1979c) that the palaeo-tidal range for the last 4000 years

has been constantly 2 m. in the Netherlands. Further development in this research field is awaited.

Therefore the errors involved in assessing tidal relationships and indicative meanings can be reduced by studying a small homogeneous area, "small" being dependent on tidal complexities, coastal morphology, isostatic movement and, in practice, information available. The errors discussed have a greater influence on the absolute, cf. relative, tide-or sea-level solution and on between-area correlation. Accuracy will be increased by comparing dated material from similar palaeoenvironments.

Section 6.5.4 : Age of the sample

Organic layers are used to give age limits for periods of clastic sedimentation. Once the indicative meaning of the organic sediment is assessed the next consideration is the accuracy of the ^{14}C date.

Streif (1972) and Churchill (1970) have shown that Phragmites peats can provide unreliable dates while Kidson and Heyworth (1979) have suggested that saltmarsh peats may be equally unsuitable.

Problems have been encountered in the dating of Fenland Flandrian sequences (see also Downholland Moss in table 1, Tooley 1978a) : the Welney and Saddlebow sites were discussed by Churchill (1970) and in chapter 3. Discrepancies were noted for adjacent samples from Bourne Fen (tables 5.6 & 5.8), the implications of these in terms of Fenland chronology are discussed in the next chapter but the possible causes of error are now assessed.

The main sources of error in the ^{14}C assays from Bourne Fen are likely to be from either the penetration of younger roots, presumably Phragmites, or by the inwashing of older organic material. The latter is always likely in coastal fen deposits with intermittent overland flow of water. Care was taken to remove the visible remains of Phragmites although the samples from the regressive overlap of BFP1 were extremely rich in well preserved monocot. rootlets and therefore only the largest rhizomes were then removed. These samples showed high Gramineae pollen frequencies indicating that at least some of the monocots. were contemporaneous with the sediment accumulation.

The ^{14}C samples from Bourne Fen were submitted on two occasions and the second batch, Hv 9264 to 9268, may be more reliable, a greater sample size was sent and the removal of rootlets was more thorough.

The 10 dates from the Bourne Fen site noticeably fall within 2 age groups, 3400-3600BP and <3000BP, but only in the regressive overlap of BFP1 is there a consistent age gradient.

The lack of an age gradient for the transgressive overlaps may be due to allochthonous older sediment redeposited during the stages prior to clastic sedimentation (see also Behre et al. 1979 p.101). Upwards of 30% contaminant aged 4500BP would be required to age a sample from 3300 to 3500BP (Olsson 1979 fig. 5). Such contamination was not evident in either pollen or stratigraphic analysis, but may be impossible to identify anyway. No Phragmites rhizomes were seen to pass completely through the clastic sequence and therefore any younging effect would be associated with the plant succession during the transgressive phase. It is interesting to note that these age inversions coincide with the time of submission of the samples, the youngest and lowest samples, Hv9265 and Hv9268, may have possibly suffered bacterial activity during storage.

No rational decision favours either the younger or older dates, the arguments for both are equally valid. A possible solution is to combine the two dates for each site to give a mean estimate.

Even though the samples differ by 15 cm. in the vertical succession this is not great compared to other altitudinal errors. However in terms of palaeoenvironmental reconstruction this is far from the perfect solution.

Olsson (1979) gives the following equations for the estimate of the mean age and error of 'n' samples:

$$\bar{x} = \frac{\frac{1}{\sigma^2_1} \cdot x_1 + \frac{1}{\sigma^2_2} \cdot x_2 + \ldots \frac{1}{\sigma^2_n} \cdot x_n}{\frac{1}{\sigma^2_1} + \frac{1}{\sigma^2_2} + \ldots \frac{1}{\sigma^2_n}}$$

$$\sigma_m = \sqrt{\frac{1}{\frac{1}{\sigma^2_1} + \frac{1}{\sigma^2_2} + \ldots \frac{1}{\sigma^2_n}}}$$

$\bar{x}$ = mean age

σ_m = standard error

These give mean values of 3448 ± 40BP at BFP2 and 3451 ± 47BP at BFP1.

The regressive overlap at BFP2 provided a very complicated series of assays. Hv8647 contained too little carbon for a reliable assay due to allochthonous inorganic particles, and therefore may also contain inwashed older carbon. However the great difference between the adjacent samples Hv8646 : 3435 ± 65BP, and HV9264 : 2635 ± 100BP is difficult to explain. The samples were treated in the same way as those from BFP1 which gave a consistent age gradient for the regressive overlap and therefore contamination by Phragmites rhizomes is unlikely, especially for such a localised effect on two adjacent samples. Hv8646 and Hv8647 show very similar ages to the 4 assays on the transgressive overlap and this could be indicative of the inwashing of eroded peat. The close proximity of channels has been revealed, part 5.2, and LPAZ BFP2C shows rapid changes in the pollen percentages and concentration of local taxa; Gramineae, Cyperaceae and aquatics, at the stratigraphic boundary (figs. 5.17 to 5.21). Contamination in excess of 30% (Olsson 1979), and in specific layers, would be required to explain the age discrepancies.

While accepting the possibility of such an explanation, which would also conform with the BFP1 results, with Hv9265 being "the most acceptable estimate", the alternative is to calculate the mean : 3208 ± 54BP or 3197 ± 54BP if Hv 8647 is omitted.

The samples from BFP1 show an age gradient for over 30 cm. of the regressive overlap. Any arguments considering contamination must allow for an equal effect over this unit of sediment and therefore the 3 samples would appear to be the most reliable indication for the age of the regression overlap.

The 3 dates from AL2 show a satisfactory age gradient, are corroborated within the accuracy of pollen analysis, and confirm the stratigraphic and pollen indicated break in peat accumulation between Hv9262, 6275 ± 125BP, and Hv9261, 5580 ± 70BP. However the age relationship to marine conditions, slight erosion and poor marine indicators between Hv9261 and the overlying clastic sediment were revealed in part 6.4

Three assays are available from AL4. The two from the intercalated peat layer, 4180 ± 75BP (SRR 1589) and 4500 ± 50BP (SRR1590), show a clear age gradient and confirm the pollen analyses for a post-Ulmus decline age. The age on the regressive overlap of the uppermost peat, 1845 ± 50BP (SRR 1588), can only be analysed further by comparison with other sites (see part 7.2).

Other ^{14}C results are awaited for AL4 and CW7. In addition the reliability of the ^{14}C data described in chapter 3 as sea-level index points in the chronology for the Fenland are assessed in the next chapter.

Part 6.6 : Lithologic changes and sea-level movements

There is incontrovertible evidence that microfossil analysis of intercalated peat and clastic sediments can reveal periods of rising watertable and falling watertable. However the relationship to sea-level movements is not necessarily so clear (cf. Tooley 1979, p.504 op.cit).

> "The whole system of changing water quality and water depth, however, is governed by the ecologically valid relevant hydrology, which is not necessarily related to sea-level fluctuations." (Streif 1979a, 304).

The relationship between watertable changes at any particular site to sea-level changes at the open coast is now one of the most important questions to be solved in sea-level studies.

There are too many estimates of altitude to be made and the overall imprecision of the palaeoenvironmental reconstruction from even the most detailed analyses prevents the elucidation of the altitudinal changes of relative sea-level just by studying single sites. However, although the errors involved in the estimation of ancient tide levels may be great, such errors in themselves are insufficient to reject the hypothesis of a fluctuating relative sea-level curve. The altitudinal errors hinder correlation with increasing distance between sites but do not explain away the lithologic changes at individual sites or the associated change in process associated with their formation. Therefore normal statistical smoothing, or the more frequently used non-statistical smoothing, of data points on a time-depth curve from different stratigraphic boundaries, e.g. transgressive and regressive overlaps, is invalid. Changes in the time and space environments which can be measured in both horizontal and vertical dimensions in Flandrian sequences must be assessed.

It is the scale of resolution in both time and space that is important in such studies as sea-level change. No scientist at present rejects the hypothesis that sea-level fluctuated during geological time, e.g. since the Tertiary, or during the Quaternary glacial and inter-glacial periods, and even during the period 20,000BP to 10,000BP. Furthermore the daily, monthly and yearly fluctuations in tidal cycles are noted. But there is a reluctance to accept fluctuations within the generally rising sea-level curve during the last 10,000 years. The processes controlling sea-level movements change in importance as the time and spatial resolution scales change. Short term tidal changes can be easily measured directly while sea-level changes before 10,000 BP can be broadly correlated with climatic changes and ice-cap volumes. Between these two scales fall the Flandrian sea-level changes; direct observation is not possible except for the last few hundred years (e.g. Mörner 1973b) and for most of the period it has not been possible to correlate the fluctuations of ice-cap volume and ocean-levels. There is also opposition in the demonstration of fluctuations in relative sea-level changes on more local scales. The main problem is that no model developed to explain the succession in one area is easily applicable to other areas. For example the successional build-up and breakdown of coastal barriers (e.g. Jelgersma et al. 1979) is not applicable to those areas where evidence for supra-tidal barriers has never been found, yet similar Flandrian successions are recorded (e.g. Devoy 1979, Tooley 1978a, b).

The main discussion relates to the interpretation of the regressive overlap. Dates on this horizon were once rejected as unreliable indicators due to the effects of consolidation (Jelgersma 1961). However, unless the consolidation is invoked as the cause of the alternating clastic and biogenic deposition then it only affects the altitude at which the formation is recorded and not the processes which formed the sequence.

There is little objection to a regressive overlap representing a relative fall in sea-level in time-space situations, apparently, other than of Flandrian age in a subsiding area. For example, Jelgersma (1979) interprets the regressive overlap in the Eems valley to represent the fall of sea-level at the beginning of the next glacial period. Similarly Sissons and Brooks (1971) interpret the regressive overlap in the western Forth Valley as a relative fall in sea-level and since this is an uplifted area during the Flandrian stage the interpretation remains unchallenged. Streif (1979a,b) implicitly contrasts the differing interpretations of the regressive overlap in their age and altitudinal relationship to present sea-level, i.e. between uplifted and subsided sequences, by stating that the height of these overlaps gives the local limiting value for sedimentation under marine influence but each point need not itself represent the onset of a fall in sea-level. In the case when peat accumulation is in excess of sea-level rise a regressive overlap occurs. However by evaluating the tendencies of sea-level movement using a number of indicators, i.e. time depth points, Streif (1979b) accepts a fall in sea-level at the location of the regressive overlap in question.

Therefore, it is the tendency of sea-level movement, in time and three-dimensional space, that must be evaluated, individual points themselves can rarely prove sea-level movement. At the same time observations cannot be purely rejected on the basis of poor height correlation, e.g. due to consolidation. The local factors must be studied and resolved and the tendencies of movement then evaluated. Streif (1979a) has listed 3 particular situations revealing changes in local water table :

- fen peat layers,
- horizons of decomposition of fen peat,
- horizons of soil formation.

Even these cases by themselves need not represent a fall in sea-level, but with other evidence showing the same tendency of sea-level movement, although the time and altitude errors may allow no exact level to be given, the probability of sea-level movement can be inferred.

> "If the curve had been based on the...top layers of the sediments only (without regard to the vegetational development), the curve would have been nearly smooth... The depressions in the curve are mainly based on changes in vegetation and on lithological changes." (Behre et al. 1979 p.102).

Therefore it must be concluded that a regressive overlap can represent a fall in sea-level. The necessity is to indicate over which scale it is applicable, the accuracy with which the age and altitude can be given, and what outstanding evidence is required to confirm or refute the fall in sea-level. The conclusion allowable is governed by the accuracy of the temporal and spatial scales required and therefore by the original hypothesis.

Part 6.7 : Models of the Saltmarsh-freshwater fen transition

There is an obvious need to present clearer models to explain the environmental changes associated with the sedimentary changes at the transgressive and regressive overlaps. The evidence available can then be compared, eventually by statistical evaluation, with the relevant models. At present there is too much uncoordinated evidence related to poorly defined models thus providing a plethora of equivocal conclusions. Modern analytical techniques, in a mathematical sense, have outstripped the amount and quality of data available.

Section 6.7.1 : Time-stratigraphic model

The rise in relative sea-level along the southern North Sea coast amounts to c.25 m. during the last 8000 radiocarbon years (Streif 1979a). The related facies units are generally thickest at the present coastline, thinning out rapidly seawards as erosion rather than deposition dominates. Landward there is a wide belt of clastic and organic deposits as presented in fig. 3.1. Detailed micro-fossil and stratigraphic analysis can be used to reveal periods of rising and falling local watertable and changes in sedimentary environment but the models developed need to assimilate these fluctuations with the horizontal shifting of facies zones over many kilometres and vertical sea-level movements.

A diagrammatic, two-dimensional, stratigraphic model is given in fig. 6.4 indicating the detailed evidence

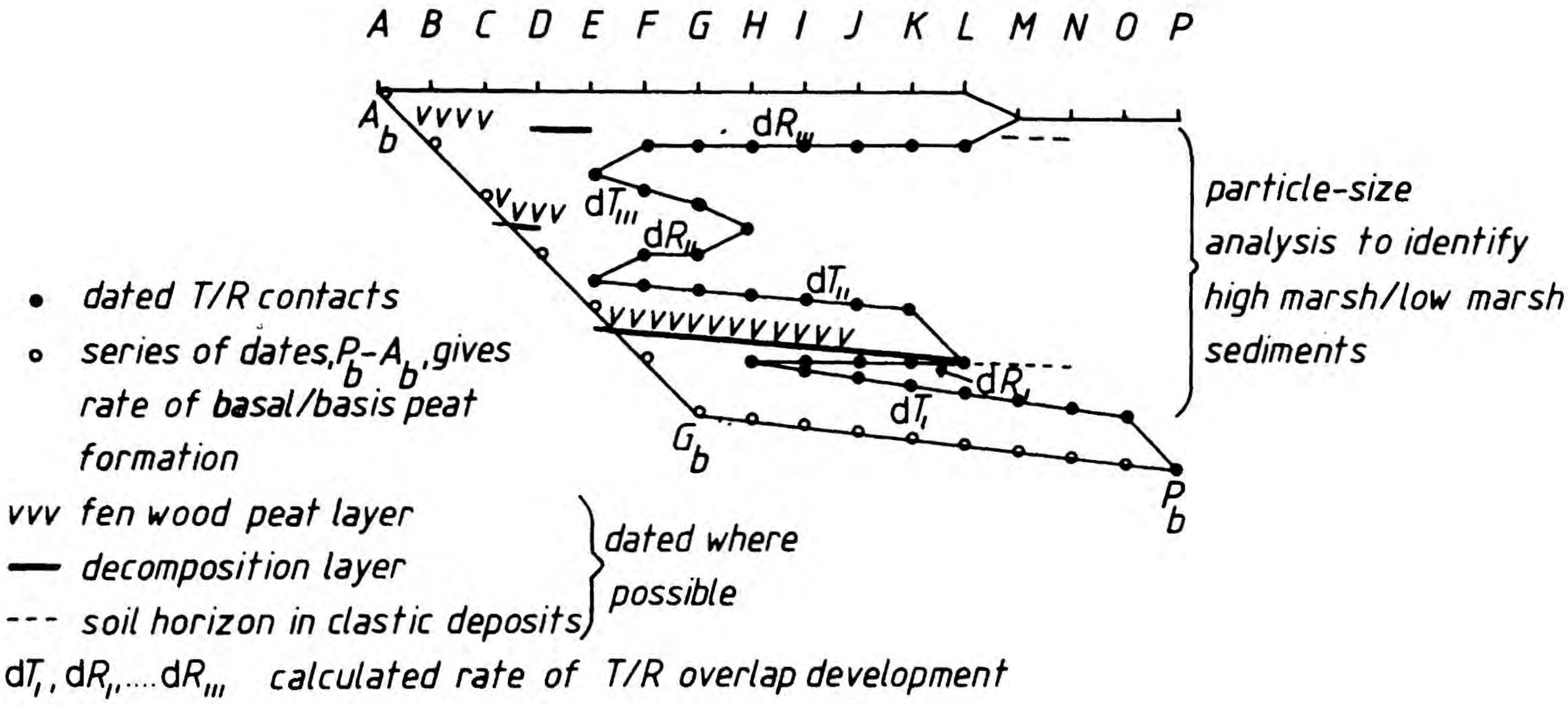


Figure 6.4 : First stage of a time-stratigraphic model of data requirements to analyse changes in sedimentation and sea-level movements. Rates of basis peat and special organic layer development must be resolved both horizontally and vertically. Analysis of pollen and diatom spectra would form the next stage.

required to substantiate the vertical sea-level changes associated with the horizontal and vertical facies changes. Fig. 6.4 assumes that ^{14}C dates are available wherever necessary and may therefore be required in great numbers.

The following assumptions are made. Firstly each ^{14}C sample from the base of peat directly above the pre-Flandrian sand has been shown to fulfil the criteria of "basis peat". The indicative height is taken as MSL (equal to MTL) after van de Plassche (1979) but the uniformity of this relationship must be questioned. As the horizontal distance between the site and the nearest tidal water is reduced the hydrological conditions change and the indicative height may be nearer to MHWST (Godwin 1940a). The problem of using the lowest peat layer to construct a sea-level curve has also been noted by Behre _et al_. (1979 p.99) :

> "This marker [the beginning of marine influence] was assumed to be more significant than the start of peat formation. However, the relation between the start of peat formation and the mean sea level (or mean high water level) at that time will remain to be a puzzling problem, and only the upper parts of most of the mentioned layers are "Basistorf" in the sense of Lange and Menke."

The problem of a variable relationship to tide-levels for "basis peat" is clearly evident from table 6.3 and fig. 6.3 and could be applicable to the situation between E_b and D_b in fig. 6.4.

Secondly each transgressive and regressive overlap is shown to be transitional, with no erosion. The indicative range is as indicated in table 6.2, related to functions of MHWST and HAT. Individually a regressive overlap is interpreted solely as the replacement of marine tidal sedimentation by freshwater organic sedimentation and without further analysis and correlation the arguments for a fluctuating sea-level cannot be substantiated. It is necessary to assess the tendency of sea-level movement by as many lines of evidence as possible. The certainty of the resulting hypothesis is dependent on two factors : 1 - the observation of similar features over, presently undefined, regional distances, 2 - sufficient accurate ^{14}C data for correlation.

The identifications of the tendencies of sea-level movement are suggested to be found with the following evidence:-

(i) The correlation of periods of slower rise of the regional water table up the sloping pre-Flandrian surface with a regressive overlap suggests a halt or even fall in the regional water table.

(ii) Decomposition layers in peats attenuating against the pre-Flandrian sand and the development of palaeosols within the latter at the contact are very strong evidence of a lowering in the regional watertable. This is because there will be a time lag between a fall in tide-level at the seaward location and a fall in watertable against the sloping sand surface due to the ponding back of water by the peat land whereas a subsequent rise in tide-level would lead to a much quicker response in watertable rise.

(iii) Sufficient mapping of sequences and the dating of the significant horizons must show that the fluctuations in the rate of peat growth on the sloping sand surface does not indicate a change in indicative meaning due to the horizontal movement of the coast line. The importance of this factor depends on the present and inferred past tidal regime.

(iv) By the correlation of time-depth points on the pre-Flandrian sands with the development of peat layers, and the special case where marine facies actually attenuate against these sands, accurate data can be gathered to check the combined effects of consolidation, indicative meanings and tidal changes to reconstruct past water levels.

The identification of the development of fenwood peat, decomposition layers or soil horizons within intercalated peat horizons or directly on top of clastic sediments are much better indicators of the tendency of water level movements than homogeneous peat layers. The latter can only show the tendency before and after their deposition and therefore a dated sample from the middle of such a layer is not directly related to a change in the tendency of water level movement. If changes in peat stratigraphy can be traced over significant areas then the evidence for a fall in sea-level is good. Whereas soil horizons may develop at seaward locations the equivalent formation inland might be a decomposition layer or the change from monocot. to fenwood peat. These equivalent but not identical changes are of great significance.

The problem of estimating sedimentation rates is important in any model of sea-level movement in order to explain both the horizontal and vertical sequence development. At the landward limit of the vegetated salt marsh zone there is a quite stable low energy environment with clay sedimentation and little erosion away from creek systems. There is a delicate balance with the freshwater fen system. The reduction in particle size distribution noted for present day salt marshes may reveal important changes in fossil sequences. It has already been shown that typically the clastic layers do not reveal high energy environments, especially at the contacts, thus giving little weight to the opinion of Heyworth (1978) for the breach of a coastal barrier model as being a general model of sequence development.

Any possible check on the variation in sedimentation rate is dependent on the accurate estimation of consolidation. Changes in sedimentation rate should be revealed in the particle size distribution since as the rate of sea-level rise increases the higher marsh environment becomes narrower (Kidson and Heyworth 1979) and therefore the coarser sediments, in effect, are deposited closer to the organic layer below. However with a regressing shoreline the equilibrium position of accretion and sea-level movement is within the high marsh and freshwater fen and with a significant reduction in watertable this moves to more landward zones, resulting in a wedging out of the depositional zones in a seaward direction. Therefore the transition on the regressive overlap should get thinner seaward, as is perhaps revealed in the stratigraphy at BFP1 and BFP2, until the situation of soil development on clastic deposits is possible. Therefore no sudden change in sedimentation rate is envisaged. Furthermore the average sedimentation rate of the different thicknesses of clastic deposits should be calculated and compared with the growth, and inferred consolidation, of the basal and intercalated peat layers.

The development of a universally applicable model may be rendered impossible until the importance of local environmental factors such as freshwater input, estuary or open coast situation, nature of onshore and offshore sediment supply, and wave environment are assessed. For example Streif and Koster (1978 p.37) point out :

> "This pattern of distribution [barrier islands and sand bars] can be traced back to the tidal range. In tide free areas, or in coastal zones with small tidal ranges continuous barrier systems are built up. Towards the inner part of the German bight where the tidal range increases, these are broken and replaced first by barrier islands and then by a system of sand banks."

Therefore any model envisaging a coastline with sandy barriers or islands must incorporate these tidal changes if their permanent build-up or breakdown is suggested.

However the possibilities of sediment-types and processes are becoming too complex to be considered and the data of suitable quality are not available. The only possible development is two-fold. Firstly to collect the data, initially involving considerable field mapping, and secondly to develop the model by computer simulation techniques. For the present, however, only the fragmentary evidence for the tendency of sea-level movements is available for correlation. Formal correlation schemes should be kept separate, e.g. lithostratigraphic and chronostratigraphic, but comparable, to allow for flexibility during the period of model modification.

Section 6.7.2 : Pollen content model

A possible new insight is the development of pollen concentration techniques in the coastal environment. The model relating to the changes at the saltmarsh-freshwater fen transition is given in fig. 6.5. No scales are shown for any axes since too few empirical data are available. The model is only intended to portray the trends along the ecological gradient.

As it stands the model explains many of the features observed not only in Bourne Fen, Cowbit Wash and Adventurers' Land but also as outlined by Godwin (1940a, 1978, Godwin and Clifford 1938) and Tooley (1978b): the change from fen oak wood to alder carr, to freshwater swamp, characterized by peaks of aquatic taxa and Cyperaceae. A further seaward movement often reveals an increase in Gramineae and then saltmarsh taxa. Furthermore the behaviour of the *Quercus* and *Alnus* curves is also represented.

The distance decay effect suggested by the model is revealed in BFP1 and BFP2 during the periods of clastic sedimentation. In BFP2 the proportion of trees as %TLP is less than at BFP1, concentration of TLP is lower and *Quercus* is >*Alnus* as %AP in BFP2 whereas *Alnus*>*Quercus* as %AP in BFP1.

Pollen concentration figures throughout the period of clastic sedimentation for non-saltmarsh taxa, i.e. other than *Chenopodiaceae*, *Triglochin* and Gramineae, are remarkably constant. The major changes occur at the transgressive and regressive boundaries. Pollen concentration and influx diagrams have been widely used for the analysis of lake sediments (e.g. Pennington 1975) whereas peat, because of its variable structure and sedimentation rate has not been widely used for such studies. The situations where peat has been

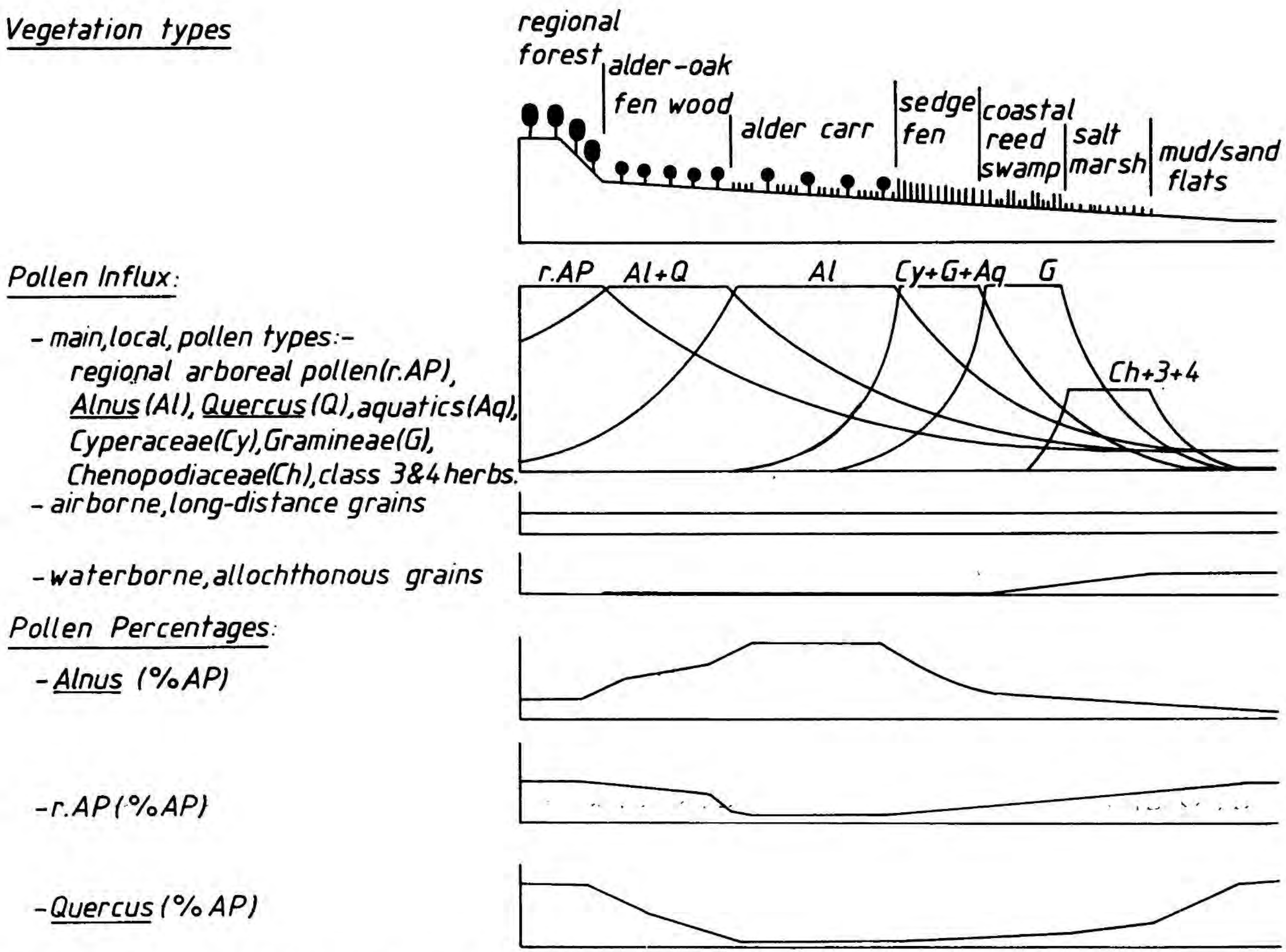


Figure 6.5 : Model of pollen influx and percentage changes through a coastal succession. It is assumed that Alnus and Quercus are both fully established trees and that man has little influence on the succession.

studied (e.g. Beckett and Hibbert 1976, Moore and Webb 1978) have been quite different to the intercalated peats and clays of the coastal Flandrian sequence. Normally pollen influx can be calculated by the product of the pollen concentration and the sedimentation rate. If however the pollen influx can be assumed constant then the concentration data will reveal changes in sedimentation rate. Therefore if the local and regional pollen component can be identified, when the percentage diagrams reveal no significant changes in the regional and local pollen assemblages, then any significant change in the concentration is the result of changes in either the sedimentation rate and/or sedimentary environment.

Without further information the following suggestions are tentatively proposed. The major fluctuations in pollen concentration for Bourne Fen are related to stratigraphic changes and therefore pollen concentration cannot be used as an indicator of changing sedimentation rates where there is a major change in pollen trapping conditions. However where internal stratigraphy appears constant and the regional pollen percentages reveal no significant changes then pollen concentration reveals changes in sedimentation rate. The definition of "regional tree pollen" must be assessed since it is dependent on the stability of the regional forest and therefore the same relationships cannot be applied over long time periods as the vegetation changes. Within the Bourne Fen context the lack of variation of pollen concentration for most of the tree species in the clastic sediments may provide evidence of a rather constant sedimentation rate since the main changes, e.g. at BFP1 50 cm., clearly coincide with stratigraphic changes. Rapid changes of the clastic sedimentation rate are not suggested. Therefore it would be helpful to compare the rate of peat accumulation before and after the clastic sedimentation but the ^{14}C data are not available.

Obviously to confirm these observations as being more generally applicable it is necessary to have many more sites studied to show the relationships between thickness and internal homogeneity of the clastic deposit, inferred sedimentation rate, distance from the inferred regional forest, local environments and ^{14}C calculated sedimentation rates.

Finally pollen concentration may be useful in the investigation of peat accumulation rates and consolidation. For, other factors being equal, pollen concentration is proportional to the amount of consolidation although the results from AL2, AL4 and CW7 are inconclusive in this respect. However the reduction or halt in peat accumulation in AL2 at 842 cm., suggested by the pollen assemblage and corroborated by ^{14}C analysis, revealed a maximum in pollen concentration at 844 cm.

Therefore it is suggested that the model given in fig. 6.5 can be adapted not only to reveal the expected pollen changes in inferred coastal palaeoenvironments but may also permit the investigation of possible changes in sedimentation rate and consolidation.

Part 6.8 : Conclusions

This analysis of transgressive and regressive overlaps, from both original research and published data or informal models, has shown that while there is evidence for major horizontal fluctuations of the coastline and vertical changes of local water table in the Fenlands during the Flandrian Stage, due mainly to the uncertainties of the altitudinal parameters it is not possible to confirm or refute the presence of fluctuations within the overall rising sea-level curve. However different techniques of analysis have shown that there are examples of the tendency of falling water tables and it is an aim for future research to assess their spatial and temporal extent. Computer simulation (e.g. Randerson, unpublished) appears an attractive method of modelling complex coastal systems.

Therefore it is proposed that the analysis of sea-level index points on a time-depth graph, chapter seven, should not exclude the tendencies of falling water-levels since the altitudinal errors only relate to the absolute level and do not refute either the stratigraphic or inferred vegetational changes.

CHAPTER SEVEN

Tendencies of sea-level during the Flandrian Stage

It is now possible to relate the sea-level and environmental changes in the Fenlands to a general chronostratigraphic scheme based on the tendencies of relative sea-level movements. Periods of positive and negative tendencies of sea-level movement are given the names Wash I - VIII and Fenland I - VII respectively. When these tendencies are shown to be of regional significance they would be comparable with the terms transgression and regression as used by Mörner (1976a,b) but not with Devoy (1979) and Tooley (1974, 1978a). The chapter is divided into 4 parts -

- 7.1 : Existing chronologies of sea-level movement in the Fenland.
- 7.2 : Methods used in developing the new chronology.
- 7.3 : Proposed Flandrian chronology of Fenland development.
- 7.4 : Conclusions.

Part 7.1 : Existing chronologies of sea-level movement in the Fenland

Section 7.1.1 : Godwin's relative sea-level curve and chronology

Godwin (1978 fig.33) has presented a relative sea-level curve for the Fenland which effectively supercedes the earlier chronologies of himself and others working from Cambridge (Godwin 1940a, Godwin and Clifford 1938, Willis 1961). Godwin's curve shows an uninterrupted rise in relative sea-level culminating around 4200 BP at c.1.5 m. above "present sea-level". This was the "Fen clay" transgression. A regression then took place to 2 m. below "present sea-level" at around 3400 BP. The next rise in sea-level, depositing the "Upper" or "Romano-British Silts" attained +2 m. at c.1900 BP (AD50). Falling sea-level then predominated until c.1100 BP (850 AD) apart from a small transgression at 1750 BP (AD200) to 1625 BP (AD325). Finally sea-level rose to its present level.

However Godwin and Vishnu-Mittre (1975) pointed out that the nature and timing of the "Fen Clay' transgression away from the type area of the southern Fenland may well be quite different. This, and other differences, are confirmed here (see 7.3).

Section 7.1.2 : Other chronologies.

Two other chronologies are of interest due to their recent publication . They are both derived from the interpretation of limited ^{14}C data with an incomplete assessment of stratigraphic and microfossil analyses and regional significance.

Firstly Gallois (1979) proposed the following stratigraphic division. It has already been criticised (part 3.3) and should be developed no further as a scheme for the whole Fenland.

Lower Peat c.6500-5000 B P
Barroway Drove Beds 5000-4000 BP (inferred)
Nordelph Peat c.4000-2000 BP
Terrington Beds ? to 3250/2250 BP

Tooley (1974 fig.11) proposed the following transgression sequences (cf.chapter 1) for the Fenland : (approximate dates)

I - 6000 BP

II	5600 - 4750 BP
III	4600 - 4000 BP
IV	3300 -
V	2250 - 1750 BP
VI	1700 - 1300 BP

This chronology was based on limited ^{14}C data and the time limits for VI are from direct correlation with Tiel II/Dunkirk II in the Netherlands. This chronology was accepted by Devoy (1979 fig. 31) without question but will be seen to be erroneous in view of the evidence discussed in part 7.3

Part 7.2 : Methods used in developing the new chronology

The data base on which the chronology is founded comprises the 81 ^{14}C dates discussed in chapter 3 (table 3.1), 16 new assays from Bourne Fen and Adventurers' Land, and 5 new dates, as yet unpublished communicated by R.J. Wyatt to M.J. Tooley, from the Welland Washes, upstream of Cowbit Wash. The changes since c.2000 BP in particular have been inferred from published archaeological and historical data. Table 7.1 shows those ^{14}C assays not listed in table 3.1.

The first stage of analysis is shown in fig.7.1 where the 102 ^{14}C data available are plotted on a time-depth graph with no consideration of the accuracy of their altitude or indicative meaning. However, the chronology explained in part 7.3 is not inferred purely from the ^{14}C data since the stratigraphic evidence available must also be considered. For example data point 62 is from an intercalated peat bed and therefore the assay reveals that some time before 4950 ± 100 BP there was a period of negative tendencies of sea-level and at some time afterwards there was a period of positive

Table 7.1. New ^{14}C dates from the Fenland

No.	Code	date	height m.OD	mat-erial	layer	tend-ency	Site
82	HV8644	2970±65	+0.95 to +0.91	peat	qhOD	-	BFP1
83	HV8645	3485±75	+0.76 to +0.73	peat	qhOB	+	BFP1
84	HV9266	2625±65	+1.26 to +1.23	peat	qhOD	?-	BFP1
85	HV9267	2780±70	+1.06 to +1.03	peat	qhOD	?-	BFP1
86	HV9268	3430±60	+0.63 to +0.59	peat	qhOB	+	BFP1
87	HV8646	3435±65	+0.95 to +0.93	peat	qhOD	-	BFP2
88	HV8647	3595±325	+0.91 to +0.89	peat	qhOD	-	BFP2
89	HV8648	3580±90	+0.21 to +0.18	peat	qhOB	+	BFP2
90	HV9264	2635±100	+0.93 to +0.91	peat	qhOD	-	BFP2
91	HV9265	3415±45	+0.10 to +0.06	peat	qhOB	+	BFP2
92	HV9261	5580±70	-7.99 to -8.03	peat	qhA	+	AL2
93	HV9262	6275±125	-8.05 to -8.08	peat	qhA	-	AL2
94	HV9263	6415±185	-8.12 to -8.17	peat	qhOB	+	AL2
95		2550±60	_c_.+1.5	peat	qhO	?+	WW5
96		3860±80	_c_.-3.3	peat	qhA	+	WW4
97		4030±80	_c_.-3.4	peat	qhA	-	WW4
98		5000±70	_c_.-3.9	peat	qhOB	+	WW4
99		5140±60	_c_.-4.2	peat	qhOB	?+	WW4
100	SRR1588	1845±50	-0.67 to -0.73	peat	?qhA	-	AL4
101	SRR1589	4180±75	-4.05 to -4.11	peat	qhA	+	AL4
102	SRR1590	4500±50	-4.27 to -4.32	peat	qhA	-	AL4

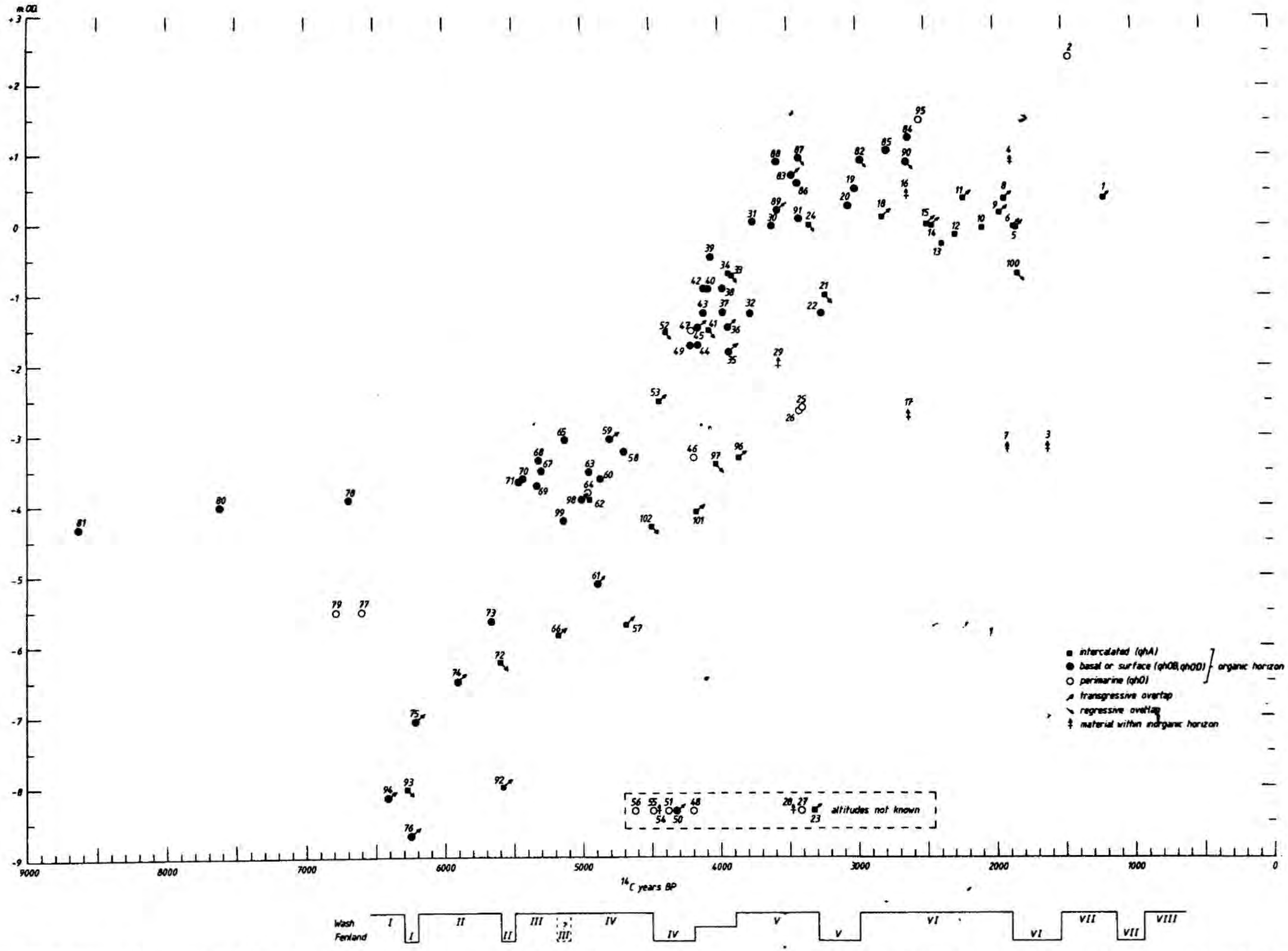


Figure 7.1 : 102 ^{14}C data from the Fenland. These data are related to OD if possible, either recorded or estimated, but their reliability as sea-level index points are not shown. The Fenland/Wash chronology is given.

tendencies, further clarification of this single data point is not possible.

Therefore the chronology given in part 7.3 is considered the most satisfactory scheme for explaining the periods of positive and negative sea-level tendencies when both the stratigraphic and dating evidence is considered. However this must then be resolved in the dimensions of altitude and space. It is not possible to trace the altitudinal changes in relative sea-level with any great accuracy. Due to many serious inadequacies of the data, eg. lack of an accurate relationship to O.D. Newlyn, no accurate assessment of indicative meaning in many cases, no adequate method to allow for the consolidation of sediments, and limited data relating to the regional significance of a horizon, only the general trend of MHWST can be given in figs. 7.2 and 7.3, based on the interpretation of 31 ^{14}C data, considered to be the most reliable, and 8 inferred index points, based on stratigraphic and/or archaeological considerations.

Each ^{14}C index point is related to MHWST according to the relationships given in table 6.2 and table 6.4. Obviously this assumes a constant relative tidal regime. A constant absolute tidal regime must be assumed to relate the curve to present conditions. By making these assumptions the value of the curve is reduced but it is necessary whenever index points with different indicative meanings are used.

Figure 7.2 is constructed from the data given in tables 7.2 and 7.3. The difference in table 7.2 between "altitude of sample" and "error range of measured level" is due to the

Table 7.2. ^{14}C data used for constructing fig. 7.2

No.		Lab. code	^{14}C.BP ±	altitude of sample m.OD	error range of measured level m.OD.	range of MHWST M.OD.
94	+	HV9263	6415±185	-8.12 to -8.17	-7.94 to -8.24	-7.58 to -8.34
93	-	HV9262	6275±125	-8.05 to -8.03	-7.91 to -8.20	-8.03 to -8.60
74	+	IGS-C14/123	5905±100	-6.49 to -6.51	-6.09 to -6.87	-5.79 to -6.77
72	-	IGS-C14/122	5600±100	-6.23 to -6.26	-5.83 to -6.62	-5.97 to -7.02
66	+	IGS-C14/121	5175±100	-5.83 to -5.88	-5.43 to -6.21	-5.13 to -6.11
65	+	Q-581	5130±120	-3.05 to -3.06	-2.95 to -3.16	-2.75 to -3.06
61	+	IGS-C14/119	4890±100	-5.09 to -5.14	-4.69 to -5.50	-4.39 to -5.40
59	+	Q-580	4800±120	-3.04 to -3.05	-2.94 to -3.15	-2.74 to -3.05
58	+	Q-499	4695±120	-3.20	-3.05 to -3.35	-2.95 to -3.45
57	+	Q-31	4690±120	-5.70	-5.55 to -5.85	-5.45 to -5.95
102	-	SRR1590	4500±50	-4.27 to -4.32	-4.13 to -4.44	-4.27 to -4.84
53	+	IGS-C14/118	4445±100	-2.52 to -2.55	-2.14 to -2.91	-1.84 to -2.61
52	-	Q-263	4390±120	-1.50	-1.15 to -1.85	-1.49 to -2.45
47	-	Q-544	4195±110	-1.50	-1.15 to -1.85	-1.29 to -2.25
101	+	SRR1589	4180±75	-4.05 to -4.11	-3.91 to -4.23	-3.61 to -4.13
45	+	HAR150	4162±130	-1.45	-1.30 to -1.60	-1.00 to -1.50
36	+	IGS-C13/109	3945±100			
35	+	Q-685	3943±100	-1.82	-1.72 to -1.94	-0.70 to -1.24
33	-	Q-489	3905±120	-0.71 to -0.73	-0.56 to -0.88	-0.70 to -1.28
83	+	HV8645	3451±47	+0.76 to +0.59	+0.86 to +0.49	+1.19 to +0.46
86	+	HV9268				
89	+	HV8648	3448±65	+0.21 to +0.06	+0.31 to -0.04	+0.64 to -0.07
91	+	HV9265				
24	-	Q-686	3340±110	0.0	+0.12 to -0.12	+0.77 to +0.15
87	-	HV8646	3208±54	+0.95 to +0.89	+1.05 to +0.79	+1.01 to +0.39
88	-	HV8647				
90	-	HV9264				
82	-	HV8644	2970±65	+0.95 to +0.91	+1.05 to +0.81	+1.01 to +0.41
18	+	Q-844	2815±100	+0.12	+0.24 to 0.0	+1.26 to 0.70
15	+	Q-805	2495±110	0.00 to -0.02	+0.15 to -0.17	+0.45 to -0.07
6	+	Q-549	1875±100			

Table 7.3 : Inferred data points for constructing figure 7.2

No.	± tendency	age BP.	range (m.OD) MHWST	Comments
IP1	- +	5600-5500	-5.6 to -6.9 -6.0 to -7.4	ranges for regressive and transgressive overlaps of intercalated peat layer at AL4
IP2		2400-2150	< +3.7	lowest level of Iron Age salterns, +4.6 m.OD (Simmons 1978) gives coarse approximation of MHWST dependent on the relationship of salterns to tide-levels : H.A.T. or higher? - gives maximal estimate.
IP3		2350-1900	+3.3 to +2.2	highest level of levees colonised by Romans (Hallam 1970) = +3.3m. Indicative meaning estimated : HAT to MHWST
IP4	-	1900-1750	+1.24 to +0.74	regressive contact of 2 undated peat layers near Spalding : CW7 and NC1
IP5		1850-1750	c.+1.2?	Roman ditching down to +1.2 m.O.D. (Hallam 1970) ≈ MHWST?
IP6		1850-1750	< +2.1	Roman salterns down to +3.0 m.OD (Simmons 1978), cf. IP2 and IP5.'
IP7		1550-1150	c.+2.9?	level of post-Roman estuarine deposits (Smith 1970) ≈ MHWST?
IP8	-	3400-3300	+1.48 to +1.02	maximum recorded altitude of the regressive overlap in Bourne Fen = +1.52 m.OD.

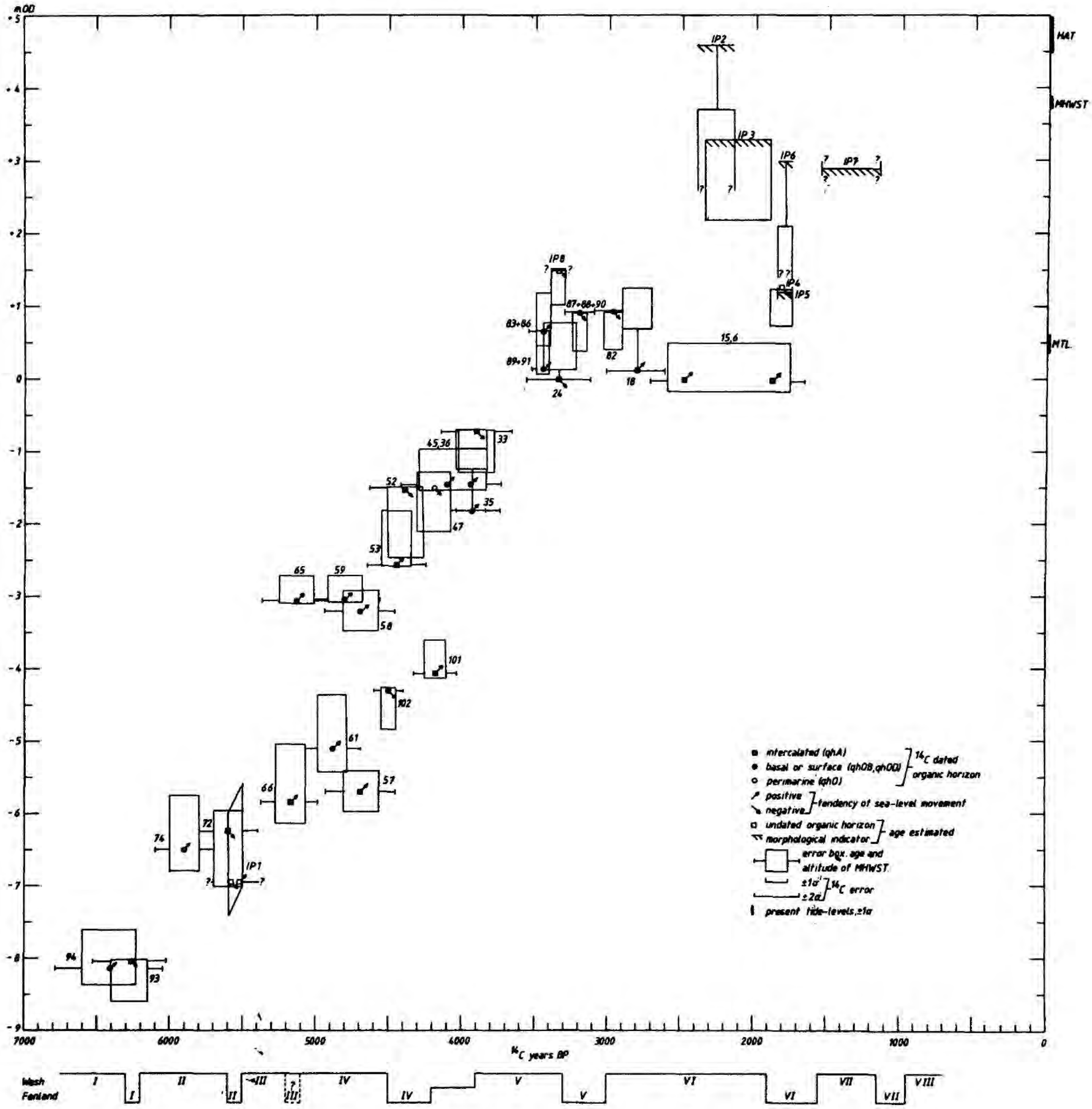


Figure 7.2 Estimate of MHWST from 31 ^{14}C data and 8 inferred index points.

allowance made for errors in the measurement of depth, identification of boundaries, sampling method, borehole density, and an assessment of compaction where local evidence is available, eg. between AL2 and AL4. Where there is insufficient evidence available the errors themselves are estimated in relation to table 6.1. For example index point 74, IGS-C14/123 : 5905 ± 100 BP is measured at an altitude -6.49 to -6.51 m.OD, however the following errors are allowed for:-

identification of boundary	± 0.01 m.
measurement of depth	± 0.05 m.
angle of borehole	+ 0.04 m.
sampling density	± 0.30 m.
total sampling error	$^{+\,0.40}_{-00.36}$ m.

This gives a possible error range of the measured altitude as -6.09 to -6.87 m.OD. The indicative range of a presumed *Phragmites* or monocot. peat subjacent to marine sediments is taken as 20 cm. below MHWS ± 0.10 m. giving a range for MHWST as -5.79 to -6.77 m. OD at 5905 ± 100 BP.

The curve in fig. 7.3 is for MHWST for the inner Wash (see table 6.4) and therefore to enable the Chapel Point data to be used the difference between the Skegness and inner Wash tidal data must be allowed for. However this may mean that data points 35, 24 and 18 (fig. 7.2) are less reliable. The alternative was to relate all of the data to the total tidal data for the Wash giving a greater error range for all the index points.

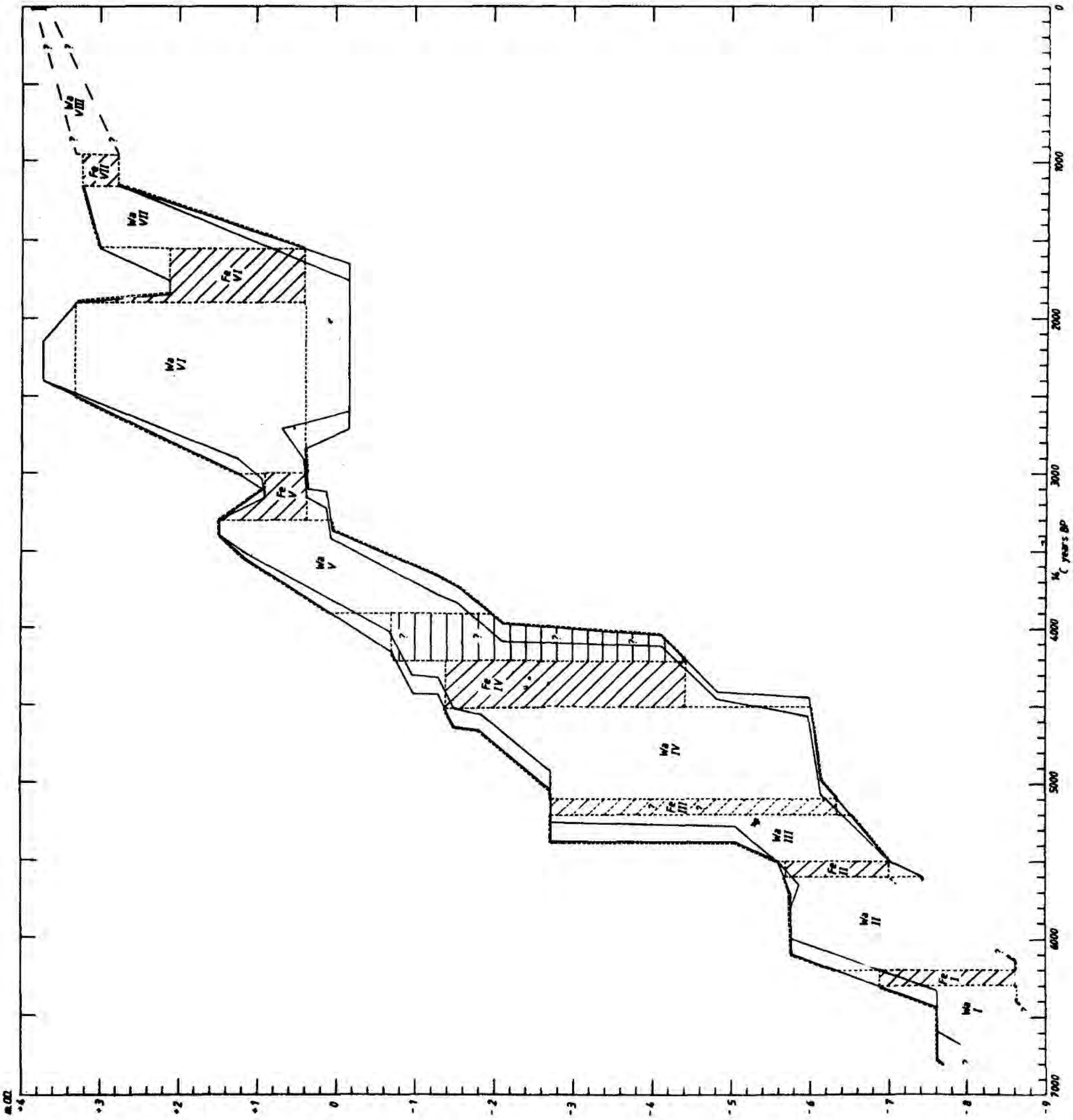


Figure 7.3 : Trend of MHWST in the Fenland since c.7000BP. The solid lines enclose $\pm 1\sigma$ and $\pm 2\sigma$ of the ^{14}C data. The constrained curve, interpreted from the periods of positive and negative tendencies, is shown by dashed lines.

Figure 7.3 is inferred from fig. 7.2 and shows the approximate 60% and 90% confidence limits for MHWST. The two confidence bands are taken from the same altitudinal ranges but $\pm 1\sigma$ and $\pm 2\sigma$ of the ^{14}C data. The "extra" 5% error is to allow for those errors not yet assessed and in fact the 60% and 90% figures themselves are only meant as a guide.

Consolidation is hardly allowed for in this curve and therefore future research may show that the "true" curve lies towards the top of this band or even higher.

Therefore the confidence bands show no unequivocal fluctuations in sea-level but this is due to the resolution of altitude and time which the evidence and methods of analysis allow. Very rarely have the limits of positive and negative tendencies been identified and dated, eg. at Bourne Fen, and until the extent of the intercalated peat and clay deposits are carefully mapped the importance of each period of rising and falling tendencies of sea-level movement cannot be further assessed. Therefore fig. 7.3 shows the likely limits within which MHWST will have occurred and identifies the periods most likely to be characterised by rising and falling sea-level.

Part 7.3 : Proposed Flandrian chronology for the Fenland

The time limits discussed below are given as an estimate only, with a probable accuracy of ±100 years. The boundaries are not expressed as a single ^{14}C assay since this may suggest an unwarranted accuracy. However where a period of, say, falling tendencies of sea-level is designated a length of 100 years it is not valid to argue that this period is unrecognizable due to the size of the age errors because the period is in fact defined by stratigraphy as well as ^{14}C data. The uncertainty arises from the method of absolute dating which is insufficiently accurate to elucidate changes over short time periods. Each suggested boundary is within ± 2σ of the limiting ^{14}C assays for presumed transitional contacts.

<u>Wash I</u> : ? - <u>c</u>.6300 BP

Dated evidence for a rising water-table and subsequent inundation by tidal waters is limited to the Guyhirn-Adventurers Land area (Godwin and Clifford 1938 fig. 27, and fig. 7.4). The lack of evidence reflects the paucity of research and the difficulty of retrieving samples from these seaward locations.

Positive tendencies are dated, AL2: 6415 ± 185 BP, and are reported further east at Guyhirn and west to Cross Guns PH-B. The latter borehole and AL4 together point to a limit of <u>c</u>.-7.8 m. OD for clastic sediments of that age. On the basis of height correlation alone, some of the basal peats from boreholes around Spalding, fig. 6.2, may be of similar age. The age of the eroded basal peat at Wiggenhall St.Germans is not known. Earlier datable material probably lie offshore (see part 3.4 and Gallois 1979).

The local limiting age of marine influenced sedimentation is given as 6275 ± 125 BP at AL2, with the regressive overlap recorded <u>c</u>.1.5 m. lower at <u>c</u>.-9.5 m. OD at Guyhirn. Pollen evidence for marine species is generally lacking and the diatoms show a high freshwater input for the transgressive contact and a pure brackish regressive overlap. Overall the direct evidence for the nature, extent and age of this episode of rising sea-level is very limited (fig. 7.4).

Fenland I : c.6300 - c.6200 BP

The evidence is once more limited to the Adventurers' Land - Guyhirn section. Immediately after 6275 ± 125 BP there is a break in peat accumulation of AL2. The regressive tendencies are recorded to -9.5 m.OD. at Guyhirn. The end of this period is defined from data at Spalding for the opening of Wash II. However the stratigraphic and microfossil control is very poor and this boundary may have to be amended when further data are available.

Wash II : c.6200 - c.5600 BP

Only two areas, Adventurers' Land and Cowbit Wash/Spalding, provide evidence of rise-and-fall tendencies of sea-level for the sixth millenium before present.

The opening of Wash II is given as c.6200 BP from 2 rather unsatisfactory dates on peat at Spalding (no.75 and 76 fig. 7.1) which are of unknown relationship to sea-level. Therefore these dates are maximal, if the peat started to form independently of sea-level then only the upper boundaries of the layers would provide suitable data.

Better evidence is available from the borehole Sp-2, correlated by stratigraphy with CW-7, in which the arrival and end of marine sedimentation are dated between 5905 ± 100 BP and 5600 ± 100 BP. The altitude of the regressive overlaps are -6.2 m.OD at Sp-2, -6.96 m. OD at AL4 and c.-6 m.OD at Cross Guns Public House-B (Godwin and Clifford 1938).

The time limits of Wash II do not agree well with the assay from the transgressive overlap at AL2 : 5580 ± 70 BP. It is thought that this date is slightly young, although by allowing -2σ of the error it just falls within Wash II, but this would leave little time for the accumulation of the overlying clastic sediment. The result of an assay on the equivalent horizon from AL4 is awaited.

Fenland II : *c*.5600 - *c*.5500 BP

The tendency for a fall in sea-level is inferred from the date at Sp-2 : 5600 ± 100 BP. The basal peat dated 5665 ± 100 BP at Sp-1, at a higher altitude, is of unknown indicative meaning. The onset of marine conditions at Sp-1 is not recorded until 4890 ± 100 BP, at -5.09 m.OD and in Sp-2 at 5175 ± 100 BP, -5.83 m. OD. The onset of tendencies of rising water levels is not dated at any location and therefore the end of Fenland II is probably maximal, given at *c*.5500 BP.

Wash III/IV : *c*.5500-*c*.4500 BP or ? Wash III : *c*.5500-*c*.5200 BP
? Fenland III : *c*.5200-*c*.5100 BP
? Wash IV : *c*.5100-*c*.4500 BP

The period 5500-4500 BP is a complex one in the Fenland. It is generally dominated by transgressive tendencies but the correlation between the southern and northern Fenland by both lithostratigraphy and the available ^{14}C data is difficult.

Prior to the results of the ^{14}C assays from AL4 the stratigraphic evidence presented by Godwin and Clifford (1938) suggested that the highest peat in the Dog-in-a-Doublet - Pear Tree Hill section correlated with the "upper peat" of the southern Fenland. Therefore the peat layer at c.-4 m.OD, also recorded in AL4, must have formed between Fenland II and Fenland IV, the latter being dated in the southern Fenland at Denver. Thus this peat layer was taken as the evidence for the period Fenland III (Shennan 1980). The supporting evidence was not strong, the fen oak wood layer at Wiggenhall St. Germans, dated 4690 ± 120 BP, may have started to have been formed in Fenland III but this assay represented the time of its destruction rather than formation. The main reasoning for the identification of the period Fenland III was the interpretation of the stratigraphy given by Godwin and Clifford. However it is important to stress that their sampling interval was often between 1-3 km. and no detailed or complete stratigraphic investigation linked the Nene Valley sites to the southern Fenland. Their transect (fig. 33 Godwin and Clifford 1938) significantly shows that the "Fen Clay" was not continuous throughout the section, not being recorded at Coldham Bank.

The alternative to the identification of Fenland III in the Adventurers' Land area was to equate the peat layer at c.-4 m.OD with the initiation of the "upper peat" of the southern Fenland. This would then agree better with the evidence from the Spalding area but there would be a sizeable altitudinal difference with the southern Fenland, -4 m.OD compared to c.-1.5 m.OD. However chronostratigraphic correlation of the -4 m.OD peat layer at AL4 with the period Fenland IV was confirmed by the ^{14}C analyses. Therefore the now favoured chronostratigraphic scheme designates the period Wash III/IV from c.5500 - c.4500 BP.

The evidence for rising water-levels from *c*.5500 BP is good. At Shippea Hill whereas the lowest 60 cm. of peat accumulated between 8620 ± 160 BP and 5330 ± 120 BP an assay on *Phragmites* peat 65 cm. higher gave 5130 ± 120 BP. This apparent increased peat growth is taken to represent the rising freshwater table associated with Wash III/IV. However, only a further 2 cm. higher an assay yielded 4800 ± 120 BP and may indicate a decrease in peat accumulation prior to the deposition of the clastic sediments which are of Wash III/IV age.

At Setch NV-1 the base of the lower peat was dated 5440 ± 100 BP but unfortunately the transgressive overlap to the clastic sediments was undated.

The recognition of the combined Wash III/IV period gives much easier correlation between Adventurers' Land and the Spalding/Cowbit Wash area. At Sp-1 peat accumulation was continuous between 5665 ± 100 BP and 4890 ± 100 BP (basal peat) and at Sp-2 following negative tendencies at 5600 ± 100 BP the transgressive overlap is dated 5175 ± 100 BP. Very similar records are given by the assays at Sp-0 and Welland Wash-4.

The rise in water levels indicated by the replacement of peats by clastic sediments at Spalding/Cowbit Wash, Adventurers' Land, Shippea Hill and Wiggenhall St. Germans was also registered at various perimarine sites : Adelaide Bridge - Ely, Holme Fen, and probably at Wicken Fen (table 3.1). The maximum extension of the "Fen Clay" *sensu* Godwin in the southern Fenland falls towards the end of Wash III/IV (fig. 7.4).

Fenland IV : c.4500 - c.4200/3900 BP

While this is the period during which the well-recorded "upper peat" of the southern Fenland started to form there is a major distinction to be made between the southern and northern Fenland. The maximum extension of marine sedimentation was not synchronous, with marine transgressions recorded after c.4200 BP away from the southern Fenland. It is now clear that the traditional "Fen Clay" was deposited in two separate periods.

The Wash III/IV/Fenland IV boundary is given by dates from AL4, SP-1 and Denver after which time negative tendencies have been recorded but their timing and duration appears very dependent in local conditions.

The Denver site is particularly enlightening. Wood, in peat, above the regressive contact gave an age of 4390 ± 120 BP and a second assay 8 cm. higher : 4085 ± 110 BP. The environment of deposition can be compared with pollen analyses at Nordelph, 3 km. to the west, where the same broad stratigraphic sequence is recorded (Godwin and Clifford 1938, Godwin 1978). These pollen analyses showed that following the period of fen woods Sphagnum raised bog and pine communities developed until a further episode of fen wood and then renewed marine deposition. This is a clear indication of a negative tendency of sea-level followed by a renewed rise.

Further south the end of the extensive marine transgression in the southern Fenland is recorded at Shippea Hill, Southery and Wood Fen. At the former two sites the base of the upper peat is given as early Bronze Age which could be c.4100 BP (Godwin 1978 fig.33). At Wood Fen a ^{14}C assay on pine wood gave 4195 ± 110 BP and was interpreted as indicating the extension of Sphagnum bog communities at a perimarine site following the maximum landward extension of marine deposits (Godwin and Willis 1961).

At Sp-1 a date on the top of an intercalated peat layer, shown by correlation with the Cowbit Wash sites to be of variable thickness, gave an assay of 4445 ± 100 BP. The upper surface may be eroded and is not used to estimate the next positive tendencies.

The best registration of Fenland IV is at AL-4 where positive tendencies have resumed by 4180 ± 75 BP, although the transgressive overlap suggests slight erosion.

However, while negative tendencies are recognizable from c.4500 BP the conditions vary locally within the Fenland and this may suggest a period of almost stillstand in sea-level tendency c.4200 - c.3900 BP. Negative tendencies are not recorded until 3915 ± 120 BP at Saddlebow and 4030 ± 80 BP at Welland Washes, but there is no micropalaeontological evidence from the latter site to give an accurate indicative meaning. But there is good evidence for a renewed rise in water table from Chapel Point at least by 3943 ± 100 BP, in the Witham Valley at 3945 ±100 BP and possibly as early as 4205 ± 100 BP and at AL4 by 4180 ± 75 BP. Variation between sites in the Fenland is also seen with the altitudinal evidence for the associated transgressive and regressive contacts. The dated regressive tendencies of Fenland IV generally occur at -0.7 m. to -1.5 m.OD between Saddlebow and Shippea Hill while the levels at Sp-1 and AL-4 are c.-2.5 m.OD and c.-4.2 m.OD although these may have been more greatly affected by consolidation. Transgressive overlaps are again lower in the Spalding and Adventurers' Land sites while in the Witham Valley they range from -1.7 m.OD to c.0.0m.OD the latter from a date of 3620 ± 130 BP. These within-Fenland differences of age and altitude may indicate changes in sedimentary and geological processes. Differential crustal movement cannot be overlooked as a possible cause but no more evidence is yet available. An important area is around Adventurers' Land where the altitudinal correlation shows the greatest discrepancies.

Part of the explanation is attributable to the regional differences prior to 4500 BP. Marine transgressions were more widespread in the southern Fenland but it is not known if this was due to differential crustal movement or the altitude of the pre-Flandrian topography. At 4500 BP the southern Fenland was covered by a relatively horizontal, extensive clay surface. When sea-level fell, first fen wood and then raised bog could develop aided by the impeded drainage conditions on the clay surface. Raised bog was to develop as far seaward as Nordelph. Raised bog communities also occurred at Holme Fen, dated 4190 ± 130 BP, but prior to the arrival of marine conditions at slightly seaward locations. However, away from the southern Fenland the deposits of Wash III/IV were much less extensive (fig.7.4), drainage was better and therefore peat development less rapid. When sea-level started to rise once more the situation was quite different between the north and south.

Peat development could keep pace with the sea-level rise in the south. The transition between the two areas appears to be the Guyhirn to Holme Fen/Woodwalton sections.

Wash V : c.4200/3900 - c.3300 BP

Clastic deposits of this age were excluded from the southern Fenland (fig. 7.4). At Holme Fen/Woodwalton Sphagnum bog began to develop but did not produce a regressive overlap and the continued rise of water-table is represented by the silts and clays abutting against ombrogenous peats. Within this drainage area between the March-Ramsey-Chatteris and Whittlesey ridges of pre-Flandrian deposits there is adequate ^{14}C data to illustrate the chronology. Woody peat formation is dated 4345 ± 110 BP at Glass Moor, but this date is likely to be maximal since shells of Cardium edule were recorded in their growth position on pine stumps. The actual age of these shells could be much younger. Ombrogenous peat growth was initiated at 4190 ± 130 BP at Holme Fen and the maximum extension of the clastic deposits is estimated at c.3415 ± 120 BP and Sphagnum bog was only able to form a regressive overlap by c.3260 ± 110 at Ugg Mere.

Marine deposits of Wash V age were the first transgressive tendencies to be recorded at Bourne Fen, the Witham Valley, and Chapel Point up to at least 3450 BP. The altitudes recorded for transgressive tendencies range from c.-2 m.OD, in the Witham Valley to well above OD. Regressive tendencies are recorded up to +1.52 m.OD at Bourne Fen, and in the Guyhirn-Holme Fen-Whittlesey transition area the levels are up to +1.0 m.OD. These are clearly higher than the Wash IV deposits to the south.

However much more evidence is needed to estimate the amplitude of the negative tendencies associated with Fenland IV. Two apparent anomalies to this scheme should be noted, the dates at Flaggrass and Magdalen Bend both being affected by erosion at the transgressive overlap (Godwin and Willis 1961).

Fenland V : c.3300 - c.3000 BP

This period is marked by the end of marine sedimentation at Bourne Fen, Ugg Mere and Chapel Point. No direct evidence, ie. transgressive overlap, is dated until 2815 ± 100 BP at Chapel Point but 3000 BP is estimated as the renewal of positive tendencies from an assay in a basal peat layer at Horbling Fen, 3010 ± 80 BP.

Wash VI : c.3000 - c.1900 BP (AD.50)

This transgressive episode is quite widely dated, eg. Chapel Point,but some of the ^{14}C data have proved difficult to interpret, eg. the transgressive overlaps at Welney and Saddlebow. Archaeological evidence reconciles much of the evidence and provides a more accurate time scale. The time limits are therefore based on archaeological dating methods and the ^{14}C data would therefore be slightly young (Damon et al. 1973) but with confidence bands that are too broad to corroborate the changes. Fluctuations in sea-level have been shown by Simmons (1978), Salway (1970), Hallam (1970) and Churchill (1970) for different times from the Iron-Age to post-Roman times which are not well represented by peat-clay sequences.

Archaeological evidence suggests no regressive tendencies before AD.50 (1900 BP) (Salway 1970) although local conditions may have prevented colonisation of former marshes until AD.150 (Hallam 1970, Simmons 1978). An important criterion to be assessed is the social change which occurred with the Roman invasion and therefore the regressive tendencies may be given a minimal estimate by the archaeological evidence. The evidence is clear for a fall in the altitude of salterns between the Iron Age and AD.150 (Simmons 1978) but the actual onset of negative tendencies is not identified.

The ^{14}C data from Saddlebow, Welney, Spalding and Setch may suggest transgressive tendencies after this time but their interpretation and accuracy are not unequivocal (see part 3.4). The assay from AL4 on the regressive contact of the highest peat layer, 1845 ± 50 BP, is interesting and requires future verification. Correlation with the Dog-in-a-Doublet-Pear Tree Hill Section (Godwin and Clifford 1938 fig. 27) indicates a pre-Romano-British age for the peat layer, with clastic deposits of Wash VI above, and of Wash V below. But the assay suggests that the peat started to form in Fenland VI and therefore the subjacent clays must be of combined Wash V and VI age, with no peat layer of Fenland V age recorded. There is a slight change in the stratigraphy of the clastic layer at -1.53 m.OD in AL4 but only detailed analysis of the clastic layer and a mapping survey will indicate whether any regressive tendencies are recorded. Similarly, re-dating of the peat layer, preferably at sites where the peat is at slightly greater depth, (cf. 1m. at AL4) to lessen the possibility of recent contamination of the sample, will confirm or refute the assay from AL4.

Fenland VI : c.AD.50 (1900 BP) - c.AD.400 (1550 BP)

There is some disagreement over the movement of sea-level during the Roman period. During the late 3rd and the 4th century AD. arable land was returned to pasture and once prosperous fen settlements languished (Hallam 1970) and at Welney two occupation layers are separated by 1.9 m. of silt (Churchill 1970, Godwin 1978). This was attributed to a small transgression although problems with the silting up of drainage channel outfalls were evident from AD.200 onwards (Hallam 1970). Hallam therefore concludes that the main transgression was not underway until the 5th - 7th centuries AD.

At first it may appear that the evidence for sea-level change since the Roman period should be more easy to identify than earlier changes. However from this period onwards the evidence is more readily destroyed by later activities since it is generally found nearer the surface and furthermore very little direct research has been made. Most of these conclusions are inferred from settlement studies and the differentiation between sea-level change and periods of flooding becomes very difficult. As man changes the coastlands by the construction of drainage channels, sea defences and the removal of peat for fuel the movement of the coastline becomes less dependent on sea-level change and more dependent on local sedimentological, social, technological and economic factors. Therefore it will be to the credit of historians and archaeologists to modify this scheme in the future.

Wash VII : c.AD.400 (1550 BP) - c.AD.800 (1150 BP)

Settlement and saltmaking studies provide the time limits for this transgressive episode during which there was first a landward movement of the coastline covering Roman deposits (eg. Smith 1970) followed by continued accretion in the coastal zone (Hallam 1965, Healey 1978).

Fenland VII : *c*.AD.800 (1150 BP) - *c*.AD. 1000(950 BP)

This period of a relative fall in sea-level is inferred from settlement studies and documentary evidence (Hallam 1965).

Wash VIII : *c*.AD.1000 (950 BP) -

From this time onwards land reclamation and natural accretion dominate the coastline of the Wash and therefore vertical and horizontal changes in sea-level and the coastline cannot be easily separated. The altitude of sea-banks and reclaimed land testify to a generally rising relative sea-level (Fowler in Godwin 1940a). Whereas deposition became dominant in the Wash, along the Lincolnshire coast a more high energy environment developed.

Part 7.4 : Conclusions

The following periods have been identified on the basis of sea-level tendencies:-

	Wash I	- *c*.6300 BP
	Fenland I	*c*.6300 - *c*.6200 BP
	Wash II	*c*.6200 - *c*.5600 BP
	Fenland II	*c*.5600 - *c*.5500 BP
	Wash III/IV	*c*.5500 - *c*.4500 BP
or	? Wash III	*c*.5500 - *c*.5200 BP
	? Fenland III	*c*.5200 - *c*.5100 BP
	? Wash IV	*c*.5100 - *c*.4500 BP

Fenland IV	c.4500 - c.4200 or c.3900 BP	
Wash V	c.4200 or 3900 BP - c.3300 BP	
Fenland V	c.3300 - c.3000 BP	
Wash VI	c.3000 - c.1900 BP	1050 BC - AD.50
Fenland VI	c.1900 - c.1550 BP	AD.50 - AD.400
Wash VII	c.1550 - c.1150 BP	AD.400 - AD.800
Fenland VII	c.1150 - c.950 BP	AD.800 - AD.1000
Wash VIII	c. 950 -	AD.1000 -

This chronology is the most satisfactory scheme to explain the stratigraphic, pollen, diatom and ^{14}C evidence presently available. It is not dependent on any one type of evidence in isolation and since the data are only estimates, with a certain probability of representing the true values, the questioning of the accuracy of exceptions to, or residuals from, the general chronology is to be expected. The major problems that are apparent with the present chronology are summarized:-

1. there is no single site which exhibits all of the periods listed above. This is not surprising since Fenland VI - Wash VIII are based on archaeological and historical data. However the combination of AL2 and AL4 appears to cover Wash I - Wash V at least, and possibly up to Fenland VI.
2. the major ^{14}C problems are those from Saddlebow and Welney (eg. Churchill 1970) and are as much technical problems as chronostratigraphic ones. For Saddlebow it is necessary to investigate the late development of regressive tendencies, c.3900 BP compared to c.4500 - 4400 BP at Spalding, Denver and AL4, while

transgressive tendencies were being recorded in the Witham Valley, AL4 and Welland Washes. Furthermore it is necessary to explain the exclusion of clastic deposits during Wash V at Saddlebow. Did raised bog develop here as it did at Nordelph?

3. the series of dates from Setch do not agree well with the other dates in the vicinity and re-investigation of the stratigraphy and dating of sequences in the Setch-Saddlebow - Wiggenhall St. Germans area would provide much useful information.

4. the major lithostratigraphic problem is the explanation of the altitudinal difference between Fenland IV peat layers in the southern Fenland and those further north : at Spalding and Adventurers' Land in particular. However the problem cannot be dismissed as being due to consolidation(the Spalding sites and AL4 record Fenland IV as an intercalated peat) since at more landward sites(Bourne Fen, and between Guyhirn and Holme Fen) dated sequences reveal basal peats apparently forming at lower altitudes than the upper peat of the southern Fenland but of Wash V age.

5. figure 7.3 shows a broad sea-level band, compared to the misleading "curve" usually drawn in sea-level studies, due to the errors involved in the assessment of sea-level index points. However the band is particularly wide for two periods, Wash III/IV and Wash VI. For the former this is believed to be the combined effect of consolidation and within-Fenland differences of

sedimentation processes and possibly crustal movement. For the period Wash VI the altitudinal range is due to the as yet unresolved relationship of certain archaeological evidence (saltern levels, and levels of colonised levees) to past tide levels and the interpretation of limited ^{14}C data (table 7.2, 7.3, fig.7.2).

6. the chronology is dependent on the ^{14}C method. Technical problems and the measured variability of the ^{14}C and dendrochronologic time-scales (eg. Damon _et al_. 1973) do not permit the identification of short time periods. Age gradient reversals for closely spaced samples are quite common, eg. Shippea Hill, Saddlebow, Bourne Fen; and these all together indicate that ^{14}C analyses must be dependent on other forms of analysis in the development of any chronology. It is on these combined criteria that the periods of rising and falling sea-level tendencies have been identified.

Therefore, despite the problems arising from this chronology, it can be said that the evidence is overwhelming for the identification of periods of alternating rising and falling sea-level tendencies at individual locations. The dating and correlation of individual locations to identify the regional significance of these tendencies are the major aims for future research. Figure 7.4 indicates the extension of clastic deposits of the periods Wash I - VI. Later coastlines cannot be readily related to periods of sea-level tendency. Furthermore it can be seen that large areas of the Fenland still require investigation to identify the age, nature and extent of the marine deposits.

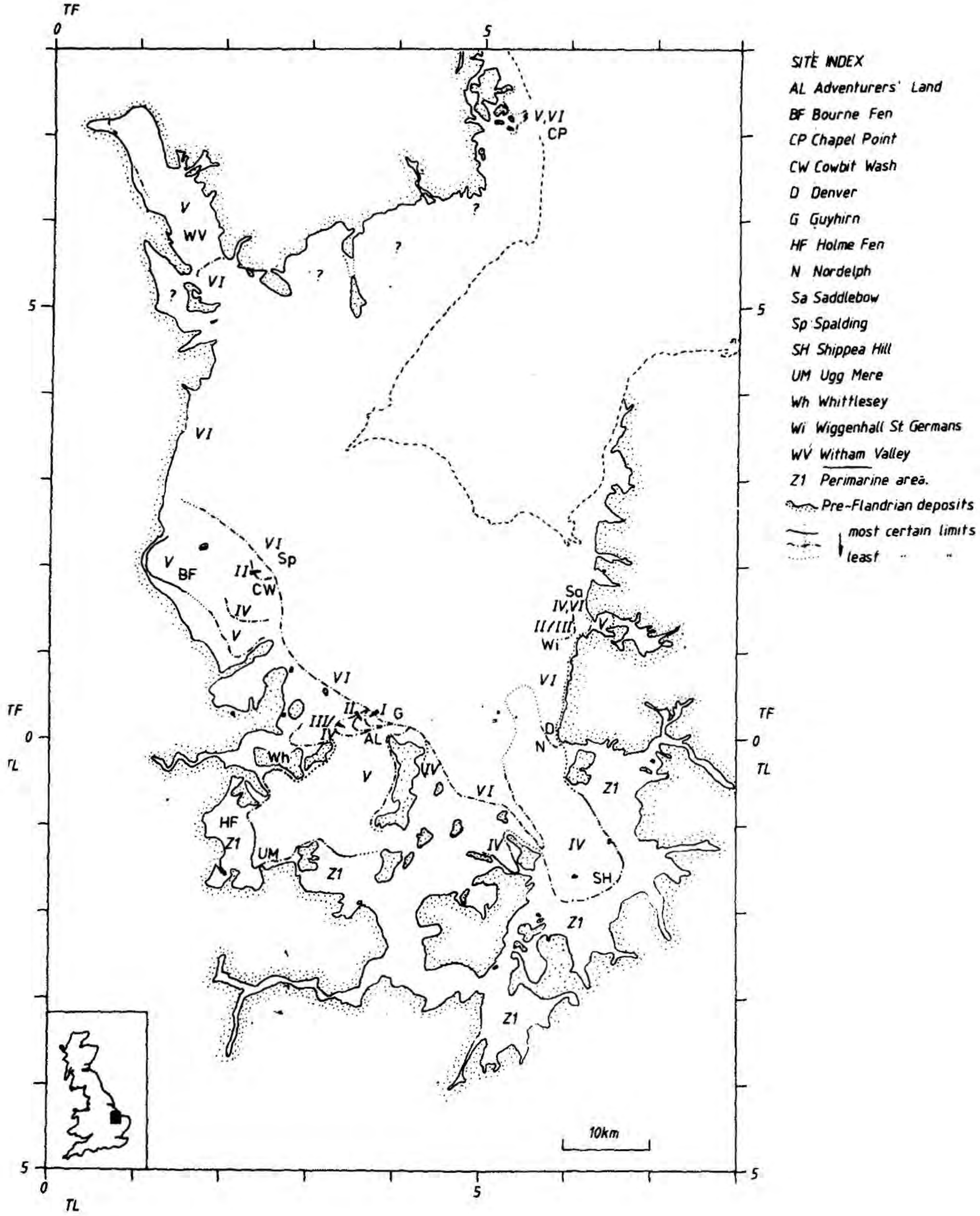


Figure 7.4 : The maximum extension of marine deposits, Wash I-VI, in the Fenland.

Differences in the extent and age of the various marine deposits have been noted. It is apparent that the most extensive marine deposits are gradually younger from the south to the north, up to the Witham Valley (fig.7.4). The altitudinal limits of the different organic and clastic horizons also require further investigation. Whether differential crustal movement during the past 7000 years within the Fenland has occurred, with hydro-isostatic effects being a factor, is a question deserving an answer. Certainly the Fenland did not act in a uniform manner to the changes in sea-level identified throughout this analysis. Figure 7.4 shows that there are several drainage basins within the Fenland which would have affected the local nature and extent of transgressions. It is necessary to resolve the palaeoenvironmental conditions at the seaward end of these basins to see how they have controlled the sedimentary conditions within the basins.

It is concluded that the data available indicate 7 (possibly 8) periods of rising sea-level interspersed with periods of regressive tendencies. The regional and altitudinal significance is not always clear due to the combined effects of the errors involved in the assessment of sea-level index points and the use of the whole Fenland as the scale of study. If the periods of regressive tendencies are considered to be of regional importance then fig. 7.3 can be resolved one stage further to give a constrained confidence band. Whereas the 60% and 90% confidence bands are effectively drawn by smoothing between the extremes of the error boxes the constrained curve is based on the tendencies of sea-level for that time. Once more it is clear that the regional significance of negative tendencies needs to be assessed to elucidate the detailed sea-level, environmental and isostatic history of the region.

CHAPTER EIGHT

Inter-regional comparison of sea-level chronologies

The alternations of clastic and biogenic sediments discussed in the preceding chapters reflect the interaction of local and regional phenomena, of which real eustatic movement of sea-level is only one variable. In isolation a relative sea-level graph from a single area, e.g. the Fenland, can seldomly show unequivocal evidence of regionally significant eustatic fluctuations and comparison with other areas must be made. This comparison is developed in the following parts:-

8.1 : Problems of scale and technique.

8.2 : Comparison with other areas.

8.3 : Crustal movements.

8.4 : Statistical evaluation of ^{14}C data.

8.5 : Conclusions.

Part 8.1 : Problems of scale and technique

Each sea-level index point has dimensions of location, age and altitude. Regional comparison therefore requires the assessment of within-area variance and between-area variance of the age and altitude parameters for the index points taken to represent a defined area. In practice coastal units are subdivided into areas of investigation for which certain variables can be taken as constant, for example, where differential isostatic movement is not considered likely, or where tidal parameters can be considered constant. It was shown in the preceding chapter that it may not be valid to treat the Fenland as an homogeneous coastal unit. Moreover it is clear that individual sea-level index points, transposed from the time-location-altitude dimensions, as they exist in reality, to the time-altitude dimensions of a sea-level graph, are subject to a variability which must be taken into consideration. Therefore the measurement errors of age and altitude and the extent to which they represent the defined coastal unit must be assessed in order to estimate the within-area variance. Without such an assessmant between-area comparison is of much lower value.

In Chapter 7 it was shown that in using widely accepted fieldwork techniques the indicative altitude of an individual sea-level index point can be given to c. ± 0.40 m. This assumes that the indicative ranges given in table 6.2, inferred from Kidson and Heyworth (1979) are correct, and should they not be so then this error must be greater. Furthermore, the complicated allowance for consolidation has not been made. The figure of ± 0.40 m. assumes a dense borehole network, i.e. a c. 150 m. grid, and therefore for less detailed borehole surveys this error must be assumed minimal.

In addition to the error in the estimate of altitude of the former sea-level given by individual index points, the variance is increased by extending the area over which the sea-level index point is assumed indicative. For treating the Fenland as a whole it was shown that the accuracy could only be ± 2.0 m. for certain periods at which the available data show greatest discrepancies.

The within-area error of the age estimate which ought to be expected can be illustrated from the difficulties encountered in the preceding chapters to develop chronologies both for individual sites, BFP1, and BFP2, and also for the whole Fenland. Only 102 ^{14}C data, of variable quality, were available and the proposed chronology could not expect an accuracy better than ± 100 years and future modification of the chronology is likely. However this number of ^{14}C assays is greater than the total used elsewhere in the UK (eg. Devoy 1979, Kidson and Heyworth 1973, Tooley 1978a). The reliance on isolated ^{14}C assays is particularly hazardous since the "real" error is greater than the "technical" error given by the radiocarbon dating laboratory. The problem is easily illustrated by the Fenland data (tables 3.1 and 7.1). There are only 9 sites which have been dated by 2 or more samples with less than 15 cm. between the samples, and of these, 4 sites : Saddlebow, Shippea Hill, BFP1 and BFP2, reveal inversed age-gradients. In addition, two sites from Woodhall Spa, WS-TB and WS-5.4, have had replicate samples sent to different laboratories with inconsistent results obtained. Therefore, of 11 sites used for the within-area chronology, 6 show age discrepancies. The conclusion is unavoidable that too few ^{14}C data oversimplify the assumed chronology and reflect too much reliance on the ^{14}C method to identify short periods of change. Clearly further research is required to assess the accuracy that can be expected from the ^{14}C method for the development of local chronologies.

Part 8.2 : Comparison with other areas.

The methodology developed for the correlation of different areas is virtually non-existent and the same may be said of local chronologies. Even though the preceding chapters have identified and partially quantified errors which have previously been either disregarded or not quantified, the development of the chronology and the comparison of the evidence within the Fenland was still very subjective. The chronology was developed by "informed comparison" rather than statistical correlation. The technique can only be defended by pointing to the lack of data available and the statement of the errors involved. This approach is not unusual in sea-level studies and only rarely are statistical methods employed (eg. Smith et al. 1969). This practice must be encouraged, although the difficulty of retrieving samples and the expense of ^{14}C dating will always limit the size of the data set.

Just as the unwarranted accuracy portrayed by a sea-level curve drawn as a line must be criticised - although Mörner (1980) does assess the error in his curve and concludes an accuracy of 0.1 m. - then the present practice of correlating transgression episodes must also be criticised. The methodology for the correlation of these time series has not been developed. Mörner (1980, p.285) does, however, acknowledge,

> "Due to chrono-stratigraphical uncertainties, differences in dated material and it's relation to sea level, and differences between various radiocarbon laboratories, it is generally not possible to achieve so good a time resolution that correlations closer than within some 100-200 years can be substantiated."

Even so the techniques of "correlation" are generally no more than educated guesses, yet the following statement, quoted from the original text, is not uncommon -

> "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".(Devoy 1979, p.391).

The justification of these statements by Devoy requires close scrutiny. Firstly he assumes that all of the authors from whom he derives evidence have defined the terms "transgressive and regressive phases" on the same bases. In view of the discussion in chapter 1 this is highly unlikely. Even if this were so the evidence as presented does not allow such conclusions. Mörner (1969) explained that during the Flandrian Stage regions of subsidence, ie. the southern North Sea region, will have been dominated by transgressive tendencies and therefore only major regressions should be recorded. However Devoy's (1979) figure 30 shows very poor agreement for the correlation of regressive tendencies, for only between c.2750-c.2850 BP do the sequences he quotes all show regressive periods. This is hardly "the same trend of sea level rise and timing of transgressive/regressive phases" for the 9000 years the diagram covers.

Similarly the use of such diagrams as given by Devoy (1979 fig. 31) and Tooley (1976 fig. 3) should be discouraged due to the different definitions used for transgressions by authors. Furthermore, Devoy's (1979) conclusions are still not justified. The broad synchroneity of relative sea-level movements in NW Europe is not well demonstrated. From

Devoy's figure 31 each region can show either a transgression (t) or regression (r), therefore for a given time total agreement would be shown by either all transgressions or all regressions and no synchroneity by an equal division (NB. further analysis may relate these with uplifted and subsided areas). This can be measured by a similarity index (Is) given by the form:-

$$I_s = \left| \frac{\sum t - \sum r}{\sum t + \sum r} \right|$$

I_s has a range zero to 1, no similarity to total similarity, and if calculated for each 200 year period between 8600-1000 BP from Devoy's diagram gives an overall mean of 0.38. This represents a situation only slightly better than where for each 2 regions showing a transgression 1 shows a regression : hardly "broad synchroneity".

Therefore in the absence of any acceptable methodology, and without the re-interpretation of other researchers' data to compare uniformly defined periods of positive and negative tendencies of sea-level movement it would be unwise to attempt a correlation with other areas except in the broadest terms.

The main question to be answered is whether the lithologic changes noted for the Fenland, and interpreted in a chronological scheme of periods of rising and falling sea-level tendencies, represent local phenomena or synchronous events over larger areas. The major difficulty preventing a solution to the problem is the correlation of data describing lithostratigraphic units, ie. alternations of peats and marine facies, with sea-level movements. Without considerable re-evaluation of the published data this is not feasible at the moment. However on the assumptions that the Fenland has been an area of crustal subsidence throughout the Flandrian Stage and the regional eustatic sea-level has shown a generally rising level then any periods characterised by evidence of falling sea-levels, i.e. Fenland 1-V11, should be identified in areas less affected by crustal subsidence if the periods of negative tendencies are of more than local significance.

The only possible approach considering the data and methodology available is to indicate those areas which show broad agreement and disagreement. This method, however, cannot give unequivocal results.

The area nearest to the Fenland which has been studied is the Humber Estuary (Gaunt & Tooley 1974). Only isolated data are available from this area. A possible oscillation in sea-level movement prior to any recorded in the Fenland is recorded at Kingston-upon-Hull while the first possible correlation between the two areas is the development of woody peat above marine deposits at Spur. This peat is dated 6170 ± 180 BP (Hv 3359). This would represent the development of woody communities following the period of negative tendencies designated Fenland I.

At Stoneferry the transgressive tendencies recorded some time after 5240 ± 100 BP (IGS-C14/97) may probably be correlated with Wash 1V, and Wash V appears to be represented by the dates on shells of <u>Cerastoderma edule</u> and <u>Macoma balthica</u> at Stoneferry. Furthermore the transgressive deposits at Brigg, indirectly dated to 2552 ± 120 BP (Q-77)and 2784 ± 100 BP(Q-78) fall within Wash V1. However the nature, extent and timing of marine influenced deposits in the Humber estuary and adjoining valleys is not clear (Smith 1958, Tooley 1978a). Conflict with the proposed Fenland scheme may be given by the site at North Ferriby and Brigg where ^{14}C assays on Iron Age boats and associated structures suggest the deposition of clastic sediments c.3500-3100BP (McGrail & Switsur 1975), two further assays on the "Brigg Raft" (McGrail & Switsur 1975) corroborate those given above (Q77, Q78), and therefore the two periods of clastic deposition would appear to correlate with Wash V and Wash Vl. However, there is no apparent stratigraphic evidence for an intervening regressive phase and the suggested time limits for one of the boats from North Ferriby would fall in Fenland V. Detailed mapping and palaeoenvironmental investigations are clearly required in this important area to corroborate further or refute the scheme for the Fenland as being of more regional importance.

Transgressive and regressive tendencies are noted at Hartlepool (Gaunt and Tooley 1974, Tooley 1978c), where c.1.7 m. of clastic deposits were dated as accumulating between 5285 ± 120 B P (Hv 4712) and 5240 ± 70 BP (Hv 3459). These virtually identical assays are not very satisfactory but may give weight to the significance of the Wash 111/Fenland 111 oscillation at c.5200 BP.

To the south of the Fenland it is less easy to compare the Fenland chronology with existing schemes. The Norfolk Broads appear to be a suitable area for correlation (Jennings 1952, Lambert et al. 1960) but only now are the required investigations being undertaken (Alderton Pers.comm.).

The evidence available from the outer Thames estuary (Greensmith and Tucker 1973) is not directly comparable to the Fenland data since different techniques of analysis have been used. These problems were noted by Tooley (1978a) in identifying the lack of detailed concurrence between the outer Thames estuary and west Lancashire. However, while the techniques can be criticised (Tooley 1978a), Greensmith and Tucker have resolved the evidence into a curve of sea-level movement. Their curve, however, bears little visual resemblance to the curve for Tilbury given by Devoy (1979). The lack of agreement between two relatively close sites must be the result of a combination of the following factors within or between each area : incomplete evidence, unreliable indicators of past sea-levels, local differences in tidal parameters, or differences in the techniques used. Perhaps, therefore, it is not surprising that the outer Thames estuary curve does not closely agree with the Fenland scheme. The former curve is dominated by transgressive tendencies but regressive tendencies are noted for the periods c.5100-4300 BP, c.3200-2700 BP and c.1900-1700 BP. These, from an area likely to have been affected by more subsidence than the Fenland, only show broad agreement with regressive phases in the Fenland : Fenland (?111)1V, Fenland V, Fenland V1.

The problems originating from the use of different techniques should not arise during a comparison with the evidence from the rest of the Thames estuary (Devoy 1979). However Devoy's analysis is remarkable in that he utilises 3 curves to represent the data (Devoy 1979 fig.29). Firstly, he describes 2 oscillating curves separated in altitude by up to 3 m.- although his index point 16 from Broadness Marsh lies significantly below both of the curves. Indeed, the recognition of 2 curves is less justified when viewed in a spatial sense; the Broadness Marsh site is midway between Tilbury and Stone Marsh - New Dartford Tunnel, with Crossness further removed, yet Tilbury is isolated from the others for the curve drawing exercise. This is important since it means that the amount of relative downwarping, 1.5 m. since 7000 BP, is applicable over a much shorter distance, c.5-9 km, rather than c. 18 km. (Crossness-Tilbury) as suggested by Devoy (1979). With the limited information available it is better to consider the Thames data as a whole with the present index points indicating the likely range of past sea-levels. The data could then be given in a form similar to fig. 7.3, giving the confidence band within which MHWST was likely to have occurred and at the same time showing the periods dominated by rising or falling sea-levels. This approach is more useful than Devoy's third curve : a mean curve calculated from all the sea-level index points, which is of little value when no error range is expressed since it is obviously designed to show the mean trend, but gives no indication of variance around the mean.

However, by interpreting Devoy's evidence in terms of periods of rising and falling tendencies of sea-level a comparison can be made with the Fenlands. Thames I ended c.7000 BP which is prior to any direct evidence of sea-level movements in the Fenland and therefore the first comparison should be the culmination of Thames II.

Devoy designates the period Thames II as a period of rising sea-level between 6600-5500 BP but "Between 5500/5000 and 4000 BP a major regression, Tilbury III, took place..." (Devoy 1979 p.389). The evidence from the Thames estuary is very complex for this period as is evident from Devoy's difficulty in giving a clear delimitation for Tilbury III. Furthermore he had previously shown (eg. fig.28) that a regressive overlap at Tilbury was dated 6200 BP. In fact Devoy shows an age range for the end of clastic deposition designated Thames II of 6200-4930 BP, with renewed clastic deposition starting c.4000 BP, possibly as early as 4190 ± 100 BP. Obviously it is not possible to correlate this complex period with the situation in the Fenland since no such long period of regression was recorded, Fenland I-IV all fall between c.6300 and c.3900 BP.

The best correlation between the Thames estuary and the Fenland, but by no means unequivocal, is the age of Tilbury IV; regressive tendencies were initiated as early as 3240 ± 75 BP at Tilbury, and transgressive tendencies resumed at 3020 ± 65 BP, although the dates at Broadness Marsh and Stone Marsh are slightly younger. The older dates suggest close agreement with the period Fenland V. Overall, however, it must be said that the Thames estuary does not show close agreement with the Fenland while the period 6200-4000 BP remains so complex in the former area.

Of the other sections of the coastline of England and Wales which have been subject to suitable study : Bridgwater Bay and the Bristol Channel (Kidson and Heyworth 1973, 1978), the Dovey Estuary (Wilks 1979), and NW. England (Tooley 1974, 1976, 1978a); only the evidence from the latter area is interpreted in terms of periods of rising and falling sea-levels, even though Kidson and Heyworth claim that their corrected curve represents a regionally significant eustatic curve. Devoy (1979) has re-interpreted Kidson and Heyworth's evidence and selected 24 sea-level index points to represent an oscillating curve for SW. England. This curve shows very little agreement with the Fenland scheme but the curve Devoy devises (1979 fig.33) clearly needs more information to delimit accurately the periods of rising and falling sea-level. Indeed if the evidence from SW. England is to be interpreted differently from the way in which Kidson and Heyworth have concluded it must be with a re-appraisal of all their data, ie. stratigraphic, pollen, diatom etc., and not by the retrieval of isolated ^{14}C index points. Therefore it is not considered possible to correlate the sequences of SW. England with the Fenland at the moment.

Wilks (1979) gives the most recent analysis of the Dovey estuary and reaches general conclusions similar to those of Kidson and Heyworth, while noting further that the stratigraphic sequence there "is, in all likelihood, a localised phenomenon." (Wilks 1979 p.33).

The best possible correlation with the Fenland that can be attempted is from NW. England. Tooley (1974, 1976, 1978a) recognised 11 periods of marine transgression but it has been shown, (part 1.2), that these periods do not represent solely times of rising sea-levels. However by comparing the estimated limits of periods of rising and falling sea-level, (from figure 2 Tooley 1976), a good fit is gained with the Fenland data. Therefore the periods discussed below are indicated as L'I - L'X to distinguish these, inferred from the sea-level curve, from the periods designated in the text by Tooley (1976 p.144).

A regressive overlap at Nancy's Bay-6 is dated 6290 ± 85 BP, L′IV, and provides the earliest correlation with the Fenland scheme, Fenland I. Positive tendencies are recorded soon after at the same site at 6245 ± 85 BP which agrees with the suggested short duration of the regressive phase in the Fenland. A further fluctuation is recorded c.6050 BP but no similar event is recorded in the Fenland. The next period of negative tendencies after the L′V maxima is dated 5775 ± 85 BP, 175 ^{14}C years before the opening of Fenland II.

L′VI is given two maxima, the first dated at 5250 ± 385 BP may correlate with Wash III/Fenland III, but the second, at 5005 ± 65 BP has no equivalent in the Fenlands.

However L′VIa is clearly represented by Fenland IV, the assay at Altmouth (4545 ± 90 BP) being equated to the opening of Fenland IV at c.4500 BP. The ensuing period of falling and then rising sea-level is interpreted from Tooley's graph and is seen to reach a minimum in the transition period Fenland IV/Wash V and reaches a maximum sometime prior to 3150 ± 150 BP. This is in very close agreement with Wash V/ Fenland V. The following fluctuation does not agree so well with the Fenland scheme, ie. negative tendencies are dated 2270 ± 65 BP at Lytham Hall Park - 8 while Wash VI was given as continuing until c.1900 BP. However it was noted (part 7.2) that the ^{14}C evidence for the end of Wash VI was not very strong and the archaeological data could indicate a pre-Roman age for the initiation of regressive tendencies.

Final direct dating evidence of sea-levels are the minimal dates for regressive tendencies following L/IX, c.1600 BP, and appears out of phase with the Fenland scheme, falling at the end of Fenland VI.

Brief mention can be made of the comparison with the sea-level record from south-east Scotland where the uplifted region is obviously dominated by a falling relative sea-level after c.7000 BP (Sissons 1967). A broad correlation of the positive fluctuations since that time reveals a close agreement with the beginnings of Wash IV, V and VI.

The Fenland scheme should also be compared to some of the European schemes. It is difficult to compare directly with those enunciated by many Dutch workers since in their operational definitions (eg. Jelgersma 1979) negative movements of sea-level are not allowed for, and the chronistratigraphic schemes developed are not readily adapted to an interpretation of relative sea-level movements. However, without a re-interpretation of the original author's work only a few published accounts allow direct correlation.

This is possible due to the invaluable palaeobotanical and biostratigraphic work of Menke and Behre (1973). They appeared until recently to stand alone in the recognition of significant periods of regressive tendencies :

> "Considering the hydrographic conditions during the growing season, which can be deduced from changes in the former plant communities a much more complicated picture of ecologically important water levels is resulting. As there was no sedimentation over vast areas during the more or less regressive phases, but wide-spread peat and...even soil formation, the regressive phases are taken only insufficiently into consideration when subdividing the Holocene in coastal regions lithologically (Brand et al. 1965)" (Menke & Behre 1973 p.263).

Further they noted the "great marine ingressions" as occurring c.7200 - 6500/6300 BP (Wash I), c.6000 - 5300 BP and c.5000 - c.4400 BP, which together do not correlate with the Fenlands in that Fenland II has no corollary although Fenland III falls between their latter two periods of ingression. Fenland IV falls at the end of their period of ingression at 4400 BP. Closer agreement for the next interruption in ingressions in NW. Germany and the Fenlands is seen : c.3300 - 2600 BP cf. 3300 - 3000 BP. Finally Menke and Behre note an interval between two ingressions for the period c.2050 - 1950 BP. This is further evidence suggesting that the ^{14}C data for the Roman period in the Fenland may be insufficiently accurate and that the archaeological evidence relating a fall in sea-level between the pre-Roman Iron Age and Roman colonisation is probably a better dating technique.

The German evidence suggests renewed transgression from AD100/200. This is at odds with the Fenland evidence. Clearly there appears evidence throughout the southern North Sea for a pre- or early Roman fall in sea-level followed by later ingression. However it is at this time that man was able to modify the coastline and therefore the time limits indicated by both archaeological and biostratigraphical techniques may be diachronous due to social and economic variables.

A more recent scheme for Schleswig-Holstein has been published (Behre et al. 1979), recording 8 periods of regression between c.9000 - 1400 BP. All of these do not agree in detail with the Fenland scheme. However there are periods of regression in Schleswig-Holstein during

Fenland I, III, IV, V and once more the c.2000 BP regression is placed as being pre-Roman. This may be so on the time-depth diagram but in the text the settlement of coastal lands was shown as being diachronous and often later. Clearly the detailed work from Germany suggests that the Fenland scheme may be too simplified at the moment due to inadequate data. However the Fenland evidence certainly agrees with Streif's (1979a) assertion that there was a fall in sea-level c.2000 BP and c.3200 - 2800 BP. Regionally significant periods of falling sea-levels also appear at c.4500 - 4200 BP but pre-5000 BP events are less clear.

Finally a comparison can be made with Mörner's (1976b) eustatic curve for North West Europe. On the assumption that the Fenland is an area marked by subsidence throughout the Flandrian Stage then periods of rising sea-levels in the Fenlands may occur either during periods of eustatic rise or fall depending on the absolute height relationships. However periods of regression in the Fenland should always coincide with periods of regression in Mörner's chronology. This is not always the case, although given the age accuracies of ± 100 years described in part 7.2 and Mörner's own comment, part 8.1, a conclusion of no correlation for short periods of falling sea-levels is equally untenable. Briefly the periods Fenland I-VII compare with Mörners scheme in the following way.

Fenland I actually coincides with PTM-3B and Fenland II with the end of PTM-4. Fenland III correlates with the regression prior to PTM-5A and Fenland IV with the regression between transgressions 5B and 6. Fenland V occurs at the end of the regression prior to transgression 6/7 but also overlaps the beginning of that transgression and once more Fenland VI appears slightly late. Fenland VII coincides with PTM-10.

In general the agreement is not always good. However, given the errors involved in the ^{14}C method better agreement may not be possible. It is becoming increasingly apparent that most of the periods of falling sea-level recorded in the Fenland have been recorded elsewhere, particularly Fenland I, IV, V and VI (slightly earlier than the present ^{14}C evidence suggests).

Part 8.3 : Crustal movements

An important part of any research involving relative sea-level change is to assess the individual roles of the ocean-based and land-based variables. The regionally significant land-based variables are dominated by crustal movements. It has been suggested throughout the preceding sections that the Fenland is an area characterised by crustal subsidence throughout the Flandrian Stage. Subsidence has been a noticeable feature of the area for much longer periods (see chapter 2) but it should be recalled that Eden et al. (1978) noted that average subsidence rates for the North Sea north of the Forties Field were over 50 times greater for the Flandrian Stage compared to the average rate of Tertiary subsidence. It will be an aim of future research to compare these figures with those from the southern North Sea area and to differentiate between long term crustal subsidence and that attributable to isostatic movements (cf.Jelgersma 1979). The first stage is to compare the altitudinal variations of sea-level index points for the Fenland and other areas through the Flandrian Stage.

The usual method to show crustal movement is to compare sea-level curves from different areas, each curve related to its local "sea level" (Kidson & Heyworth 1979), so that changes since the present can be compared. Conclusions made from such analyses (eg. Devoy 1979, Kidson and Heyworth 1978, Mörner 1976b, Tooley 1978b) are based on visual comparison and compound all the errors inherent in all of the previous stages of analysis. Present evidence suggests that the south-east of England is an area marked by subsidence and the north of England and Scotland are characterised by isostatic uplift. However there is dispute over the extent of crustal movement in south-west England and mid-Wales (eg. Devoy 1979, Kidson and Heyworth 1978, Wilks 1979). Further indication of differential crustal movement in the British Isles may be indicated by recent geodetic and tide gauge data (Kelsey 1972, Rossiter 1972) but there are other possible explanations for their systematic altitudinal differences.

The present analysis can be used to test the general model of north-south differential movement and also the methodology on which the model is based.

The problem must be viewed on different scales. Firstly there is the possibility of differential crustal movement within the Fenland. Indeed unless the movement took place in the form of vertical and uniform block movement there should have been a gradual tilt within the Fenland. However, present methods of analysis do not allow the identification of such movements although the confidence bands shown in fig. 7.3 would include their temporal and altitudinal effects.

Along the east coast of England there is evidence of differential movement. Although there are few reliable sea-level index points available (i.e. where the indicative meaning is clear) a direct comparison can be made with the Fenland data by allowing for sampling errors and present tidal range. By calculating the errors as for the Fenland data (table 7.2) and allowing for the present value for MHWST : +3.4 m.OD for the Humber and +2.4 m.OD at Hartlepool, the relationship to present tide-levels can be compared. Table 8.1 shows the relevant data. Only if the confidence bands for the Fenland and east coast data do not overlap is there a significant differential crustal movement identifiable. The values shown relate to the relative sea-level rise at that site since the age of the sample. Therefore only where the maximum rise indicated by the east coast data (the minimum value being ignored for the comparison with the Fenland) is less than the minimum estimated rise for the Fenland (similarly the maximum value is ignored) then are the two estimates deemed significantly different.

Table 8.1 : Minimum estimate of sea-level rise in the Fenland compared to maximum estimate of sea-level rise for other east coast sites.

Site	Age	Code	m.OD	Max.	Fen. Min.	Significant
West Hartlepool - 2	5240±70	Hv3459	-0.34	3.2	6.4	yes
West Hartlepool - 3	5285±120	Hv4712	-1.95	5.1	6.4	yes
Spurn	6170±180	Hv3359	-2.35	6.6	9.6	yes
Stoneferry - A	5240±100	IGS-C14/97	-4.00	8.2	6.4	no
Brigg trackway	2552±120	Q-77	*c*.-1.00	5.2	0.5	no

There are significant differences in relative sea-level rise between the Fenland and Hartlepool but the confidence bands in comparison with the Humber area overlap since at least 5240 BP. Only the inferred differential movement between the Fenland and the Humber estuary can be identified for sediments at least as old as 6000 BP, for which relative movement has been greater than present sampling and interpreted errors. Therefore conclusive evidence of differential movement within the Fenland shall only be identified when sea-level index points giving ages 6-7000 BP have been sampled unless detailed mapping and other advances in research reduce the values of the errors suggested in chapter 6.

For comparison with the rest of England figure 8.1 shows the individual data points for NW. England (Tooley 1976), the Thames estuary (Devoy 1979), Bridgwater Bay/Bristol Channel (Kidson and Heyworth 1973), and the c.90% confidence bands for the Fenland, without the use of corrections for consolidation in any case. In addition the maxima for each PTM shoreline for the proposed eustatic curve for north-west Europe are shown (Mörner 1976b). All of the curves are reduced to "present sea-level" on the assumption of constant palaeo-tidal regimes (cf. Tooley 1979 cf. Kidson and Heyworth 1978). By assuming Mörner's curve to be eustatic it is confirmed that the Fenland is subsiding, always occurring below the transgression maxima. The Fenland's relative position to the rest of the country is less clear; the curve always lies below that for the north-west, but occasionally overlaps those from the south-west and south-east. The significance of these points cannot be substantiated until the errors identified for the Fenland have

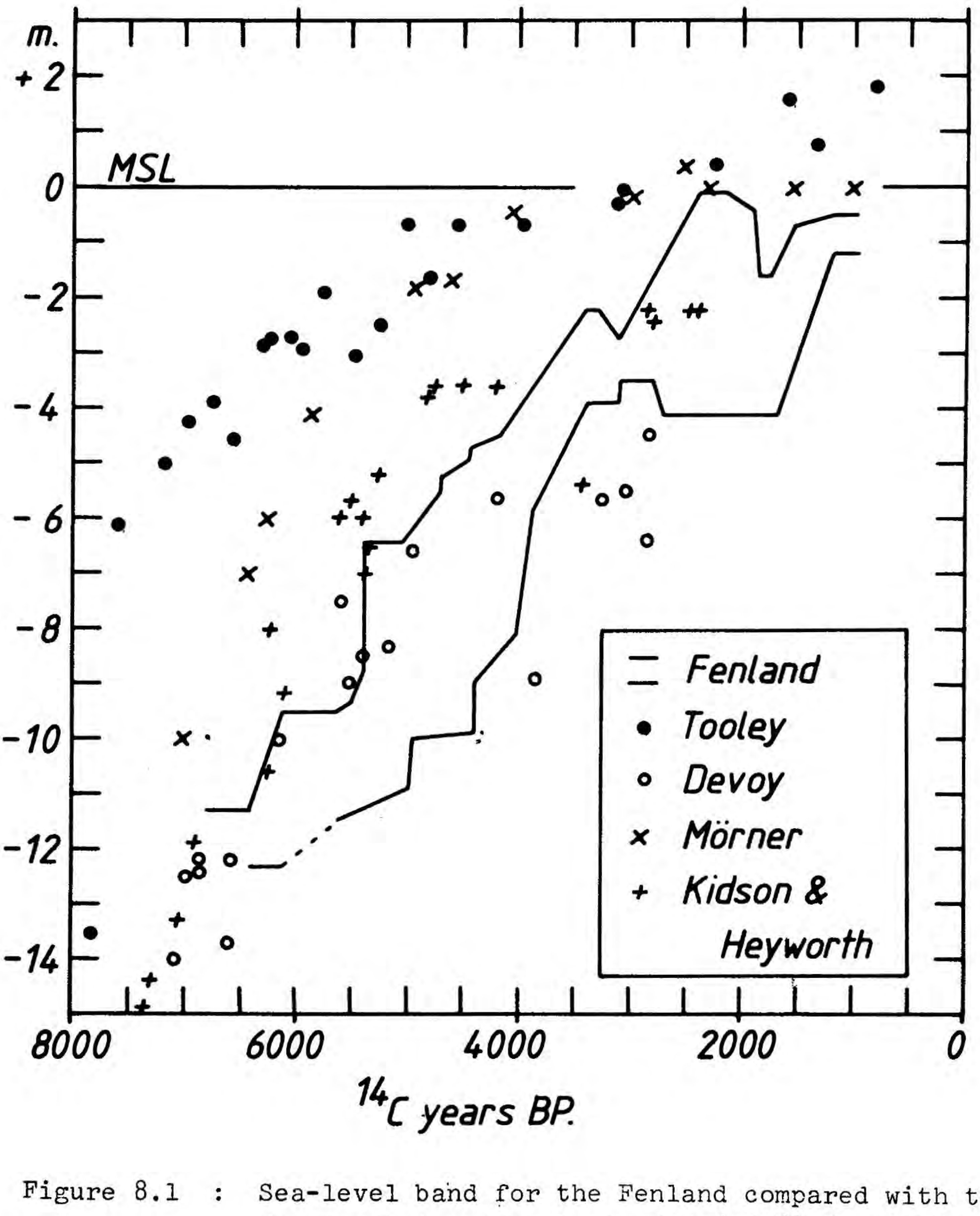
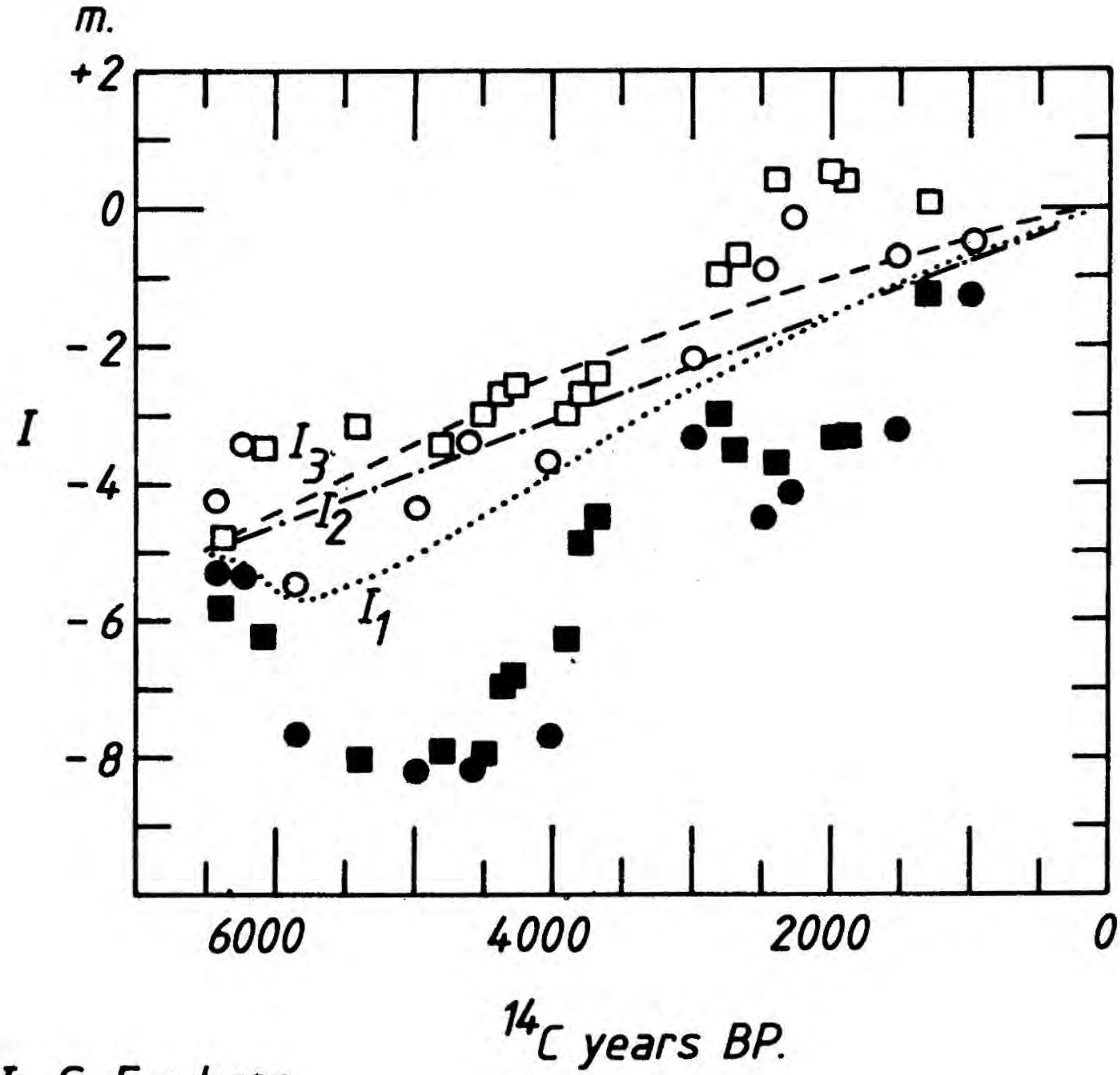


Figure 8.1 : Sea-level band for the Fenland compared with the index points given by Tooley (1976) from West Lancashire, Devoy (1979) from the Thames Estuary, and Kidson and Heyworth (1973) from the Bristol Chanel, and the PTM maxima of the proposed regional eustatic curve (Mörner 1976a). All are reduced to present mean sea-level.

been quantified for other areas.

These conclusions may appear somewhat broad compared to the statements made by others using essentially the same type of data and techniques (eg. Kidson and Heyworth 1978, Devoy 1979, Mörner 1976b). The degree of accuracy, as given by Mörner for example, is unwarranted, considering the errors of measurement, assessment of indicative meaning, interpretation of present tidal parameters from tide-tables, and assumptions of constant palaeo-tidal parameters (cf. Tooley 1979).

An attempt has been made to estimate net downward movement of sea-level index points in the Fenland since c.6500 BP (fig. 8.2). Of course, this is a combination of, essentially, consolidation and crustal subsidence. The method involves calculating the difference between the relative sea-level curve (S), adjusted to present "sea-level" (fig. 8.1), and the eustatic depth (E), from Mörner (1976b). In the absence of any rational method of "shifting" the time limits of periods of positive and negative tendencies in the Fenland to correlate directly with the PTM maxima (cf. Mörner 1976b), I-values (where $I = S+E$) were calculated for the maxima and minima on Mörner's curve. Therefore for each E-value two I-values for the Fenland are calculated. Three hypothetical curves, I_1, I_2 and I_3, are drawn. I_1 falls totally within the limits indicated by the Fenland data but shows an inflexion in a smooth curve c.6500-5500 BP. I_2 shows a straight line from c.6500 BP to present while I_3 shows a smooth curve for the same period. Any interpretation of these curves assumes that tidal regimes have not changed through time.



I = S+E where

S = Fenland (maxima: unshaded) levels

E = PTM (maxima: circles) levels

Figure 8.2 : Possible limits of the Isostatic factor (I) curve for the Fenland. Calculated from the relative sea-level maxima and minima for the Fenland (S) and the eustatic depth (E), PTM maxima and minima, from Mörner (1976b).

The point at c.6500 BP comes from the Adventurer's Land site where the dated material lies directly on pre-Flandrian sands and gravels and subjacent to brackish sediments. Therefore it should not be affected substantially by consolidation. Thus, if its assumed indicative meaning is correct it should be the most reliable index point in an altitudinal sense. All the other data may have been affected by consolidation to some extent and therefore, notwithstanding all of the assumptions made so far, the difference between either curve I_2 or I_3, or any lying above I_3, and the index points must represent the effects of consolidation.

However, the inflexion minima at c.5800 is interesting. The sea-level index point on which the Fenland S-value originates is from Spalding-2, where the stratigraphy is not reported (Welin et al. 1974) but correlation with CW-7 (part 5.3) indicates 0.17 m. of compressible organic material near to the limit of marine sedimentatinn. Consolidation in excess of 1 m. must have occurred if a smooth (I_3) or straight (I_2) I-curve is to be assumed. These broad conclusions differ greatly to the similar analysis of Tooley's curve (1974) by Mörner (1976b) when no consideration of consolidation was made.

Therefore to summarise the evidence of crustal movement in the Fenlands during the Flandrian Stage, it can be said that about 5 m. of subsidence has occurred since c.6500 BP, compared to c.6 m. suggested by Churchill (1965), and the area is subsiding relative to the north-west and north-east of England. It is not possible to differentiate between areas to the south given the present stage of analyses.

Furthermore the precise nature of crustal subsidence; linear, exponential, variable; cannot be resolved at present but should be a major aim for research. However, the mean rate of subsidence in the Fenland over the last 6500 years appears to be in the order of 77 mm/100 years. In comparison with the figures for the Central Graben of the North Sea (Eden et al. 1978) this rate is greatly in excess of the mean subsidence since the opening of both the Tertiary Period, c.5 mm/100 years, and the Quaternary Period, c.30 mm/100 years in that area. The Fenland is towards the periphery of the subsiding Tertiary structure and this comparison of mean rates suggests that crustal movements operating during the Flandrian Stage, due to the isostatic factor, overshadow any long-term movement for which therefore no figure can be suggested.

Part 8.4 : Statistical evaluation of ^{14}C data

The statistical evaluation of sea-level data can be divided into two groups. The first is the statistical analysis of both time and altitude parameters, and always results in a smoothed or mean curve (eg. Devoy 1979, Segota 1973). The use of such analyses is totally dependent on the resolution required for further analysis. The applicability to local changes in sea-level tendency is misleading. Statistical assessment of the significance of periods of fluctuations in local sea-level is presently undergoing consideration (Preuss 1979). Until Preuss' research is complete the main attention on statistical techniques lies in the treatment of time data only.

The statistical evaluation of ^{14}C data has been used in the recognition of periods of movement of the shorelines around the North Sea (Geyh 1969, 1971, Geyh and Streif 1970), solving problems of Weichselian chronostratigraphy (Geyh and Rohde 1972), the age distribution of post-glacial marine deposits of Eastern Canada and New England, U.S.A. (Hillaire-Marcel and Occhietti 1977), and the chronology of marine changes on the western seaboard of Europe during the last 10,000 years (Morrison 1976). Considering the number of ^{14}C assays published in each volume of Radiocarbon it is likely that the collective analysis of ^{14}C data, rather than dependence on individual assays, will become an important field of future research, and not just for sea-level studies.

Each ^{14}C date is represented by a normal distribution curve, the dimensions of which are dependent on the standard deviation of the date, and the same weight is applied to each date by keeping the area under the curve constant. Morrison (1976) used a method of summing the ordinates of a continuous curve while Geyh approximated the normal distribution curve by using four rectangles. If Geyh's method is employed it is important to decide the size of the class interval into which the histogram is to be divided. A very small class interval used for the time axis will give many fluctuations superimposed on larger changes, while a too large class interval will smooth out possibly important changes. Hillaire-Marcel and Occhietti (1977) illustrate this point using classes of 100 and 200 years. However the best size of the class interval is probably dependent on the average size of the standard error of the dates used (Geyh 1979). Such problems are not overcome by using Morrison's (1976) technique since the minimum significant time period of a fluctuation in the complete histogram must then be defined.

The construction of the histograms is fairly standardised but the rest of the analyses can follow one of two approaches. Geyh (eg. 1979) and Hillaire-Marcel and Occhietti (1977) relate the maxima and minima of the histograms of the collective ^{14}C-data to sea-level and/or climatic events whereas Morrison (1976) first screens the data into separate classes and then analyzes the differences and similarities of the different histograms. Both of these approaches should be investigated.

Although Geyh's approach is essentially the analysis of a single histogram there must be some screening of data to make sure that all the data fulfil the relevant conditions. For identifying periods of enhanced or retarded peat growth in low-lying coastal zones, which are therefore dependent on local sea-level or coastline changes, the broad assumption is that ingressions inhibit peat growth in the tidal flat and lagoonal zone. Therefore basal peats and perimarine peat data should be excluded from the data set. Further data verification techniques should be employed to show that there is no bias in age or spatial distribution due to the accessibility of samples or their preferred collection to date, say, human occupation horizons or pollen zone boundaries, since the data used need not have been sampled specifically for sea-level studies.

Once the histogram has been constructed the problems to be overcome can be divided into two types : statistical and interpretational.

The statistical problems are firstly in dealing with the problems of random fluctuations and therefore the significance of the size of maxima and minima and the number of ^{14}C data available. Geyh and Rohde (1972) noted that a large number of dates were necessary but the minimum number was not defined. Illustration of the problem was clearly made by Shennan (1979) using randomly generated data. It was shown that at least 200 dates per 5000 year period, using a 50 year class interval, were necessary to give a Coefficient of Variation for the whole histogram clearly different from one expected from random data. This analysis, however, did not give any method of measuring the significance of maxima and minima. However, Geyh (1979) indicated that the significance of maxima and minima was dependent on the size of the population and the selected class interval, concluding that reliable histograms are constructed from at least 25 dates per class interval, of two standard deviations of the "average" ^{14}C data, when real gaps of a width of at least one class interval can be reliably recognized.

Obviously a large number of data are required for this type of analysis since the measurement of significance of deviation is taken from the mean of the whole population. This problem has been tackled by Hillaire-Marcel and Occhietti (1977) by measuring the deviation from a floating mean using up to 19 class frequencies. However, it is not clear how the decision of the size of the population for calculating the floating mean should be arrived at since both real and statistical fluctuations will be smoothed.

Therefore although the methodology behind the analysis of histograms of ^{14}C data is advancing the statistical validity is not yet adequately proven and merits further research in this different approach to sea-level studies.

Further to the statistical problems of such an analysis there are interpretational problems. Once maxima and minima have been shown to be significant, although it appears that minima are probably more reliable (Geyh 1979, Shennan 1979), their geological significance must be assessed. The significance of peat growth in the tidal flat and lagoonal zone is not clear in its relationship to sea-level movement, it may form a regressive overlap but at the same time the subsequent transgressive overlap relates to periods of rising water levels. Therefore while such an analysis may reveal the significance of regionally synchronous periods of peat growth in the tidal flat and lagoonal zone it is not clear how to relate these to sea-level chronologies established by other techniques. While present data sets are not really large enough to allow significant statistical evaluation (eg. Geyh 1979 fig. 5) it is probably only a matter of time until such an approach is practicable. Such an analysis will also give information on the relationship between sea-level changes, climatic change and ^{14}C fluctuations through time (Geyh 1979, Hillaire-Marcel and Occhietti 1977).

Morrison's (1971, 1976) approach was quite different, it involved the separation of data into different classes dependent on their indicative meaning and also used data from widely differing depositional and isostatic environments covering all of the Flandrian Stage. In light of more recent analyses (eg. Geyh 1979, Shennan 1979) the conclusions given by Morrison (1976) relating periods of eustatic sea-level change of as little as 100 years duration from about 500 dates for a 10000 year period must be rejected. All the problems noted for the earlier method of analysis are still present and further problems occur. The problem of biased sampling is very important, particularly relating to areas of differing isostatic and environmental history. The spatial distribution of data must be related to isobase maps rather than simple areal measurements to allow for the different recognition of transgressions and regressions in uplifted and subsiding areas (Mörner 1969). However, assuming such verification of data and a sufficiently large data set the approach of Morrison appears promising. Much more testing is required, in the first instance using randomly generated ^{14}C data from an hypothesized area showing isostatic variability, since the significance of maxima and minima of the transgression and regression histograms, as defined by Morrison (1976), may not be best represented by a 'mean or difference cumulative histogram'. However Morrison's approach may offer a method of defining the limits between periods of positive and negative tendencies whereas the other methods only define the maxima and minima with no method of defining boundaries.

Therefore the whole approach of analysing ^{14}C data in cumulative histograms is believed to offer an increasingly viable method of identifying regionally and even globally significant processes; however it is clear that given the presently available data for the Fenlands such a statistical approach is not yet possible on a local scale. The data base is growing for an analysis of the data from the southern North Sea region as a whole (Geyh 1979).

Part 8.5 : Conclusions

This chapter has shown that present methods of inter-regional comparison of sea-level chronologies are inadequate, being little in advance of informed visual correlation. Explicit statements relating to the synchroneity of events are not made since the available data precludes any great degree of accuracy. However, an indication is made to the effect that periods of negative tendencies in the Fenland do occur at approximately the same time as similar tendencies in other areas. Until an objective method of correlation is available it is always possible to find some correlation with any local chronology; but if the problem is too difficult to solve, one cannot claim that it is solved by indicating those efforts made to solve it. However, the presence of regionally significant periods of rising and falling sea-levels is not dismissed since it would be equally misleading to say that a smooth rise in sea-level has occurred during the Flandrian Stage. Periods of locally significant falls in water-table are unequivocal but the errors involved in their assessment do not allow comments of regional significance to be substantiated. As the body of ^{14}C data increases their statistical analysis will offer an alternative approach.

Even though clear correlation with other areas is not possible the Fenland has been shown to have been characterised by crustal subsidence throughout the past 6500 years but the rate of such movement, and its variation through time, within the Fenland and in England is not quantifiable to any great degree of certainty.

CHAPTER NINE

Conclusions

The conclusions are discussed under the following headings:

9.1 : The physical evolution of the Fenland during the Flandrian Stage.

9.2 : Sea-level research techniques and methodology.

9.3 : Planning considerations.

9.4 : Future research topics.

Part 9.1 : The physical evolution of the Fenland during the Flandrian Stage.

102 ^{14}C dates form the chronological framework on which the Flandrian evolution of the Fenland is discussed. Reference has been made to published accounts of stratigraphic and palaeontological investigations to assess the accuracy of these dates. By comparison with the guidelines set by the I.G.C.P. Project 61, many are of relatively poor quality. Therefore, some dates assume more importance than others within the context of this research programme.

Four new sites, Freiston Marsh, Bourne Fen, Cowbit Wash and Adventurers' Land, in areas of the Fenland not studied previously in any great detail, were investigated. The details of each site are given in chapter 5. The main aims were to indicate the proximity to marine conditions at the transgressive and regressive overlaps, to assess the evidence indicating directions of water-table and sea-level movements, to outline the evolution of the Fenland during the Flandrian Stage, and to permit an assessment of the present and future stability of the Fenland. Additionally, the data from the sites provided much valuable information on general sea-level research techniques and methodology (Part 9.2).

Freiston Marsh was investigated in order that a comparison could be made between the present coastal environment of the Wash and the fossil sequences recorded at the other sites. The latter were found to differ greatly in most aspects of sediment and microfossil content investigated. The role of man, through the embankment schemes, is probably the main reason for this.

The pollen analysis from each site was categorized using local pollen assemblage zones which were then the basic units for description, correlation, model building and, wherever possible, corroboration of ^{14}C dates. The micropalaeontological techniques were used collectively to interpret the tendencies of water table and sea-level movement. The development of fen wood layers and peat humification were noted as being particularly important but many different lines of evidence were also used.

The reliability of the data has been assessed throughout and quantified wherever possible. Even though, for example, 102 ^{14}C dates were used the chronology elaborated in chapter 7 can only have an accuracy of ± 100 years. The following scheme has been produced to classify the data presently available. As research techniques improve and the data base increases, modification of this scheme is inevitable:-

Wash I		-c.6300 BP
Fenland I	c.6300	-c.6200 BP

Wash II	*c*.6200	-*c*.5600 BP
Fenland II	*c*.5600	-*c*.5500 BP
Wash III/IV	*c*.5500	-*c*.4500 BP
or ? Wash III	*c*.5500	-*c*.5200 BP
? Fenland III	*c*.5200	-*c*.5100 BP
? Wash IV	*c*.5100	-*c*.4500 BP
Fenland IV	*c*.4500	-*c*.4200 or 3900 BP
Wash V	*c*.4200 or 3900	-*c*.3300 BP
Fenland V	*c*.3300	-*c*.3000 BP
Wash VI	*c*.3000	-*c*.1900 BP
Fenland VI	*c*.1900	-*c*.1550 BP
Wash VII	*c*.1550	-*c*.1150 BP
Fenland VII	*c*.1150	-*c*. 950 BP
Wash VIII	*c*. 950	-

The Wash periods represent times when a rising water-table and sea-level is predominant in the area while the Fenland periods indicate those times when the evidence for a falling water table and/or sea-level appears to be of more than local significance and a freshwater or terrestrial regime obtained. The reliability with which these alterations can be identified is variable. The period Fenland III was originally suggested on the stratigraphic evidence given by Godwin and Clifford (1938) but this lithostratigraphic correlation was not confirmed by the ^{14}C dates from AL-4. Therefore there is a possibility that Fenland III should not be individualised but its omission makes correlation between the Fenland south-east of the March "island" and the Fenland north-east of the same feature less straightforward. There would be a recorded altitudinal difference of 4m. for organic sediments, of Fenland IV age, between these two areas. Furthermore there is a significant regional diversity within the Fenland at the end of Fenland IV. At sites to the south and east negative tendencies are apparent until c3900 BP while to the north, particularly in the Witham valley, a rise in sea-level may be inferred from c4200 BP onwards. The explanation of these differences in altitude and processes within the Fenland requires further investigation.

The Wash/Fenland scheme was used to describe relative sea-level changes and the geographical extent of marine facies. The use of present research techniques and the variability of Fenland sea-level index points in the time/altitude dimensions give a broad band of relative sea-level change. The accuracy may be no better than ±2m. for some periods (fig.7.3). Within the confidence bands shown fluctuations in the mean tidal parameters are very likely and have caused great horizontal changes in the coastline. The extent of the clastic deposits associated with each period of rising sea-level is not known in detail for much of the Fenland. However the limits, where known, clearly show (fig. 7.4) that the maximum extent of marine deposits was diachronous. The pre-Flandrian topography was likely to have been a major explanatory factor. Knowledge of the earliest transgressive episodes is limited to a few sites where deep boreholes have been made and more detailed sampling of the areas close to the present coast will show how extensive the deposits of pre-6300 BP age are. At present they appear to be restricted to the floors of narrow valleys in the pre-Flandrian Fenland.

More recent marine deposits become more extensive although in the southern Fenland they are characteristically in semi-enclosed basins. Variation in conditions at the mouth of these basins would control the timing of marine sedimentation. However it is clear that the age of the maximum extent of marine deposits varies from the Cambridgeshire fens, Wash IV age, to some of the Lincolnshire fens, Wash VI age. Furthermore the sediments of Wash IV and later are generally coarser than the earlier clastic sequences. Thus further attention should be given to the changes in processes which would explain the differences in age and nature of the sediments found within the Fenland. The different results from real changes in 'regional eustatic sea-level' are due to within-area variability of coastal morphology, hydrology, sedimentation and consolidation rates and crustal movements. The importance of these local and regionally significant parameters cannot be assessed at present.

Crustal subsidence over the last c.6500 years gives a mean rate of c.77mm/100 years. This is likely to be a maximal figure for the present since the form of the recovery curve remains hypothetical within certain limits. The mean rate, c.77mm/100 years, is calculated from the estimation of 5m. subsidence since 6500 BP. The different factors, particularly isostatic subsidence, consolidation of sediments, crustal downwarping since the Tertiary Period, could not be individually identified although the latter is likely to have had the least affect during the Flandrian. Differential crustal movement within the Fenland may contribute to the variation in age and altitude of the marine sediments and any correlation with geological structures merits investigation (cf. the conclusions of Greensmith and Tucker (1980) relating to the Essex coast). Continuing crustal subsidence may be indicated by geodetic levellings although other interpretations of such data have been offered (Kelsey 1972).

It has been possible to study the effect of sea-level changes in the Fenland since 6500 BP. The inferred changes since c.2000 BP have not been directly investigated within the present research programme since the approach taken uses techniques of analysis favouring undisturbed, subsurface sampling. Thus the micropalaeontological analyses have shown that between 6500 and 2000 BP the Fenland has undergone substantial changes in coastline. Despite the differences in age and altitude one point remains remarkably applicable to the whole area. The nature of the clastic sediments in most of the sequences described show that a low energy environment of deposition has been present for most of the Flandrian. Typically sediments of Wash VI, and later, are slightly coarser but even these reflect lower energy environments than occur in the present salt marshes around the Wash. Prior to the saltmarsh reclamation schemes and fenland drainage the sedimentary record has revealed no periods of extensive erosion by a transgressing sea. The transition is typically gradual. The freshwater fen/salt marsh transition would have been a location protected by a wide inter-tidal marsh and intertidal flats which reduced the energy of any exceptional tide levels or surges. The combination of natural accretion processes and embankment schemes for coastal protection and fenland drainage has reduced the inter-tidal areas so that the more recent coastal sequences exhibit higher energy environments.

However it cannot be over-stressed that all of the conclusions must be viewed with consideration of the errors inherent in the original data. Such considerations must also lead to a re-assessment of the methodology of sea-level studies.

Part 9.2 : Sea-level research techniques and methodology.

The lack of an accepted methodology for sea-level investigations was noted in chapter 1. This point has been particularly evident whenever comparison between this research programme and previous accounts has been attempted. Due to inadequate operational definitions it has been impossible to compare and classify the data for inter-regional correlation using a common language. Therefore the population available for statistical testing is very limited and some methods could not be adequately tested, yet while the conclusions made may appear rather broad their precision is indicated. The accuracy of the data, interpretation and conclusion must be assessed at every stage. This has not been the case with most published sea-level studies.

Imprecision of the datahas been indicated both in the collection of stratigraphic data and with its interpretation. Particularly it must be realised that a transgressive or regressive overlap will not be a plane surface but an undulating and inclined one. An inadequate assessment of the topography of buried surfaces, using a suitable sampling plan, will give serious errors in subsequent conclusions. Furthermore, large data sets of borehole results supplemented by ^{14}C and micropalaeontological analyses could then be used in the development of computer simulation models of sequence development in an attempt to overcome the present impasse concerning the problem of consolidation. Thus a more integrated approach is required giving a three dimensional analysis of stratigraphy, horizontal and vertical movements of coastlines, consolidation and sedimentation rates. While detailed micropalaeontological investigations of a single borehole will reduce within-borehole error - i.e. give an accurate assessment of indicative meanings - it is of little value if between-borehole variance is not assessed. Furthermore, the value of detailed investigation is ultimately limited by the radiocarbon analyses : the accuracies of the detailed microfossil analyses from Bourne Fen were severely limited by the resultant unsatisfactory ^{14}C dates. If radiocarbon techniques are the only method of dating available the other types of analysis must be restricted accordingly and not purport to show a correlation between samples with an absolute age difference, giving no error, less than the statistical errors of the radiocarbon data.

The assessment and importance of statistical errors have been shown in the pollen analyses given in chapter five. Whereas a specific pollen sum could be employed to give a pollen diagram favouring a particular interpretation of the data to confirm or refute a predetermined point of view the combined use of different pollen sums and their effect on the confidence limits enables the insignificant changes to be identified and the local and regional phenomena to be assessed. Furthermore, it was shown that the occurrence of ecologically significant pollen types in low frequencies were best interpreted collectively on a continuous presence or absence distribution rather than the changes in low frequencies which are seldomly statistically significant.

These comments regarding statistical confidence limits of data sets do not only apply to pollen and diatom frequencies. They should be related to all stages of sea-level analysis. Such tests have not been applied so rigorously to the rest of the analysis for the following reasons:-

- available data sets are often small;
- the formulae are not always known;
- data, particularly from other published sources, are not in a suitable or equivalent form to be statistically analysed.

Therefore, it is suggested that it is now time to pause in the analysis of sea-level data using well established techniques in order to draw up rules for the collection and classification of data and to develop a methodology which allows the statistical testing of data, giving a real assessment of the errors, and permit true correlation, in a mathematical sense, to be measured.

The complexity in the development of the research methodology has been the transfer of age-altitude - location data to the two dimensions of age and altitude and the final description of such data in a graphical form. Thus, essentially the same data have been interpreted in one of three ways in the recent past ; a smooth curve drawn through selected points; a fluctuating curve drawn through selected points; and occasionally a statistically calculated curve. None of these are universally acceptable. It is suggested that a confidence band drawn from the error boxes of the reliable data is the best representation of past sea-levels since the relevant variance is clearly shown.

The identification of past sea-levels always entails correlation of data from individual sites. This correlation relates to age, altitude and location. The present methodologies do not allow all the errors to be considered and often the process of correlation is little in advance of visual comparison. Therefore a sea-level curve, ie. a line, is misleading. But it is also misleading to describe the mean of a confidence band as indicative of the Flandrian restoration of sea-level unless the variance from the mean is considered an adequate description of the data when used in any subsequent interpretation. In the interpretation of the development of the Fenland during the Flandrian this would be misleading since there is incontrovertible evidence that there have been periods characterised by a falling water table and/or sea-level tendencies. The scales at which the various data may be averaged are time-dependent and it is necessary to recognize the temporal and spatial scales at which the status of each variable is decided. Thus, processes occurring over 10^1 years may be indicated but their absolute age, regional significance and correlation cannot be confirmed due to the analytical errors. Events occurring over periods of 10^2 years are likely to be more widely recorded yet dating techniques may still prevent unequivocal correlation. Thus, evidence exists for a lowering of sea-level or water table at individual locations but present techniques cannot yet differentiate between events at the required level of resolution.

Whether or not sea-level has fluctuated during the Flandrian Stage is only important over the specific time scale of the study and area considered. A smooth curve is equally as misleading as a fluctuating one. The only conclusion that can be made within the limitations of present data and techniques is that sea levels are likely to have occurred within the specified band and fluctuated within the band as shown by the dominance of positive or negative tendencies for certain periods, even though the regional and altitudinal synchroneity cannot be assessed. The importance of recognising the predominant sea-level tendencies of a given period and the associated altitudinal limits are totally dependent on the underlying problem. For time scales in excess of 10^3 years the sea-level band may be generalised and the alternations of periods of positive and negative tendencies may become insignificant as the time scale approaches 10^4 years when the altitudinal errors are considered. As the resolution decreases to 10^2 years the same variables reflected by the confidence band of the sea-level curve increase in importance yet their accuracy is unchanged. The generalizations that could relate to the longer periods can no longer be made. The long term variables may have changed their status from dependent to independent, the smaller scale variables from indeterminable to dependent. As the time scale approaches 10^1 years the results of this research programme become less applicable. The variability of the data is too great, the variables measured become independent and quite different research techniques are required. However, only by consideration of the relevant temporal and spatial scales can the applicability of these research results be assessed.

Part 9.3 : Planning considerations.

Due to the nature of the data available clear fluctuations in the sea-level curve cannot be confirmed or refuted either in altitude or time. Tendencies of sea-level movement have been clearly identified and therefore the use of a smooth sea-level curve is dangerously misleading for sea-defence planning since the fluctuations may occur over 100 years. Future planning should allow for a range of tide-levels inferred from the confidence bands and the changes in dominant processes indicated.

The building of sea-defences and reclaiming marshes is removing the natural protection against widespread marine flooding. By reducing the area of vegetated marsh the situation has arisen where any tide above c.MHWST will rise against an embankment. This bank will have to withstand every exceptional tide and the wave energy will not have been reduced by a long journey over a vegetated marsh. Therefore the occurrence of sea floods has been compounded by man's defence schemes and the lowering of the landward fens due to drainage projects increases the disaster factor if the banks are overtopped. Land values turn the argument into an economic one but even so the variability of the data available to predict changes over 100 years and more should be carefully considered in the future.

Part 9.4 : Future research topics

There are many research problems, both scientific and applied, to be investigated. These are of significance to the Fenland itself, to regional phenomena and also methodological developments. Throughout this thesis it has been noted where more research is considered necessary. The proposed route of investigation has stressed the need for accurate definition of terms to allow a numerical and statistical analysis of variables. A few new techniques have been introduced to sea-level research, e.g. pollen concentration, analysis of borehole levels and sedimentary surfaces, histogram analysis of ^{14}C data by random numbers, confidence limits of pollen data, and models have been tentatively developed. These require testing and modification but correlation with other areas will only be feasible when firstly the data from other areas are assessed, the errors identified, and then when reliable methods of correlation have been developed. This mainly theoretical research is urgently required.

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APPENDIX I

Lithological Classification

This scheme for the lithological classification of coastal Flandrian sequences was developed at Niedersächsisches L desamt für Bodenforshung, Hannover, (Barckhausen *et al*. 1975, 1977, Barckhausen & Streif 1978, Streif 1978).

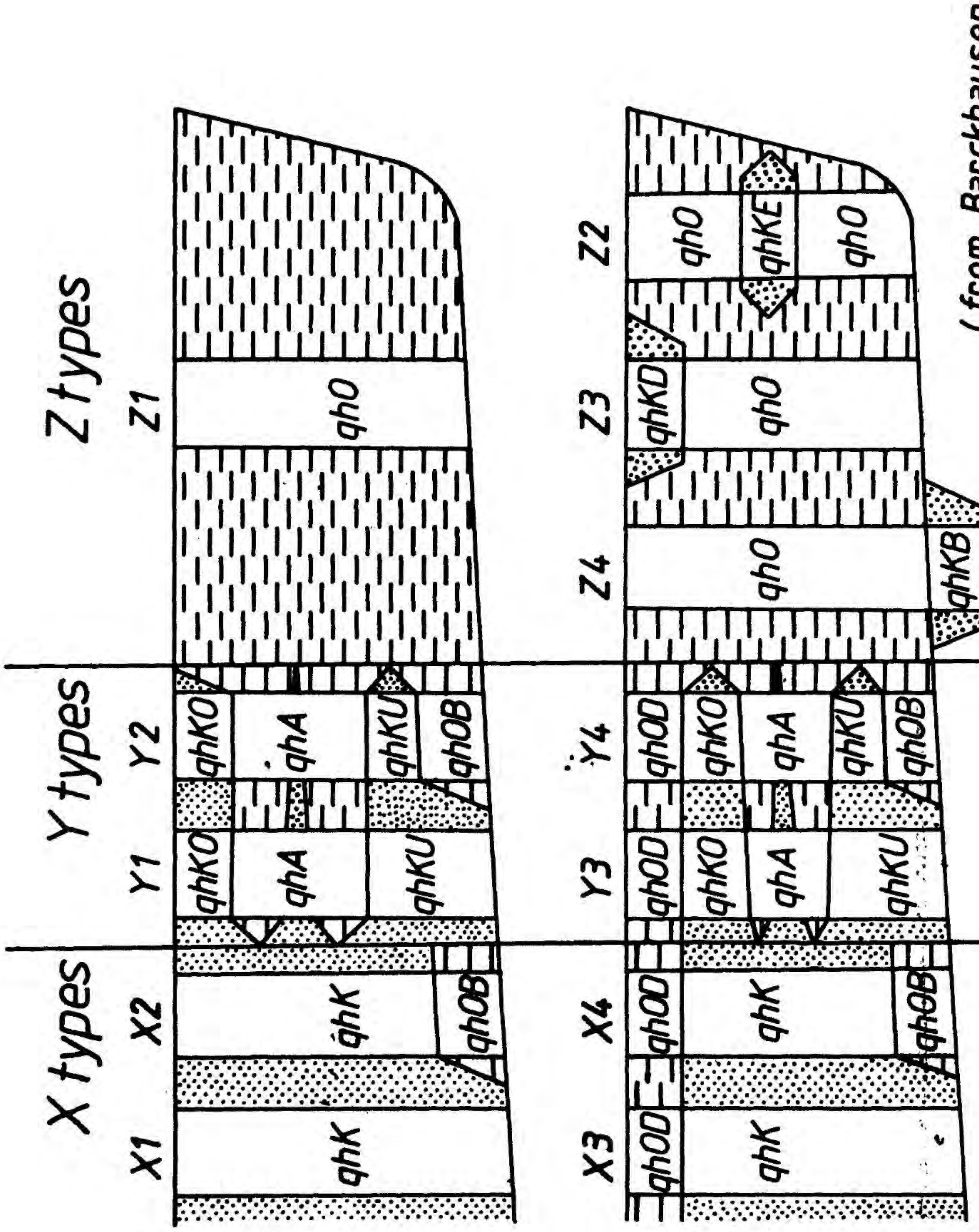
The first level of the hierarchic system defines the complexes:-

- X Type : clastic complex (seaward region)
- Y Type : interfingering complex (transition zone)
- Z Type : peat complex (back swamp region)

The middle level consists of the sequences, which are considered as stratigraphical elements and labelled according to the system "Symbolschlussel Geologie" (Barkhausen *et al*. 1975, Streif 1978). The 12 sequences are represented schematically in figure A1 and described below (from Streif 1978):

- clastic sequence (qhK) : clastic sedimentary succession without intercalated peat layers. Soil horizons and layers in which rootlets of *Phragmites* are abundant are regarded as a part of the clastic sequence.
- Organic basal sequence (qhOB) : succession of peat and limnic ooze or organic soil horizons at the base of clastic Flandrian (Holocene) deposits.
- Organic cover sequence (qhOD) : succession of peat or limnic ooze which occurs at the present surface and which is underlain by clastic Flandrian (Holocene) sediments.

The organic basal sequence and the organic cover sequence can occur in the clastic complex and interfingering complex but



(from Barckhausen *et al.* 1977)

Figure A.1 : The 12 possible sequences for the lithological classification of Flandrian coastal sediments.

may also be absent. The following are found only in the interfingering complex and are characteristic of it:

- lower clastic sequence (qhKU): clastic sedimentary unit, at least 5 cm. thick, which underlies the lowermost intercalated peat layer and may be underlain by an organic basal sequence.
- splitting-up sequence (qHA): sedimentary sucession between the bottom of the lowermost intercalated peat layer and the top of the uppermost one. Thus, the splitting-up sequence consists of peat layers (in certain cases only one layer) as well as clastic sediments which lie between the intercalated peat layer.
- upper clastic sequence (qhKO): clastic sedimentary unit at least 5 cm. thick which overlies the uppermost intercalated peat and may be overlain by an organic cover sequence.

The following sequences are found in the peat complex:

- organic sequence (qhO): succession of peat and limnic ooze with at most one interbedded layer of clastic sediments more than 5 cm. thick.
- clastic basal sequence (qhKB): clastic sedimentary unit which occurs in the basal part of the coastal Flandrian (Holocene) deposits and which is covered by an organic sequence. The thickness of the basal clastic sequence is less than that of the overlying organic sequence.
- clastic interbedded sequence (qhKE): unit of clastic sediments interbedded in the organic sequence and unrelated to an upper or lower clastic sequence as defined above or to clastic units of a splitting-up sequence. This clastic interbedded sequence

may not exceed 50% of the total thickness of the organic sequence. It may consist of one individual layer and/or of several thin layers less than 5 cm. thick.

- clastic cover sequence (qhKD): clastic sedimentary unit which occurs at the present surface and which is underlain by the organic sequence. The thickness of the clastic cover sequence must be less than that of the underlying organic sequence.

The lowest hierarchic level in the scheme is the facies unit. These are variable in number and in range, taking into account any special criteria for the study.

It should be noted that the criteria for distinguishing between a X4 profile type and a Z-type with one clastic layer more than 5 cm. thick are not made clear by Streif (1978). The former has been used throughout this thesis.

APPENDIX II

Laboratory schedule for pollen analysis

1 - Preparation for pollen concentration method.

- 1.1. Measure 0.5 cc of sediment by displacement of water in 5 cc. Grade A measuring cylinder.
- 1.2 Wash into small beaker and add 5 Lycopodium tablets.

2 - Solution of carbonates and disaggregation of Lycopodium tablets

- 2.1. + cold 10% HCL until effervescence stops. Stir.
- 2.2. Centrifuge. Decant.

3 - Evacuation of alkali-soluble organic compounds.

- 3.1. + 10% KOH. Stir.
- 3.2. Heat in boiling water 10-30 minutes. Stir occasionally.
- 3.3. Decant through sieve (mesh 180 microns). Wash residue.
- 3.4. Centrifuge, decant and wash until supernatant liquid is unstained.

4 - Hydroflouric digestion of siliceous material.

- 4.1. + HF. Stir.
- 4.2. Heat in boiling water until sediment dispenses. At least 1 hour.
- 4.3. + HCL (10%). Heat in boiling water 3-5 minutes.
- 4.4. Centrifuge. Decant.
- 4.5. Wash with distilled water. Stir. Centrifuge. Decant.

5 - Acetylation. Evacuation of unaltered lignin and cellulose.

- 5.1. +Glacial acetic acid. Stir. Centrifuge. Decant.
- 5.2. +Acetylation solution (1:9 conc.H_2SO_4:Acetic anhydride) Stir.
- 5.3. Heat in boiling water, 1 minute. Stir. Top up with glacial acetic acid.
- 5.4. Centrifuge. Decant.

5.5. +Glacial acetic acid. Stir. Centrifuge. Decant.

5.6. +Distilled water. Stir. Centrifuge. Decant. 2x.

6. - Staining.

6.1. +Tertiary Butyl Alchohol + 2 drops safranin solution. Centrifuge. Decant.

6.2. +1cc. Tertiary Butyl Alchohol, transfer to vial. Centrifuge. Decant. Drain.

6.3. +Silicone fluid. Leave overnight.

Laboratory schedule for diatom analysis

1 - Removal of carbonates.

1.1. Disperse 1 cc. sediment in a few drops of distilled water in small beaker.

1.2. +HCL (10%)

2 - Removal of organic material.

2.1. +30% H_2O_2, gently heat over water bath, 12 hours.

2.2. Wash. Centrifuge. Decant.

2.3. Transfer to storage vial.

3 - Mounting.

3.1. Flood cover slip, on hot plate, with diatom + water mixture. Evaporate slowly.

3.2. +Crystals of NAPHRAX on miscroscope slide. Heat until crystals liquify.

3.3. Place the dry cover slip, diatoms downwards, on the slide. Cool and allow to set.

```
C                  APPENDIX III
C
C                  ------------
C
C           LISTING OF PROGRAM 'NEWPLOT'
C
C  PROGRAM NEWPLOT
C  ===============
C   THIS LISTING EXPLAINS ALL THE FORTRAN CALCULATIONS
C   USED BUT THE PLOTTING ROUTINES ARE ONLY FOR USE
C   WITH *PLOTSYS AT NUMAC.FULL DETAILS ON HOW TO RUN
C   THE PROGRAM SHOULD BE OBTAINED FROM I.SHENNAN.
C  COPYRIGHT I.SHENNAN 1979
C  PROGRAM IS IN 2 PARTS
C  1:CALCULATES AND TABULATES POLLEN DATA
C  2:DRAWS POLLEN DIAGRAM WITH STRATIGRAPHY
C  CALCULATES 4 CURVES WITH 95% LIMITS
C  POLLEN CONC.IF USING LYCOPODIUM TABLETS
C  % TREE POLLEN
C  % TREES+SELCTED.OTHER TAXA
C  % TOTAL LAND POLLEN
C  INPUT DATA
C  ==========
C1:1-20:TITLE OF SITE
C2:2-3:NUM LEVELS COUNTED<50
C   5-6:NUM POLLEN TYPES<=60
C3:IN I3 FORMAT 11 VALUES IN ASCENDING ORDER GIVING
C   THE NUMERICAL ID'S OF THE FIRST AND LAST TAXA OF
C   5 SPECIAL GROUPS SUCH AS:TREES,SHRUBS,HERBS,AQUATICS,SPORES.
C   THE 11TH VALUE IS USED IF TAXA WITH GREATER ID'S ARE TO
C   BE EXCLUDED FROM "TOTAL POLLEN SUM".
C4 TO N+3,N=NUM POLLEN TYPES
C :1-2:TAXA ID FROM 1 TO 60
C :3-18:TAXA NAME
CTHE NEXT CARDS ARE IN SETS OF 4 FOR EACH LEVEL COUNTED
C  TOP LEVEL FIRST
C  COL 1-6 DEPTH RELATIVE TO DATUM (+OR- MUST BE USED)
C       5-8 NUMBER OF LYCOPODIUM GRAINS COUNTED FOR 0.5CC SEDIMENT
C  NEXT CARDS OF EACH SET IN 20I3 FORMAT THE COUNTS FOR EACH TAXA
C  MUST HAVE 4 CARDS FOR EACH LAYER
C  5 CARDS EACH WITH APPROPRIATE TITLE<20
C          POLLEN COUNTS
C          POLLEN CONC      (LEAVE BLANK IF CONC METHOD NOT USED)
C          %TREE POLLEN
C          %TREE+GROUP
C          %TOTAL POLLEN
C
C
C
C A ZERO IN COL 3 OF THE NEXT CARD WILL END
C THE PROGRAM BEFORE IT ATTEMPTS TO PLOT A DIAGRAM
C
C
       DIMENSION SITE(5),NUM(60),NTAXA(5,60),DEPTH(50),EXOTIC(50),
     #XDESC(5),NC(6),TITLE(5,60),NUMBER(60),NUMTAX(60,20),
     #TOT1(50,60),TOT2(50,60),TOT3(50,60),TOT4(50,60),XLNGTH(60),
     #X(50,60),DESC(5,5),TREES(50),SHRUBS(50),HERBS(50),AQUAT(50),
     #SPORES(50),TOTAL(50),CONMEA(50,60),CONUP(50,60),CONLOW(50,60),
     #PTREE(50,60),PTUP(50,60),PTLOW(50,60),PGROUP(50,60),PGUP(50,60),
     #TOP(20),TOTM(50,60),TOTL(50,60),TOTU(50,60),SIZE(6),
     #EXPL1(5),EXPL2(5),ZTITLE(4),ZNAME(2),
     #PGLOW(50,60),PTOT(50,60),PTOTU(50,60),PTOTL(50,60)
C
    1 FORMAT(5A4)
    2 FORMAT(I3,2F3.1,F7.1,F5.1)
    3 FORMAT(11I3)
    4 FORMAT(I2,5A4)
    5 FORMAT(2F4.0)
    6 FORMAT(20F4.0)
    7 FORMAT(1H1,'POLLEN TOTALS AND SUMMARY TABLE'/1H0,
     #'  DEPTH  TREES SHRUBS  HERBS AQUATS SPORES  TOTAL EXOTIC',
     #' TREES% SHRUB% HERBS% AQUAT% SPORE%')
    8 FORMAT(1H ,13F7.1)
    9 FORMAT(1H1,5A4)
   10 FORMAT(1H0,5A4)
   11 FORMAT(2I3,4I1,4F6.0,I2)
   12 FORMAT(I3)
   13 FORMAT(20I3)
   14 FORMAT(F6.1,4(F4.2,I3))
   15 FORMAT(1H1,5A4,' TOTAL CONCENTRATION (GRAINS X 1000 PER CC)')
   16 FORMAT(1H ,4F8.1)
   17 FORMAT(1H0,'DEPTH')
   18 FORMAT(F4.2)
   19 FORMAT(I2,4A4)
   20 FORMAT(2F6.1,2A4)
C
C
```

```
C
C READ DATA
C ==== ====
C
      READ(5,1)(SITE(I),I=1,5)
      READ(5,2)NLEV,CC,TAB1,TAB2,TAB3
      NTAX=60
      READ(5,3)LTR,MTR,LSH,MSH,LHE,MHE,LAQ,MAQ,LSP,MSP,MTOT
      DO 50 N=1,NTAX
      READ(5,4)NUM(N),(NTAXA(I,N),I=1,5)
   50 CONTINUE
      DO 51 N=1,NLEV
      READ(5,5)DEPTH(N),EXOTIC(N)
      READ(5,6)(X(N,I),I=1,20)
      READ(5,6)(X(N,J),J=21,40)
      READ(5,6)(X(N,J),J=41,60)
   51 CONTINUE
      DO 52 I=1,5
      READ(5,1)(DESC(K,I),K=1,5)
   52 CONTINUE
C
C CALCULATIONS
C ============
C
      CALL SGROUP(NLEV,LTR,MTR,X,TREES)
      CALL SGROUP(NLEV,LSH,MSH,X,SHRUBS)
      CALL SGROUP(NLEV,LHE,MHE,X,HERBS)
      CALL SGROUP(NLEV,LAQ,MAQ,X,AQUAT)
      CALL SGROUP(NLEV,LSP,MSP,X,SPORES)
      CALL SGROUP(NLEV,LTR,MTOT,X,TOTAL)
      IF (EXOTIC(1).EQ.0.0) GOTO 53
      CALL CONERR(NLEV,NTAX,X,EXOTIC,CONMEA,CONUP,CONLOW,
     #CC,TAB1,TAB2,TAB3)
   53 CONTINUE
      CALL ERRIN(NLEV,LTR,MTR,X,TREES,TREES,PTREE,PTUP,PTLOW)
      CALL ERROUT(NLEV,LSH,60,X,TREES,PTREE,PTUP,PTLOW)
      CALL ERRIN(NLEV,LTR,MTR,X,TREES,TREES,PGROUP,PGUP,PGLOW)
      CALL ERRIN(NLEV,LSH,MSH,X,TREES,SHRUBS,PGROUP,PGUP,PGLOW)
      CALL ERRIN(NLEV,LHE,MHE,X,TREES,HERBS,PGROUP,PGUP,PGLOW)
      CALL ERRIN(NLEV,LAQ,MAQ,X,TREES,AQUAT,PGROUP,PGUP,PGLOW)
      CALL ERRIN(NLEV,LSP,MSP,X,TREES,SPORES,PGROUP,PGUP,PGLOW)
      CALL ERRIN(NLEV,LTR,MTOT,X,TOTAL,TOTAL,PTOT,PTOTU,PTOTL)
      IF(MTOT.EQ.60)GOTO 56
      MDUM=MTOT+1
      CALL ERROUT(NLEV,MDUM,60,X,TOTAL,PTOT,PTOTU,PTOTL)
C
C TABULATION
C ==========
   56 CALL TABLE1(NLEV,SITE,DESC,1,DEPTH,X,NTAXA)
      WRITE(6,7)
      DO 54 NL=1,NLEV
      T=TREES(NL)*100/TOTAL(NL)
      S=SHRUBS(NL)*100/TOTAL(NL)
      H=HERBS(NL)*100/TOTAL(NL)
      A=AQUAT(NL)*100/TOTAL(NL)
      P=SPORES(NL)*100/TOTAL(NL)
      WRITE(6,8)DEPTH(NL),TREES(NL),SHRUBS(NL),HERBS(NL),AQUAT(NL),
     #SPORES(NL),TOTAL(NL),EXOTIC(NL),T,S,H,A,P
   54 CONTINUE
      IF (EXOTIC(1).EQ.0.0) GOTO 55
      CALL TABLE2(SITE,DESC,2,NLEV,DEPTH,CONMEA,CONLOW,CONUP,NTAXA)
      WRITE(6,15)SITE
      WRITE(6,17)
      DO 57 NLL=1,NLEV
      SQ=(TAB3/(TAB1*TAB2+(TAB1**0.5)))**2
      STERR=(SQ+(1/TOTAL(NLL))+(1/EXOTIC(NLL)))**.5
      CM=TAB1*TAB2*(1/CC)*TOTAL(NLL)/(EXOTIC(NLL)*1000.0)
      CU=CM*(1+STERR)
      CL=CM*(1-STERR)
      WRITE(6,16)DEPTH(NLL),CL,CM,CU
   57 CONTINUE
   55 CONTINUE
      CALL TABLE2(SITE,DESC,3,NLEV,DEPTH,PTREE,PTLOW,PTUP,NTAXA)
      CALL TABLE2(SITE,DESC,4,NLEV,DEPTH,PGROUP,PGLOW,PGUP,NTAXA)
      CALL TABLE2(SITE,DESC,5,NLEV,DEPTH,PTOT,PTOTL,PTOTU,NTAXA)
C DRAWS POLLEN DIAGRAMS
C MAXIMUM OF 15 FRAMES
C MAXIMUM OF 20 TAXA IN A GROUP
C
C INPUT FORM OF DATA:ALL RIGHT ADJUSTED
C
C FIRST CARD
C     COL 3 '1'=YES,PLOT OPTION REQUIRED
C           '0'=NO,NO PLOT REQUIRED
C     COL 5-6  =NUMBER OF PLOT FRAMES
```

```
C      COL 7     ='1'=PLOT OF POLLEN CONCENTRATION REQUIRED
C      COL 8     ='1'=PLOT OF % TREE POLLEN
C      COL 9     ='1'=PLOT OF % TREE+GROUP POLLEN
C      COL 10    ='1'=PLOT OF % TOTAL POLLEN
C      COL 11-16=SCALE OF X-AXIS=% PER INCH
C      COL 17-22=SCALE OF Y-AXIS=DEPTH UNITS PER INCH
C      COL 23-28=LOWEST LEVEL OF Y-AXIS
C      COL 29-34=Y-AXIS LENGTH (MAX =10 IN.)
C      COL 35-36=NO. STRATIGRAPHIC LAYERS
C  THEN FOR EACH PLOT,A SET OF THREE CARDS
C   1 :COLS 1-20=TITLE OF TAXA OR GROUP (ECOLOGICAL GROUP?)
C   2 :COLS 2-3 =NUMBER OF TAXA IN THE GROUP,MAX=20
C   3 :IN I3 FORMAT=TAXA ID'S FOR THOSE IN THE GROUP
C  NB. CANNOT USE %TREES+GROUP IF TAXA FROM DIFFERENT TYPE GROUPS-
C  -EG. HERBS AND AQUATICS-ARE PUT INTO THE SAME ECOLOGICAL GROUP.
C
      READ(5,11)NOYES,NPLOT,NCON,NTR,NGR,NTOT,XF,YF,DMIN,YAXL,LAYERS
      IF(NOYES.EQ.0)GOTO 9999
      READ(5,18)REDUCE
      READ(5,1)(EXPL1(I),I=1,5)
      READ(5,1)(EXPL2(I),I=1,5)
      CALL PLTSIZ(REDUCE)
C
C     DRAW TITLE
C
      CALL PLTXMX(60.0)
      CALL PSYMB(0.2,9.0,-0.3,SITE,0.0,20)
      CALL PSYMB(0.2,8.5,-0.2,EXPL1,0.0,20)
      CALL PSYMB(0.2,8.0,-0.2,EXPL2,0.0,20)
      CALLS=0.0
      DO 1000 I=1,4
      IJ=I+1
      GOTO(1101,1102,1103,1104),I
 1101 IF(NCON.NE.1)GOTO 1000
      NSYM=0
      GOTO 1105
 1102 IF(NTR.NE.1)GOTO 1000
      NSYM=3
      GOTO 1105
 1103 IF(NGR.NE.1)GOTO 1000
      NSYM=4
      GOTO 1105
 1104 IF(NTOT.NE.1)GOTO 1000
      NSYM=13
 1105 CONTINUE
      DO 1106 K=1,5
      XDESC(K)=DESC(K,IJ)
 1106 CONTINUE
      CALLS=CALLS+1.0
      YO=8.0-CALLS
      CALL PSYMB(0.2,YO,-0.2,NSYM,0.0,-3)
      CALL PSYMB(0.5,YO,-0.2,XDESC,0.0,20)
 1000 CONTINUE
      CALL PSYMB(0.2,3.0,-0.15,124,0.0,-3)
      CALL PSYMB(0.5,3.0,-0.15,'PROGRAM COPYRIGHT I.SHENNAN 1979',
     #0.0,32)
C
C
      DO 60 NP=1,NPLOT
      READ(5,1)(TITLE(J,NP),J=1,5)
      READ(5,12)NUMBER(NP)
      NUMX=NUMBER(NP)
      READ(5,13)(NUMTAX(NP,J),J=1,NUMX)
      PMAX=0.0
      DO 63 NL=1,NLEV
      TOT1(NL,NP)=0.0
      TOT2(NL,NP)=0.0
      TOT3(NL,NP)=0.0
      TOT4(NL,NP)=0.0
      TOTM(NL,NP)=0.0
      DO 64 K=1,NUMX
      NTX=NUMTAX(NP,K)
      TOT1(NL,NP)=TOT1(NL,NP)+CONMEA(NL,NTX)
      TOT2(NL,NP)=TOT2(NL,NP)+PTREE(NL,NTX)
      TOT3(NL,NP)=TOT3(NL,NP)+PGROUP(NL,NTX)
      TOT4(NL,NP)=TOT4(NL,NP)+PTOT(NL,NTX)
      TOTM(NL,NP)=TOTM(NL,NP)+X(NL,NTX)
      IF(TOT2(NL,NP).LT.200.0)GOTO 65
      TOT2(NL,NP)=200.0
   65 PMAX=AMAX1(PMAX,TOT1(NL,NP)*NCON,TOT2(NL,NP)*NTR,TOT3(NL,NP)*N
     #GR,TOT4(NL,NP)*NTOT)
   64 CONTINUE
   63 CONTINUE
      XLNGTH(NP)=(AINT(PMAX/10)+1.0)*10.0/XF
   60 CONTINUE
```

```
      NCOMB=NCON+NTR+NGR+NTOT
      IF(NCOMB.NE.1)GOTO 701
      DO 700 NP=1,NPLOT
      PMAX=0.0
      IF(NCON.NE.1)GOTO 601
      CALL CONERR(NLEV,NP,TOTM,EXOTIC,TOT1,TOTU,TOTL,
     #CC,TAB1,TAB2,TAB3)
      GOTO 699
  601 IF(NTR.NE.1)GOTO 602
      IF(NUMTAX(NP,1).GT.MTR)GOTO 6011
      CALL ERRIN(NLEV,NP,NP,TOTM,TREES,TREES,TOT2,TOTU,TOTL)
      GOTO 699
 6011 CALL ERROUT(NLEV,NP,NP,TOTM,TREES,TOT2,TOTU,TOTL)
      DO 6012 NLL=1,NLEV
      IF(TOT2(NLL,NP).LT.200.0)GOTO 6013
      TOT2(NLL,NP)=200.0
      TOTU(NLL,NP)=200.0
      TOTL(NLL,NP)=200.0
 6013 CONTINUE
 6012 CONTINUE
      GOTO 699
  602 IF(NGR.NE.1)GOTO 603
      IF(NUMTAX(NP,1).GT.MTR)GOTO 6021
      CALL ERRIN(NLEV,NP,NP,TOTM,TREES,TREES,TOT3,TOTU,TOTL)
      GOTO 699
 6021 IF(NUMTAX(NP,1).GT.MSH)GOTO 6022
      CALL ERRIN(NLEV,NP,NP,TOTM,TREES,SHRUBS,TOT3,TOTU,TOTL)
      GOTO 699
 6022 IF(NUMTAX(NP,1).GT.MHE)GOTO 6023
      CALL ERRIN(NLEV,NP,NP,TOTM,TREES,HERBS,TOT3,TOTU,TOTL)
      GOTO 699
 6023 IF(NUMTAX(NP,1).GT.MAQ)GOTO 6024
      CALL ERRIN(NLEV,NP,NP,TOTM,TREES,AQUAT,TOT3,TOTU,TOTL)
      GOTO 699
 6024 CALL ERRIN(NLEV,NP,NP,TOTM,TREES,SPORES,TOT3,TOTU,TOTL)
      GOTO 699
  603 IF(NUMTAX(NP,1).GT.MTOT)GOTO 6031
      CALL ERRIN(NLEV,NP,NP,TOTM,TOTAL,TOTAL,TOT4,TOTU,TOTL)
      GOTO 699
 6031 CALL ERROUT(NLEV,NP,NP,TOTM,TOTAL,TOT4,TOTU,TOTL)
  699 CONTINUE
      DO 698 NL=1,NLEV
      PMAX=AMAX1(PMAX,TOTU(NL,NP))
  698 CONTINUE
      XLNGTH(NP)=(AINT(PMAX/10)+1.0)*10.0/XF
  700 CONTINUE
  701 CONTINUE
C
C PLOTTING COMMENCES
C
      CALL PAXIS(6.5,0.6,'DEPTH (CM.)',+11,YAXL,90.0,DMIN,YF,1.0)
      DO 70 NP=1,NPLOT
      IF(NP.GT.1)GOTO 71
      XORG=6.5
      YDUM=0.1
      GOTO 72
   71 XORG=XORG+XLNGTH(NP-1)+0.5
   72 XAXL=XLNGTH(NP)
      IF(XLNGTH(NP-1).LT.3.0)GOTO 77
      YDUM=0.11
      GOTO 78
   77 YDUM=YDUM*(-1.0)
   78 CONTINUE
      CALL PLTOFS(0.0,XF,DMIN,YF,XORG,0.6)
      CALL PENUP(XORG,0.6)
      CALL PENDN(XORG,YAXL+0.6)
      CALL PENDN(XORG,0.6)
      CALL PAXIS(XORG,0.6,' ',-1,XAXL,0.0,0.0,XF,0.5)
      CALL PSYMB(XORG,0.14+YDUM,-0.14,TITLE(1,NP),0.0,20)
      IF(NCON.NE.1)GOTO 73
      CALL PLINE(TOT1(1,NP),DEPTH(1),NLEV,1,-1,0,1.0)
   73 IF(NTR.NE.1)GOTO 74
      CALL PLINE(TOT2(1,NP),DEPTH(1),NLEV,1,-1,3,1.0)
   74 IF(NGR.NE.1)GOTO 75
      CALL PLINE(TOT3(1,NP),DEPTH(1),NLEV,1,-1,4,1.0)
   75 IF(NTOT.NE.1)GOTO 76
      CALL PLINE(TOT4(1,NP),DEPTH(1),NLEV,1,-1,13,1.0)
   76 CONTINUE
      IF(NCOMB.NE.1)GOTO 79
      CALL PLINE(TOTL(1,NP),DEPTH(1),NLEV,1,-1,13,1.0)
      CALL PLINE(TOTU(1,NP),DEPTH(1),NLEV,1,-1,13,1.0)
   79 CONTINUE
   70 CONTINUE
C
C DRAWING STRATIGRAPHY
```

```
C
      IF(LAYERS.EQ.0) GOTO 80
      YLEV=0.6
      NCALLS=0
      TOP(1)=DMIN
      DO 81 LYR=1,LAYERS
      READ(5,14)TOP(LYR+1),((SIZE(J),NS(J)),J=1,4)
      NS(6)=NS(2)
      NS(5)=NS(1)
      MOVE=1
      SIZE(6)=SIZE(2)
      SIZE(5)=SIZE(1)
      TDIFF=TOP(LYR+1)-TOP(LYR)
      TSCALE=TDIFF/YF
      TNUM=TSCALE*4.0
      NTM=AINT(TNUM+0.5)
      TOP(LYR+1)=TOP(LYR)+(FLOAT(NTM)*YF*0.25)
      DO 82 INTM=1,NTM
      NCALLS=MOVE
      MOVE=-NCALLS
      IF(NS(1).NE.NS(3)) GOTO 85
      IF(MOVE.GT.0) GOTO 85
      MOVE=0
   85 CONTINUE
      CALL PSYMB(5.00,YLEV,-SIZE(2+MOVE),NS(2+MOVE),0.0,-3)
      CALL PSYMB(5.25,YLEV,-SIZE(3+MOVE),NS(3+MOVE),0.0,-3)
      CALL PSYMB(5.50,YLEV,-SIZE(4+MOVE),NS(4+MOVE),0.0,-3)
      CALL PSYMB(5.75,YLEV,-SIZE(5+MOVE),NS(5+MOVE),0.0,-3)
      YLEV=YLEV+0.25
      MOVE=-NCALLS
   82 CONTINUE
   81 CONTINUE
      CALL PENUP(5.0,YAXL+0.1+0.6)
      CALL PENDN(6.0,YAXL+0.1+0.6)
      CALL PENDN(6.0,0.6)
      CALL PENDN(5.0,0.6)
      CALL PENDN(5.0,YAXL+0.1+0.6)
   80 CONTINUE
C     DRAWS LOCAL POLLEN ASSEMBLAGE ZONES
C     ZERO IN COLS 1-2 OMITS LPAZS
C     FOR DETAILS TO USE THIS SECTION
C     PLEASE REFER TO I.SHENNAN.
C     NB. LPAZS ARE NOT CALCULATED BY THE
C     PROGRAM.
      XFIN=XORG+XAXL+0.5
      READ(5,19)NZONE,ZTITLE
      IF(NZONE.EQ.0)GOTO 84
      CALL PSYMB(XFIN,10.7,-0.2,ZTITLE,0.0,16)
      DO 83 NZO=1,NZONE
      READ(5,20)ZBASE,ZTOP,ZNAME
      YBASE=0.6+(ZBASE-DMIN)/YF
      YTOP=0.6+(ZTOP-DMIN)/YF
      YN=(YBASE+YTOP)/2.0-0.1
      CALL PENUP(XFIN,YBASE)
      CALL PENDN(XFIN+1.0,YBASE)
      CALL PSYMB(XFIN,YN,-0.2,ZNAME,0.0,8)
      CALL PENUP(XFIN,YTOP)
      CALL PENDN(XFIN+1.0,YTOP)
   83 CONTINUE
      XFIN=XFIN+1.5
   84 CONTINUE
      XFIN=XFIN+0.5
      CALL PENUP(0.0,11.0)
      CALL PENDN(XFIN,11.0)
      CALL PENDN(XFIN,0.0)
      CALL PENDN(0.0,0.0)
      CALL PENDN(0.0,11.0)
      CALL PLTEND
 9999 CONTINUE
      STOP
      END
C
C ==============
C ==============
C
C TO SUM THE POLLEN GROUPS
      SUBROUTINE SGROUP(NL,MIN,MAX,X,SUM)
      DIMENSION X(50,60),SUM(50)
      DO 2 I=1,NL
      SUM(I)=0
      DO 1 J=MIN,MAX
      SUM(I)=SUM(I)+X(I,J)
    1 CONTINUE
    2 CONTINUE
```

```
      END
C
C   ===============
C   TO CALCULATE CONCENTRATION 95% CONFIDENCE LIMITS
C
      SUBROUTINE CONERR(LEV,NTAX,X,SP,CONMEA,CONUP,CONLOW,
     #CC,T1,T2,T3)
      DIMENSION X(50,60),SP(50),CONMEA(50,60),CONUP(50,60),
     #CONLOW(50,60)
      DO 2 NL=1,LEV
      DO 1 NT=1,NTAX
      SQ=((T3/(T1**0.5))/(T1*T2))**2
      IF(X(NL,NT).EQ.0.0)GOTO 3
      STEPR=(SQ+(1/X(NL,NT))+(1/SP(NL)))**0.5
    3 CONMEA(NL,NT)=T1*T2*(1/CC)*X(NL,NT)/(SP(NL)*1000.0)
      CONUP(NL,NT)=CONMEA(NL,NT)*(1+STEPR)
      CONLOW(NL,NT)=CONMEA(NL,NT)*(1-STEPR)
      IF(CONLOW(NL,NT).GT.0.0) GOTO 1
      CONLOW(NL,NT)=0.0
    1 CONTINUE
    2 CONTINUE
      RETURN
      END
C
C   ===============
C   TO CALCULATE 'OUTSDE SUM' 95% CONFIDENCE LIMITS
C
      SUBROUTINE ERROUT(LEV,MIN,MAX,X,TP,PCMEAN,PCUP,PCLOW)
      DIMENSION X(50,60),TP(50),PCMEAN(50,60),PCUP(50,60),PCLOW(50,60)
      DO 2 NL=1,LEV
      DO 1 NT=MIN,MAX
      PCMEAN(NL,NT)=X(NL,NT)*100/TP(NL)
      IF(X(NL,NT).EQ.0.0) GOTO 3
      P=X(NL,NT)/TP(NL)
      E=1.96*(P*(1+P)/TP(NL)+0.9604/TP(NL)**2)**0.5
      PCUP(NL,NT)=100*(P+(1.9208/TP(NL))+E)/(1-3.8416/TP(NL))
      PCLOW(NL,NT)=100*(P+(1.9208/TP(NL))-E)/(1-3.8416/TP(NL))
      GOTO 1
    3 PCUP(NL,NT)=0.0
      PCLOW(NL,NT)=0.0
    1 CONTINUE
    2 CONTINUE
      RETURN
      END

       ==========
       LCULATE 'INSIDE SUM' 95% CONFIDENCE LIMITS
C
      SUBROUTINE ERRIN(LEV,MIN,MAX,X,TP,GR,PCMEAN,PCUP,PCLOW)
      DIMENSION X(50,60),TP(50),GR(50),PCMEAN(50,60),PCUP(50,60),
     #PCLOW(50,60)
      DUM=1.0
      IF(TP(1).NE.GR(1)) GOTO 4
      DUM=2.0
    4 CONTINUE
      DO 2 NL=1,LEV
      D=(TP(NL)+GR(NL))/DUM
      DO 1 NT=MIN,MAX
      PCMEAN(NL,NT)=X(NL,NT)*100/D
      IF(X(NL,NT).EQ.0.0) GOTO 3
      P=X(NL,NT)/D
      E=1.96*(P*(1-P)/D+0.9604/D**2)**0.5
      PCUP(NL,NT)=100*(P+(1.9208/D)+E)/(1+3.8416/D)
      PCLOW(NL,NT)=100*(P+(1.9208/D)-E)/(1+3.8416/D)
      GOTO 1
    3 PCUP(NL,NT)=0.0
      PCLOW(NL,NT)=0.0
    1 CONTINUE
    2 CONTINUE
      RETURN
      END
C
C   ===============
C
      SUBROUTINE TABLE1(NLEV,SITE,DESC,N,DEPTH,X,NTAXA)
      DIMENSION SITE(5),DEPTH(50),X(50,60),NTAXA(5,60),DESC(5,5)
    2 FORMAT(1H1,' ')
    3 FORMAT(1H0,5A4,2X,5A4)
    4 FORMAT(1H ,F6.0,20F5.0)
    5 FORMAT(1H , 9X,4(5A4,5X))
    6 FORMAT(1H ,14X,4(5A4,5X))
    7 FORMAT(1H ,19X,4(5A4,5X))
    8 FORMAT(1H ,24X,4(5A4,5X))
    9 FORMAT(1H ,29X,4(5A4,5X))
   10 FORMAT(1H0,'DEPTH')
```

```
      DO 20 MM=1,3
      MTAX=MM*20
      M=MTAX-19
      M1=M+1
      M2=M+2
      M3=M+3
      M4=M+4
      WRITE(6,2)
      WRITE(6,3)(SITE(I),I=1,5),(DESC(I,N),I=1,5)
      WRITE(6,10)
      DO 1 NL=1,NLEV
      WRITE(6,4)DEPTH(NL),(X(NL,J),J=M,MTAX)
    1 CONTINUE
      WRITE(6,5)((NTAXA(I,J),I=1,5),J= M,MTAX,5)
      WRITE(6,6)((NTAXA(I,J),I=1,5),J=M1,MTAX,5)
      WRITE(6,7)((NTAXA(I,J),I=1,5),J=M2,MTAX,5)
      WRITE(6,8)((NTAXA(I,J),I=1,5),J=M3,MTAX,5)
      WRITE(6,9)((NTAXA(I,J),I=1,5),J=M4,MTAX,5)
   20 CONTINUE
      RETURN
      END
C
C ===============
C
      SUBROUTINE TABLE2(SITE,DESC,N,NLEV,D,X,XL,XU,NTAXA)
      DIMENSION D(50),X(50,60),XL(50,60),XU(50,60),NTAXA(5,60),
     #SITE(5),DESC(5,5)
    8 FORMAT(1H1,' ')
    9 FORMAT(1H0,5A4,2X,5A4)
   10 FORMAT(1H0,'DEPTH',3X,5(3X,5A4))
   11 FORMAT(1H ,F6.0,1X,5(3F7.1,2X))
      WRITE(6,8)
      DO 2 MM=1,12
      MTAX=MM*5
      M=MTAX-4
      WRITE(6,9)(SITE(I),I=1,5),(DESC(I,N),I=1,5)
      WRITE(6,10)((NTAXA(I,K),I=1,5),K=M,MTAX)
      DO 1 NL=1,NLEV
      WRITE(6,11)D(NL),((XL(NL,J),X(NL,J),XU(NL,J)),J=M,MTAX)
    1 CONTINUE
      WRITE(6,12)((NTAXA(I,J),I=1,5),J=M,MTAX)
   12 FORMAT(1H ,8X,5(3X,5A4))
    2 CONTINUE
      RETURN
      END
```

APPENDIX IV

POLLEN AND DIATOM COUNTS OF ALL SITES INVESTIGATED

BOURNE FEN-10 POLLEN COUNTS

DEPTH	195	200	205	245	250	255	260	265	270	275	280	285	290	295	300	305	310
BETULA	6	18	4	0	1	0	0	0	0	2	1	3	3	1	1	1	0
PINUS	6	0	1	0	2	1	1	1	3	2	3	0	0	1	0	3	2
ULMUS	2	4	5	1	1	0	0	2	2	7	5	3	4	5	7	1	2
QUERCUS	33	32	33	69	48	17	15	84	84	76	72	33	50	59	60	23	56
TILIA	1	4	0	4	4	1	0	5	4	10	4	10	8	9	7	8	6
ALNUS	41	85	95	75	92	134	84	56	60	56	87	101	113	75	78	80	86
FRAXINUS	8	0	5	1	2	0	0	2	2	0	1	1	1	4	1	0	1
FAGUS	3	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CORYLOID	30	75	115	35	28	17	9	20	31	35	39	35	32	65	38	46	37
SALIX	6	13	6	4	0	6	0	0	1	1	3	2	7	2	6	1	0
ILEX	0	0	0	0	0	0	0	0	0	0	0	0	1	4	0	0	0
CALLUNA	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0
HEDERA	0	2	0	0	5	1	0	1	0	0	0	1	0	0	0	0	0
LONICERA	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
GRAMINEAE	236	542	1072	211	268	104	81	53	25	46	41	38	23	42	77	41	84
CYPERACEAE	46	16	16	42	33	31	29	36	37	38	23	10	29	38	92	5	16
CLADIUM	2	0	0	0	0	1	0	3	3	2	3	2	2	4	6	0	10
RANUNCULUS-TYPE	0	1	0	1	5	1	2	18	5	8	19	11	16	15	26	6	9
CALTHA	0	1	0	0	0	0	0	1	1	0	0	1	4	3	3	0	1
DROSERACEAE	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
POLYGONUM	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
URTICA	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
CHENOPODIACEAE	1	6	1	71	29	1	2	1	1	1	0	0	0	0	0	0	1
FILIPENDULA	1	1	1	3	10	2	1	0	1	1	2	1	0	1	1	0	1
TARAXACUM-TYPE	0	0	1	2	3	1	3	1	0	0	0	0	0	4	0	0	0
UMBELLIFERAE	0	0	0	1	0	0	0	1	0	0	0	0	1	6	0	0	0
RUMEX	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0
SUCCISA	0	1	0	3	1	0	0	0	0	1	0	0	0	0	0	0	0
CIRSIUM-TYPE	0	1	0	16	7	7	2	0	0	0	0	0	0	0	0	0	0
PLANTAGO MARITIMA	0	0	7	1	2	1	0	0	0	0	0	0	0	0	0	0	0
SENECIO-TYPE	0	0	0	9	0	0	0	0	0	0	0	0	0	0	0	0	0
ARTEMISIA	0	1	1	1	3	0	0	0	0	0	0	0	0	0	0	0	0
MENTHA	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NYMPHAEA	1	0	0	0	0	0	0	1	1	1	0	0	2	0	0	0	0
TYPHA LATIFOLIA	7	33	1	36	27	10	2	0	1	4	1	0	3	0	0	0	0
LEMNA	15	39	5	3	4	10	13	2	0	1	0	0	0	0	0	2	3
POTAMOGETON	3	2	0	11	5	3	5	20	26	21	6	5	5	12	10	1	12
T.ANGUSTIFOLIA	42	96	1	0	7	2	0	1	0	0	0	0	0	0	5	0	6
NUPHAR	0	1	0	0	0	0	0	0	2	12	0	0	0	0	0	0	0
HYDROCOTYLE	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
POLYPODIUM	6	0	0	7	0	0	2	0	0	6	5	4	1	7	2	20	5
FILICALES	142	4	4	18	41	65	33	29	17	46	20	16	12	30	2	33	32
EQUISETUM	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1
SPHAGNUM	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
PTERIDIUM	1	1	0	1	2	0	0	0	0	0	0	0	0	0	0	0	0

BOURNE FEN-10 POLLEN COUNTS-CONTINUED

DEPTH	-315	-320	-325	-330	-335	-338
BETULA	0	1	2	1	1	0
PINUS	1	0	4	3	0	1
ULMUS	0	0	2	1	2	0
QUERCUS	11	35	53	66	62	22
TILIA	4	4	3	9	4	2
ALNUS	34	30	82	80	85	176
FRAXINUS	0	0	4	4	2	3
FAGUS	0	0	0	0	0	0
CORYLOID	23	14	22	42	31	47
SALIX	0	1	4	2	3	3
ILEX	1	5	2	1	0	0
CALLUNA	0	0	0	0	0	0
HEDERA	0	0	0	0	0	0
LONICERA	0	0	0	0	0	0
GRAMINEAE	21	22	39	27	24	39
CYPERACEAE	8	14	32	25	8	10
CLADIUM	0	5	6	4	5	4
RANUNCULUS-TYPE	3	12	1	2	2	1
CALTHA	1	2	5	1	2	2
DROSERACEAE	0	0	0	0	0	1
POLYGONUM	0	0	0	0	0	1
URTICA	0	1	0	3	1	0
CHENOPODIACEAE	1	1	0	0	0	0
FILIPENDULA	1	0	0	0	0	0
TARAXACUM-TYPE	0	0	0	0	0	0
UMBELLIFERAE	0	0	0	0	0	0
RUMEX	0	0	0	0	0	0
SUCCISA	0	0	0	0	0	0
CIRSIUM-TYPE	0	0	0	0	0	0
PLANTAGO MARITIMA	0	0	0	0	0	0
SENECIO-TYPE	0	0	0	0	0	0
ARTEMISIA	0	0	0	0	0	0
MENTHA	0	0	0	0	0	0
NYMPHAEA	0	0	1	2	6	1
TYPHA LATIFOLIA	0	0	1	0	0	1
LEMNA	0	5	0	0	3	0
POTAMOGETON	4	3	0	0	0	0
T.ANGUSTIFOLIA	0	0	0	0	0	0
NUPHAR	0	0	0	0	0	0
HYDROCOTYLE	0	0	0	0	0	0
POLYPODIUM	4	2	1	2	0	3
FILICALES	5	16	15	24	22	19
EQUISETUM	2	0	0	0	0	0
SPHAGNUM	1	0	0	0	0	0
PTERIDIUM	0	0	0	0	0	0

BOURNE FEN-P1 POLLEN COUNTS

DEPTH	-30	-35	-40	-45	-48	-49	-50	-55	-60	-62	-63	-64	-66	-68	-70	-75	-80
BETULA	2	12	11	5	3	6	3	1	2	2	1	2	3	2	1	3	2
PINUS	2	0	3	0	2	0	1	1	2	0	2	3	0	3	4	6	0
ULMUS	0	2	6	7	6	8	3	3	3	3	1	2	2	1	3	1	4
QUERCUS	14	26	78	63	92	43	37	24	34	30	25	35	22	33	18	24	22
TILIA	0	3	2	1	2	1	0	1	1	0	1	2	0	1	4	16	10
FRAXINUS	0	0	5	3	4	7	3	5	0	2	0	0	0	0	0	0	0
FAGUS	0	0	5	4	4	0	0	0	1	0	0	0	0	0	0	0	0
ALNUS	22	70	100	51	64	33	64	56	60	38	47	55	198	283	291	62	60
CORYLOID	32	74	191	113	210	61	50	80	63	41	41	45	19	23	25	29	26
SALIX	0	1	5	3	5	4	0	2	0	0	0	0	0	0	0	0	1
ILEX	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1
HEDERA	0	0	1	0	0	0	0	0	0	0	1	1	0	0	0	0	0
PLANTAGO MAJOR	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CEREALIA	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
GRAMINEAE	53	229	147	86	121	45	53	23	61	51	76	104	86	101	108	87	85
CYPERACEAE	17	15	8	1	2	3	2	2	7	4	12	16	27	46	57	79	111
CLADIUM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2
MATRICARIA-TYPE	0	0	0	0	0	0	0	1	0	0	0	2	1	2	1	3	3
CIRSIUM-TYPE	0	0	2	0	0	0	0	0	0	0	0	0	1	3	0	2	2
CHENOPODIACEAE	0	3	91	26	44	30	30	31	15	20	26	28	5	2	2	1	1
POLYGONUM	0	3	8	2	6	2	3	0	0	7	2	1	1	3	2	0	1
TARAXACUM-TYPE	0	0	0	0	0	0	0	0	0	0	0	1	0	1	2	2	0
RANUNCULUS-TYPE	0	2	7	5	9	3	7	3	3	2	1	1	0	1	3	2	0
FILIPENDULA	0	1	1	0	0	0	0	0	1	3	2	1	2	4	1	1	0
ARTEMISIA	0	0	2	4	6	3	4	2	2	3	0	1	1	0	1	0	0
CARYOPHYLLACEAE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0
PLANTAGO LANCEOLATA	0	6	6	3	1	0	0	1	0	0	0	1	1	3	1	0	0
PLANTAGO MARITIMA	0	0	0	3	5	1	2	6	7	8	5	2	0	0	0	0	0
RUBIACEAE	0	0	0	0	0	0	0	0	0	0	1	1	1	2	1	0	0
SUCCISA	0	1	2	1	1	2	1	4	1	4	1	0	0	1	1	0	0
SENECIO-TYPE	0	0	0	0	0	0	0	1	0	0	2	1	0	0	0	0	0
SANGUISORBA	1	0	3	0	0	0	0	0	1	1	1	1	0	0	0	0	0
RUMEX	0	0	0	1	0	1	0	0	2	1	0	3	0	0	0	0	0
ARMERIA	0	0	1	0	1	0	0	3	0	4	0	1	0	0	0	0	0
GENTIANELLA	0	0	0	0	0	0	2	0	3	0	1	0	0	0	0	0	0
CENTAUREA	0	0	2	0	0	0	0	0	0	2	0	0	0	0	0	0	0
LIMONIUM	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0
CALTHA	0	0	1	1	3	0	0	3	0	0	0	0	0	0	0	0	0
GENTIANA	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
UMBELLIFERAE	0	2	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0
CRUCIFERAE	0	0	2	0	0	2	0	0	0	0	0	0	0	0	0	0	0
ROSACEAE	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
VALERIANELLA	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
VALERIANA	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
VERONICA	0	1	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
URTICA	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TRIGLOCHIN	0	0	0	0	0	1	0	0	0	1	1	0	0	0	0	0	0
TYPHA ANGUSTIFOLIA	58	5	13	12	6	6	9	3	1	0	3	2	1	0	0	0	0
T.LATIFOLIA	0	5	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
LEMNA	4	153	0	0	0	0	0	0	0	3	0	1	2	0	2	0	1
NYMPHAEA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
POTAMOGETON	0	0	0	0	0	1	0	0	0	1	3	9	0	0	1	0	2
NUPHAR	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0
HYDROCOTYLE	0	0	5	0	0	0	0	1	0	0	1	1	5	1	0	0	0
MYRIOPHYLLUM VERT.	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0
ISOETES	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
PTERIDIUM	0	0	9	3	0	0	0	2	1	0	0	0	0	1	3	1	1
POLYPODIUM	0	0	1	0	1	1	0	1	1	1	0	0	1	0	0	0	2
SPHAGNUM	0	1	0	1	1	0	1	0	0	2	4	1	0	0	6	106	1
FILICALES	56	1	3	3	1	5	1	5	8	6	39	36	298	170	213	50	185
LYCOPODIUM	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400

BOURNE FEN-P2 POLLEN COUNTS

DEPTH	9	7	5	3	1	0	-5	-10	-15	-20	-25	-30	-35	-40	-45	-50	-55
BETULA	5	3	12	8	15	2	1	0	1	3	0	1	1	3	0	0	0
PINUS	0	1	4	2	2	0	1	5	5	5	1	1	2	5	6	2	1
ULMUS	6	7	36	12	18	2	1	0	0	0	0	0	1	1	0	0	0
QUERCUS	51	36	96	50	76	20	19	15	24	19	9	8	9	8	5	6	7
TILIA	5	3	2	5	4	2	0	0	0	0	0	1	0	0	0	0	0
ALNUS	70	32	120	50	90	24	15	10	12	10	5	4	5	5	4	6	2
FRAXINUS	7	12	8	17	37	1	0	0	0	0	0	0	0	1	0	0	0
FAGUS	0	1	0	2	2	0	0	0	0	0	0	0	0	0	0	0	0
CORYLOID	59	53	76	45	62	18	10	4	16	13	5	4	4	9	5	0	1
SALIX	5	13	16	1	5	6	3	3	1	1	0	0	1	1	0	0	0
ILEX	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
HEDERA	3	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
CRUCIFERAE	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
PLANTAGO CORONOPUS	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
RUBIACEAE	2	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0
P.LANCEOLATA	2	3	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
GRAMINEAE	85	79	316	96	560	170	79	82	74	60	87	70	67	85	17	19	42
CEREALIA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CYPERACEAE	349	537	360	248	33	6	1	3	3	5	1	1	5	2	1	1	4
CLADIUM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
RANUNCULUS-TYPE	2	3	12	6	9	3	0	1	1	2	2	0	0	0	0	0	1
CHENOPODIACEAE	2	2	0	0	4	6	28	13	35	40	40	8	8	19	19	6	4
FILIPENDULA	0	0	2	1	0	2	0	0	0	1	0	0	0	0	0	0	0
UMBELLIFERAE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SUCCISA	0	0	0	0	0	0	1	2	1	1	1	0	0	2	0	0	0
MALVA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ARMERIA	0	0	0	0	0	0	1	0	0	1	0	0	0	1	0	0	0
SENECIO-TYPE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CIRSIUM-TYPE	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0
CARYOPHYLLACEAE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ARTEMISIA	0	0	0	0	1	0	4	2	0	4	0	1	2	4	3	2	2
POLYGONUM	4	5	0	1	16	0	6	0	0	0	0	2	0	0	1	0	0
TARAXACUM-TYPE	0	0	0	0	0	0	1	0	0	1	0	1	1	0	0	0	0
PLANTAGO MARITIMA	0	0	0	0	1	0	4	0	0	0	0	1	2	0	0	0	3
LIMONIUM	0	0	0	0	1	0	0	0	1	0	0	0	0	1	2	0	0
CALTHA	0	4	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0
TRIGLOCHIN	0	0	0	0	0	0	1	2	11	32	5	15	30	4	0	2	6
POTAMOGETON	7	2	24	8	6	0	0	0	0	0	0	3	0	0	0	0	2
LEMNA	5	1	4	4	45	0	1	0	0	0	0	0	0	0	0	0	0
TYPHA LATIFOLIA	1	0	12	0	6	0	3	2	1	1	0	0	0	0	0	0	0
T.ANGUSTIFOLIA	65	52	548	99	39	0	8	0	0	0	0	0	0	0	0	0	0
HYDROCOTYLE	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
NUPHAR	0	0	0	0	0	0	0	3	2	0	1	1	2	2	1	0	0
NYMPHAEA	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
POLYPODIUM	1	1	0	1	0	1	1	0	0	0	0	0	0	0	1	0	0
FILICALES	3	8	20	5	7	5	4	6	2	1	4	0	5	2	1	0	3
EQUISETUM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PTERIDIUM	0	0	2	1	0	1	2	2	1	4	6	3	3	0	0	1	0
LYCOPODIUM	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400

BOURNE FEN-P2 POLLEN COUNTS-CONTINUED

DEPTH	-60	-65	-68	-69	-70	-75	-80	-84
BETULA	0	2	0	2	0	0	8	3
PINUS	5	5	1	3	3	5	3	2
ULMUS	0	0	0	1	0	1	2	1
QUERCUS	16	14	19	35	23	30	54	62
TILIA	0	0	1	2	2	1	9	11
ALNUS	1	8	5	30	15	22	72	74
FRAXINUS	0	0	0	0	1	0	2	1
FAGUS	0	0	0	0	0	0	0	0
CORYLOID	7	6	13	43	28	24	61	45
SALIX	1	1	0	2	0	0	1	0
ILEX	0	0	0	0	0	0	1	0
HEDERA	0	0	0	0	0	0	0	0
CRUCIFERAE	0	0	0	0	0	0	0	0
PLANTAGO CORONOPUS	0	0	0	0	0	0	0	0
RUBIACEAE	0	0	0	0	0	0	0	0
P.LANCEOLATA	0	0	0	0	0	0	0	0
GRAMINEAE	89	87	142	185	149	155	192	117
CEREALIA	0	0	0	2	4	5	1	1
CYPERACEAE	19	37	62	159	187	118	143	85
CLADIUM	0	0	0	0	1	5	4	5
RANUNCULUS-TYPE	1	0	0	1	1	4	1	8
CHENOPODIACEAE	2	9	3	15	9	0	1	1
FILIPENDULA	0	0	1	2	2	3	1	4
UMBELLIFERAE	0	0	1	0	0	0	0	1
SUCCISA	1	1	1	4	1	0	1	2
MALVA	0	0	0	0	0	0	1	0
ARMERIA	2	0	0	0	0	2	1	0
SENECIO-TYPE	0	0	0	2	0	1	0	0
CIRSIUM-TYPE	0	0	0	1	0	0	0	0
CARYOPHYLLACEAE	0	4	7	15	0	0	0	0
ARTEMISIA	0	5	6	8	0	0	0	0
POLYGONUM	0	1	0	2	0	0	0	0
TARAXACUM-TYPE	0	1	1	0	0	0	0	0
PLANTAGO MARITIMA	4	0	0	0	0	0	0	0
LIMONIUM	0	0	0	0	0	0	0	0
CALTHA	0	0	0	0	0	0	0	0
TRIGLOCHIN	3	2	3	4	0	0	0	0
POTAMOGETON	3	2	2	5	2	5	0	1
LEMNA	0	2	0	0	3	2	1	1
TYPHA LATIFOLIA	0	0	8	17	28	39	11	10
T.ANGUSTIFOLIA	0	0	0	4	0	5	0	0
HYDROCOTYLE	0	0	2	6	2	2	0	0
NUPHAR	0	0	0	0	0	0	6	1
NYMPHAEA	0	0	0	0	0	0	0	0
POLYPODIUM	0	0	0	1	0	0	6	6
FILICALES	2	5	4	58	124	45	139	173
EQUISETUM	0	0	0	2	0	4	0	0
PTERIDIUM	0	0	1	0	0	0	0	0
LYCOPODIUM	400	400	400	400	400	400	681	437

ONBIT WASH-7 POLLEN COUNTS

EPTH	-170	-172	-176	-180	-184	-188	-192	-196	-200	-666	-668	-670	-850	-854	-856	-904	-909
ETULA	0	3	0	1	1	2	3	0	0	2	1	3	3	0	1	1	1
INUS	0	4	2	0	2	0	2	0	1	6	2	8	2	2	4	2	4
LNUS	0	0	1	0	0	0	0	0	0	4	1	2	1	1	3	2	3
UERCUS	2	10	4	1	4	0	6	2	4	42	70	57	57	9	14	13	24
ILIA	0	0	0	0	0	0	0	0	0	4	8	3	7	9	4	3	8
RAXINUS	0	0	0	0	1	0	0	0	0	2	1	0	1	0	0	0	0
NUS	0	1	2	0	1	0	0	0	4	21	21	28	28	22	49	45	120
ORYLOID	0	2	0	0	4	0	0	4	2	24	22	39	48	10	12	9	12
ALIX	0	3	0	0	0	1	5	0	2	0	3	3	4	4	14	3	7
LEX	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
EDERA	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
LLUNA	0	0	0	0	0	0	0	2	1	0	0	0	1	0	0	0	0
RAMINEAE	17	27	37	16	31	34	95	14	96	40	63	49	39	20	5	10·	17
YPERACEAE	20	79	55	112	217	33	43	390	34	8	9	4	7	12	6	1	4
ENECIO-TYPE	0	0	1	0	0	0	3	1	1	0	0	3	0	3	0	0	0
ANUNCULUS	0	0	0	0	1	0	2	0	0	2	4	1	2	2	0	0	5
OLYGONUM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2
RIACEAE	0	1	0	0	1	0	2	0	1	0	0	2	1	0	0	0	0
IRSIUM-TYPE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
HENOPODIACEAE	0	1	1	0	1	4	0	4	6	18	9	27	24	22	4	20	4
LTHA	0	0	0	0	0	0	0	1	0	0	0	2	0	0	0	0	0
PERGULA	0	0	0	0	0	0	0	0	0	0	0	3	0	1	0	0	0
UCIFERAE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0
ERCURIALIS	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
ADIUM	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
BELLIFERAE	0	1	0	0	0	1	1	0	2	0	0	3	0	1	0	0	0
LYSTEGIA	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CCISA	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
RAXACUM-TYPE	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0
ANTAGO MAJOR	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0
RYOPHYLLACEAE	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
MEX	0	0	0	0	0	1	0	0	0	0	1	1	0	0	0	0	0
TEMISIA	0	0	0	0	0	0	2	0	0	0	0	1	0	0	0	0	0
TRICARIA-TYPE	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0
LIPENDULA	0	0	0	0	0	0	0	0	0	1	0	1	2	1	0	0	0
ANTAGO LANCEOLATA	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
ANTAGO MARITIMA	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
MONIUM	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0
IGLOCHIN	0	0	0	0	0	0	0	0	0	5	1	4	0	0	0	0	0
NTAUREA	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
ANTAGO CORONOPUS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
IS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
RIOPHYLLUM SPIC.	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0
MPHAEA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	0	0
PHA ANGUSTIFOLIA	3	2	17	39	169	144	131	51	145	6	12	7	0	1	8	9	22
LATIFOLIA	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
TAMOGETON	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0
MNA	0	0	0	0	0	0	9	0	1	2	4	1	2	0	0	0	0
PHAR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DROCOTYLE	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0
ERIDIUM	0	0	0	0	0	0	0	0	1	0	1	0	1	1	1	0	0
LYPODIUM	0	0	0	0	0	0	0	0	0	1	2	0	0	2	6	0	1
LICALES	1	15	3	2	2	3	7	1	9	15	11	11	10	71	86	1	0
HAGNUM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
COPODIUM	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	400	400	400	311	400	400	400	357

COWBIT WASH-7 POLLEN COUNTS-CONTINUED

DEPTH	-912	-916	-920	-923	-925	-928	-934	-938	-942
BETULA	3	0	7	6	6	6	5	0	0
PINUS	3	1	3	6	10	6	1	6	1
ULMUS	2	3	14	14	7	14	23	2	1
QUERCUS	23	13	75	69	51	72	79	20	43
TILIA	6	1	16	17	3	10	12	7	11
FRAXINUS	1	2	1	3	2	1	1	0	0
ALNUS	74	29	60	35	28	41	31	33	94
CORYLOID	10	5	19	33	54	28	30	24	25
SALIX	10	0	0	2	0	0	0	0	0
ILEX	1	0	0	0	0	0	0	0	0
HEDERA	0	1	2	0	0	1	1	0	1
CALLUNA	0	0	0	0	0	0	0	0	0
GRAMINEAE	11	8	275	277	62	82	92	85	26
CYPERACEAE	7	2	12	14	6	20	63	20	58
SENECIO-TYPE	0	0	1	1	0	0	0	2	3
RANUNCULUS	3	1	5	1	3	3	4	0	2
POLYGONUM	0	0	0	0	0	1	0	3	2
RUBIACEAE	0	0	0	1	0	0	0	1	1
CIRSIUM-TYPE	0	0	0	0	0	0	2	1	0
CHENOPODIACEAE	1	1	4	14	17	2	2	47	0
CALTHA	0	0	1	0	0	1	0	0	0
SPERGULA	0	2	0	0	2	0	0	0	0
CRUCIFERAE	0	0	0	0	0	0	0	0	0
MERCURIALIS	0	0	0	0	0	0	0	0	0
CLADIUM	0	0	0	0	0	0	0	0	0
UMBELLIFERAE	0	0	0	0	0	1	0	0	0
CALYSTEGIA	0	0	0	0	0	0	0	0	0
SUCCISA	0	0	0	0	0	0	0	0	0
TARAXACUM-TYPE	0	0	0	0	2	0	0	0	0
PLANTAGO MAJOR	0	0	0	0	1	0	0	0	0
CARYOPHYLLACEAE	0	0	0	0	0	0	0	0	0
RUMEX	0	0	0	0	0	2	0	0	0
ARTEMISIA	0	0	0	0	0	4	0	0	0
MATRICARIA-TYPE	0	0	0	0	0	0	0	0	0
FILIPENDULA	0	0	0	1	0	0	0	0	0
PLANTAGO LANCEOLATA	0	0	0	0	0	0	0	0	0
PLANTAGO MARITIMA	0	0	0	0	0	0	0	0	0
LIMONIUM	0	0	0	0	0	0	0	0	0
TRIGLOCHIN	0	0	0	0	0	0	0	0	0
CENTAUREA	0	0	0	0	0	0	0	0	0
PLANTAGO CORONOPUS	0	0	0	0	1	0	0	0	0
IRIS	0	0	0	0	0	1	0	0	0
MYRIOPHYLLUM SPIC.	0	0	0	0	0	0	0	0	0
NYMPHAEA	0	0	0	0	0	0	0	0	0
TYPHA ANGUSTIFOLIA	8	14	62	30	30	31	52	17	0
T.LATIFOLIA	0	2	0	0	2	0	0	9	0
POTAMOGETON	0	1	4	0	0	0	0	1	0
LEMNA	0	0	21	4	2	0	32	0	0
NUPHAR	0	0	2	0	0	0	0	0	0
HYDROCOTYLE	0	0	0	1	0	0	0	0	0
PTERIDIUM	1	0	0	0	0	0	0	1	1
POLYPODIUM	1	0	0	1	1	1	1	0	2
FILICALES	0	0	2	1	10	1	0	5	48
SPHAGNUM	0	0	0	0	0	0	0	1	0
LYCOPODIUM	400	427	200	392	400	241	231	400	401

ADVENTURERS LAND-2 POLLEN COUNTS

DEPTH	-838	-840	-842	-844	-846	-848	-853	-855
BETULA	3	1	0	11	7	1	7	8
PINUS	2	4	5	6	2	0	2	8
ULMUS	11	2	7	57	25	13	30	40
QUERCUS	35	30	26	167	75	38	130	157
TILIA	13	16	14	33	14	21	20	26
FRAXINUS	6	0	0	11	3	1	1	2
ALNUS	30	19	18	75	62	38	71	95
CORYLOID	65	40	23	207	95	75	155	244
SALIX	0	0	0	2	3	0	0	5
HEDERA	0	0	1	2	1	1	0	2
CALLUNA	0	1	0	1	0	0	0	0
GRAMINEAE	35	29	27	378	154	59	308	550
CYPERACEAE	3	3	1	23	19	15	19	29
POLYGONUM	2	0	0	0	1	0	1	4
ARTEMISIA	0	0	0	1	0	0	1	1
RANUNCULUS	0	0	0	8	0	0	3	1
ROSACEAE	0	0	0	0	0	0	0	1
RUMEX	0	0	0	0	0	0	0	1
CLADIUM	0	0	0	0	0	0	2	0
CALTHA	1	0	0	4	0	0	2	0
CHENOPODIACEAE	13	0	2	4	2	7	1	0
PLANTAGO. MARITIMA	0	0	0	0	0	1	2	0
SENECIO-TYPE	0	0	0	0	0	3	0	0
CIRSIUM-TYPE	0	0	0	0	0	2	0	0
SPERGULARIA	0	0	0	0	1	0	0	0
TARAXACUM-TYPE	0	0	1	0	0	0	0	0
LEMNA	1	0	0	5	8	1	61	160
TYPHA ANGUSTIFOLIA	1	0	0	4	3	3	16	7
POTAMOGETON	2	0	0	1	0	0	0	4
NUPHAR	0	0	0	0	0	0	0	1
NYMPHAEA	0	0	0	0	0	0	2	0
MYRIOPHYLLUM SPIC.	1	0	0	0	0	0	0	0
ISOETES	2	0	0	0	0	0	0	0
POLYPODIUM	0	5	3	0	0	0	0	0
SPHAGNUM	0	0	1	0	0	0	0	0
FILICALES	12	200	1400	2	0	0	0	0
LYCOPODIUM	200	200	200	200	200	200	200	400

ADVENTURERS LAND-4 ' POLLEN COUNTS

DEPTH	-104	-108	-444	-450	-454	-458	-466	-726	-730	-818	-820	-822	-824.
BETULA	0	0	1	4	4	2	1	1	1	10	12	5	1
PINUS	0	1	2	9	5	4	4	1	1	1	3	1	10
ULMUS	0	0	0	1	0	0	0	11	14	33	19	17	7
QUERCUS	0	0	33	83	66	31	14	35	33	95	87	70	76
TILIA	1	0	3	12	7	5	2	9	2	28	10	12	20
FRAXINUS	0	0	0	0	0	0	0	1	2	3	4	2	0
FAGUS	0	0	0	0	1	0	0	0	0	0	0	0	0
ALNUS	4	3	10	41	48	17	0	12	20	78	59	45	37
CORYLOID	8	9	17	51	44	310	40	20	32	177	87	65	60
SALIX	0	0	1	4	17	6	0	0	0	1	1	0	3
HEDERA	1	0	0	0	1	0	0	1	0	1	2	1	0
CALLUNA	1	2	0	0	0	0	0	0	0	0	0	0	0
ILEX	1	0	0	0	0	0	0	0	0	0	0	0	0
GRAMINEAE	5	9	60	311	154	106	15	27	46	87	183	554	326
CYPERACEAE	4	4	3	16	10	12	3	28	54	41	38	6	7
POLYGONUM	0	0	0	0	1	0	0	0	0	0	0	0	1
ARTEMISIA	0	1	0	0	0	0	0	0	0	0	0	0	0
RANUNCULUS	0	0	0	1	4	0	0	3	2	5	7	5	4
CALTHA	0	0	0	0	0	0	0	0	1	0	0	2	1
CHENOPODIACEAE	3	5	23	171	29	1	2	12	2	2	0	0	6
SENECIO-TYPE	7	0	0	2	1	0	0	13	0	0	0	0	30
CIRSIUM-TYPE	0	0	0	2	0	0	0	0	0	0	0	0	3
TARAXACUM-TYPE	2	3	0	0	0	0	0	0	0	0	0	0	0
MATRICARIA-TYPE	0	0	0	0	0	0	0	0	0	0	0	0	2
UMBELLIFERAE	2	0	0	1	2	3	1	0	0	0	0	3	3
RUBIACEAE	0	0	2	9	7	46	0	0	0	0	0	0	1
VALERIANA	0	0	0	0	0	0	0	0	0	0	0	0	1
SPERGULA	0	0	0	0	0	0	0	0	0	2	0	0	0
FILIPENDULA	0	0	0	0	0	0	0	0	0	1	0	0	0
PLANTAGO MEDIA	0	0	0	0	0	1	0	0	0	0	0	0	0
CRUCIFERAE	0	0	0	4	0	0	0	0	0	0	0	0	0
PLANTAGO LANCEOLATA	1	0	1	0	0	0	0	0	0	0	0	0	0
LEMNA	0	2	1	2	0	0	1	2	0	13	4	66	2
TYPHA ANGUSTIFOLIA	21	18	2	159	1000	1200	1	3	4	19	11	2	3
TYPHA LATIFOLIA	0	1	0	0	1	2	1	0	0	0	0	0	0
HYDROCOTYLE	0	0	0	0	0	0	0	0	0	0	0	0	2
PTERIDIUM	0	1	0	0	0	0	1	0	0	0	1	0	0
POLYPODIUM	0	0	1	2	0	1	1	0	0	1	0	0	0
SPHAGNUM	0	0	0	0	0	0	1	0	0	0	0	0	0
FILICALES	12	28	167	60	14	5	2	1	0	5	0	1	5
LYCOPODIUM	200	100	200	214	400	400	200	400	100	157	200	249	342

BOURNE FEN - P2 : diatom counts

			25	35	45	55	65
Diploneis bombus	MB	B	1	1	-	-	1
Melosiria sulcata	M	P	-	2	4	3	2
Pleurosigma angulatum	M	B	1	-	-	-	-
Surirella fastuosa	M	B	-	1	7	6	-
Triceratium favus	M	P	-	-	-	1	-
Actinoptychus undulatus	MB	P	-	1	-	-	1
Diploneis didyma	MB	B	94	102	73	10	35
smithii	MB	E	19	8	31	43	27
Raphoneis amphiceros	MB	E	1	-	-	-	-
Synedra tabulata	BM	E	1	-	1	-	1
Caloneis formosa	B	B	2	3	5	13	2
Campylodiscus echeneis	B	B	8	-	1	2	2
Nitzschia navicularis	B	B	22	23	29	72	75
scalaris	B	B	-	5	-	-	-
Cymbella aspera	FB	E	-	-	-	-	1
Navicula radiosa	FB	B	-	1	-	-	2
Broken (unidentified)	-	-	9	13	7	2	2

COWBIT WASH - 7 : diatom counts

			160	300	666	670	750	850	923
Aulacodiscus argus	M	B	-	-	-	1	-	-	-
Auliscus sculptus	M	B	-	-	-	-	-	-	-
Diploneis bombus	M	B	-	-	-	-	1	-	-
lineata	M	B	-	-	-	-	-	1	-
Hemidiscus cuneiformis	M	P	-	-	-	-	1	-	-
Melosira sulcata	M	P	-	5	8	12	1	8	-
Navicula lyra	M	B	-	2	1	1	2	-	12
praetexta	M	B	-	1	-	-	-	-	-
Opephora pacifica	M	E	-	-	-	-	-	-	4
Podosira stelliger	M	E	-	1	1	-	-	2	-
Rhabdonema minutum	M	E	-	-	-	1	-	-	-
Surirella fastuosa	M	B	-	-	-	1	20	2	-
Triceratium favus	M	P	-	-	1	-	-	-	-
reticulum	M	B	-	-	-	-	-	-	1
Actinoptychus undulatus	MB	P	-	2	9	2	11	11	1
Cocconeis scutellum	MB	E	-	1	-	-	-	-	-
Coscinodiscus excentricus	MB	P	-	1	-	-	-	-	-
Diploneis didyma	MB	B	-	15	42	15	34	17	11
smithii	MB	E	-	-	4	2	29	-	-
Navicula arenaria	MB	B	-	-	-	-	7	-	-
marina	MB	B	-	-	1	2	3	5	-
Nitzschia acuminata	MB	B	-	-	-	1	19	3	-
ergadensis	MB	B	-	-	-	-	4	-	-
granulata	MB	B	1	1	18	44	6	76	-
Raphoneis amphiceros	MB	E	-	5	2	4	4	-	-
surirella	MB	E	1	-	-	-	-	-	-

COWBIT WASH - 7 : Diatom counts (continued)

			160	300	666	670	750	850	923
Synedra crystallina	MB	E	-	-	-	1	-	-	-
Achnanthes brevipes	BM	E	-	1	-	-	-	-	-
Nitzschia punctata	BM	B	-	4	17	8	10	21	1
Stauroneis gregorii	BM	B	-	-	-	-	1	-	-
Caloneis formosa	B	B	-	11	8	1	-	-	-
Campylodiscus echeneis	B	B	-	-	3	1	1	2	8
Diploneis interrupta	B	B	-	-	3	1	-	-	13
Gyrosigma balticum	B	B	-	-	-	-	4	-	-
Navicula digitoradiata	B	B	-	2	-	-	20	1	-
elegans	B	B	2	-	-	-	-	-	-
Nitzschia navicularis	B	B	2	16	81	108	3	92	43
Cocconeis pediculas	BF	F	13	1	-	-	13	-	-
Nitzschia sigma	BF	B	-	-	-	1	29	2	-
Synedra pulchella	BF	E	2	-	-	-	-	-	-
Amphora ovalis v. pediculus	FB	B	1	-	-	-	-	-	-
Cymatopleura solea	FB	B	2	-	-	-	-	-	-
Diploneis ovalis	FB	B	3	-	-	-	-	-	-
Epithemia sorex	FB	E	2	-	-	-	-	-	-
turgida	FB	E	22	-	-	-	-	-	-
Fragilaria brevistriata	FB	E	8	-	-	-	-	-	-
construens v.venter	FB	E	2	-	-	-	-	-	-
Gyrosigma acuminatum	FB	B	1	-	-	-	-	-	-
Navicula anglica	FB	B	2	-	-	-	-	-	-
hungarica	FB	B	10	-	-	-	-	-	-
radiosa	FB	B	21	-	-	-	1	-	-
rhynchocephala	FB	B	1	-	-	-	-	-	-
Nitzschia fonticula	FB	B	2	-	-	-	-	-	-
fruticosa	FB	B	3	-	-	-	-	-	-

COWBIT WASH - 7 : Diatom counts (continued)

			160	300	666	670	750	850	923
Opephora martyii	FB	E	8	-	-	-	-	-	-
Pinnularia viridis	FB	B	-	-	-	-	-	-	1
Surrirella ovata	FB	B	-	-	-	-	2	-	-
Synedra ulna	FB	E	3	-	-	-	-	-	-
Tabellaria fenestrata	FB	E	-	-	1	-	-	-	-
Cocconeis placentula	F	E	36	-	-	-	-	-	-
Fragilaria intermedia	F	F	1	-	-	-	-	-	-
Nitzschia angustata	F	B	1	-	-	-	-	-	-
Broken (unidentified)	_	_	40	15	38	83	46	11	170

ADVENTURERS' LAND - 2 : diatom counts

			826	828	830	832	834	836	838	848	850	852
Aulacodiscus argus	M	P	1	-	-	-	1	-	-	-	2	-
Auliscus sculptus	M	B	-	-	-	1	1	-	-	-	-	-
Biddulphia aurita	M	E	-	1	2	4	-	-	-	-	-	-
Coscinodiscus centralis	M	P	-	-	-	1	-	-	-	-	-	-
Dimerogramma minor	M	B	-	2	-	-	-	-	-	-	-	-
Druridgea compressa	M	E	-	-	-	-	1	-	-	-	-	-
Melosira sulcata	M	P	25	17	21	19	29	31	15	1	16	9
Navicula lyra	M	B	1	-	-	1	1	2	1	-	-	-
Navicula praetexta	M	B	1	-	2	3	2	-	-	-	-	-
Plagiogramma staurophorum	M	E	1	-	-	1	-	-	-	-	-	-
Pleurosigma formosum	M	B	-	-	-	-	-	2	-	-	-	-
Podosira stelliger	M	E	2	-	-	4	2	3	1	-	-	-
Rhabdonema minutum	M	E	-	-	-	-	-	1	-	-	3	-
Trachyneis aspera	M	B	-	-	1	2	2	1	-	-	-	-
Triceratium favus	M	P	1	-	2	5	4	2	-	-	-	-
Actinoptychus undulatus	MB	P	4	3	2	27	37	8	3	-	2	1
Cocconeis scutellum	MB	E	-	1	1	7	5	28	1	-	25	9
Coscinodiscus excentricus	MB	P	1	-	2	2	2	1	-	-	2	-
Diploneis didyma	MB	B	-	-	4	4	9	7	14	-	21	20
Diploneis smithii	MB	E	2	5	21	20	23	3	5	-	10	3
Navicula humerosa	MB	B	1	-	-	-	-	-	-	-	-	-
Raphoneis amphiceros	MB	E	9	-	11	4	17	9	2	-	-	5

ADVENTURER'S LAND - 2 : diatom counts (continued)

			826	828	830	832	834	836	838	848	850	852
Raphoneis surirella	MB	E	-	-	-	2	-	-	-	-	-	-
Synedra crystallina	MB	E	2	1	-	-	-	-	-	-	-	-
Synedra gallioni	MB	E	-	-	3	-	-	-	-	-	-	1
Achnanthes brevipes	BM	E	9	6	6	2	1	4	-	-	-	-
Nitzschia punctata	BM	B	139	45	88	36	14	5	-	-	-	-
Pleurosigma elongatum	BM	B	-	-	-	-	-	-	-	-	2	-
Synedra tabulata	BM	E	5	21	23	19	2	16	-	-	2	7
Caloneis formosa	B	B	-	-	-	3	1	-	-	-	-	-
Campylodiscus echeneis	B	B	1	-	1	1	-	-	2	271	55	6
Diploneis interrupta	B B	B	-	-	-	-	-	1	122	5	-	-
Navicula peregrina	B	B	-	-	-	-	-	-	-	-	1	2
Nitzschia apiculata	B	B	7	14	-	-	1	-	-	-	-	-
Nitzschia navicularis	B	B	2	4	8	11	19	26	20	1	34	4
Rhopalodia gibberula	B	E	36	44	39	22	2	13	-	-	1	1
Surirella striatula	B	B	-	1	6	8	-	-	-	-	-	-
Coconeis pediculus	BF	E	28	60	19	-	7	-	1	-	3	-
Nitzschia hungarica	BF	B	-	-	1	-	1	2	10	-	1	-
Nitzschia sigma	BF	B	3	5	1	2	3	-	-	-	-	-
Synedra pulchella	BF	E	-	3	-	-	-	-	-	-	-	2
Achnanthes lanceolata	FB	E	-	-	-	-	1	-	-	-	-	-
Epithemia turgida	FB	E	1	-	-	-	2	-	3	-	4	1
Fragilaria brevistriata	FB	E	-	1	-	7	1	-	-	-	10	108

ADVENTURER'S LAND - 2 : diatom counts (continued)

			826	828	830	832	834	836	838	848	850	852
Gyrosigma acuminatum	FB	B	-	-	-	1	4	1	-	-	-	-
Navicula hungarica	FB	B	-	-	-	-	-	1	-	-	-	-
Navicula radiosa	FB	B	1	5	4	1	-	2	1	-	1	1
Opephora martyi	FB	E	1	1	1	-	3	5	1	-	5	22
Surirella elegans	FB	B	1	-	1	-	-	-	-	-	-	-
Surirella ovata	FB	B	-	-	-	2	-	-	-	-	1	-
Synedra acus	FB	P	-	-	-	-	-	-	1	-	-	-
Synedra ulna	FB	E	-	-	-	-	-	5	-	-	-	-
Cocconeis placentula	F	E	-	1	-	8	7	-	-	-	-	-
Cyclotella antiqua	F	P	3	3	1	1	-	-	-	-	-	-
Broken (unidentified)						not counted						

FREISTON MARSH AND RIVER WELLAND, SPALDING : diatom counts

			P:0	P:5	C1:0	C1:5	C2:0	C3:0	C4:0	RW
Actinoptychus splendens	M	P	2	-	-	-	-	-	1	-
Amphora ostrearia	M	B	-	-	-	-	1	-	-	-
Biddulphia alternans	M	E	-	-	-	-	1	4	2	-
aurita	M	E	-	-	-	-	-	-	1	2
rhombus	M	E	-	1	-	7	3	2	1	-
Hemidiscus cueiformis	M	P	-	-	-	-	-	-	2	-
Lichmorphora abbreviata	M	E	-	-	-	-	2	-	-	-
Melosira sulcata	M	P	28	38	4	83	19	17	18	4
Navicula distans	M	B	-	1	-	-	-	1	4	-
hennedyi	M	B	-	-	-	1	-	-	-	-
lyra	M	B	1	-	1	-	-	3	4	-
Opephora pacifica	M	E	-	-	-	-	1	-	-	-
Plagiogramma staurophorum	M	E	1	-	-	3	-	1	4	-
Pleurosigma marinum	M	B	-	-	-	-	-	1	-	-
Podosira stelliger	M	E	2	1	1	5	2	-	3	-
Trachyneis aspera	M	B	-	1	-	-	-	-	3	-
Actinoptychus undulatus	MB	P	12	10	9	32	30	18	27	5
Cocconeis scutellum	MB	E	-	-	1	-	-	-	-	-
Coscinodiscus excentricus	MB	P	-	-	-	1	1	4	-	1
Diploneis didyma	MB	B	27	39	53	9	1	1	6	1
smithii	MB	E	1	3	-	1	2	6	1	-
Navicula arenaria	MB	B	-	-	-	-	-	2	13	-
forcipata	MB	B	-	-	-	-	1	-	-	-
humerosa	MB	B	-	-	-	-	-	-	1	-
marina	MB	B	-	-	-	-	1	-	3	-
Nitzschia acuminata	MB	B	19	-	-	-	3	3	-	1
granulata	MB	B	-	-	-	1	1	1	-	-

FREISTON MARSH AND RIVER WELLAND, SPALDING : diatom counts (cont.)

			P:0	P:5	C1:0	C1:5	C2:0	C3:0	C4:0	RW
Raphoneis amphiceros	MB	E	11	16	10	33	10	33	28	12
Achnanthes brevipes	BM	E	12	-	30	3	6	4	1	-
Scoliopleura tumida	BM	B	7	-	-	-	18	2	-	-
Stauroneis gregorii	BM	B	-	-	-	-	-	-	67	-
Synedra tabulata	BM	E	-	-	-	-	-	-	-	4
Achnanthes hauckiana	B	E	-	-	-	-	-	-	1	-
Caloneis amphisbaena f.subsalina	B	B	-	-	-	-	-	-	-	143
Caloneis formosa	B	B	3	2	9	5	4	2	-	-
Gyrosigma wansbeckii	B	B	10	17	-	1	8	2	1	3
Navicula clementis	B	B	-	-	-	-	-	-	-	1
digitoradiata	B	B	26	-	22	-	69	83	6	4
peregrina	B	B	-	-	-	1	-	1	-	-
pseudopalpebralis	B	B	-	-	-	-	-	3	-	-
Nitzschia bilobata	B	B	-	-	-	-	2	-	-	-
navicularis	B	B	25	86	55	13	1	-	1	-
Cocconeis pediculus	BF	E	-	-	3	-	2	1	-	1
Diatoma elongatum	BF	P	-	-	-	-	-	-	-	1
Navicula peregrina f. minor	BF	B	-	-	-	-	-	-	-	1
Nitzschia sigma	BF	B	13	3	2	1	11	5	1	19
Achnanthes lanceolata	FB	E	-	-	-	-	-	-	-	1
Cymatopleura solea	FB	B	-	-	-	-	-	-	-	4
Navicula radiosa	FB		-	-	-	-	-	-	-	15
Synedra acus	FB	P	-	-	-	-	-	-	-	1
Cocconeis placentula	F		-	-	-	-	-	-	-	1
Unidentified (broken)	-	-	65	38	50	33	57	83	99	23+