HOLOCENE SEA-LEVEL CHANGES

IN THE EAST KENT FENS

by

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VOLUME ONE

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DECLARATION

This thesis is the result of my own work. Data from other authors which are referred to in the thesis are acknowledged at the appropriate point in the text.

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ABSTRACT

This thesis sets out to examine the evidence for Holocene sea-level changes in the East Kent Fens. The methodology of data collection has involved the use of a variety of field and laboratory techniques, including hand-coring and seismic refraction profiling as well as pollen, diatom and elemental analyses.

Litho-, bio- and chronostratigraphic techniques have been used to establish the nature of sedimentary changes associated with transgressive and regressive contacts, as well as to identify the evidence for changes in the height and salinity of the watertable during periods of organic and inorganic deposition.

These data are used to establish a continuous chronology of watertable and sea-level changes in the study area. The results of this analysis are compared with the chronology of changes from the Essex, Kent and East Sussex coasts, using both sidereal and ^{14}C timescales.

Holocene sea-level data from the East Kent Fens and other sites in Southeast England are used to analyse the evidence for Holocene crustal movements. These analyses suggest that there are important differences in the history of Holocene crustal movements within Southeast England, and that the region has undergone periods of crustal uplift, subsidence and stability.

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1.1. Introduction.

This thesis analyses and interprets the evidence for Holocene sea-level changes in the East Kent Fens and Southeast England. Previous sea-level research in the East Kent Fens has been limited, and the area has been identified by Tooley (1982a) as being deficient in sea-level data. The sites selected have been chosen in order to determine the detailed response of a sedimentary system to watertable and sea-level changes. In addition, data are used to analyse tendencies of watertable and sea-level movements, as well as the patterns of Holocene crustal movements in Southeast England.

1.2. Thesis aims.

The aims of this thesis are summarised below :

1. To assess existing methodologies in Holocene sea-level studies.

2. To review critically the existing evidence for sea-level changes in Southeast England and the East Kent Fens.

3. To establish the pattern of Holocene sedimentation in the East Kent Fens through lithostratigraphic and seismic techniques and three-dimensional data displays.

4. To elucidate the palaeobotanical evidence associated with sedimentary changes at transgressive and regressive contacts recorded in the area under study.

5. To analyse the palaeobotanical evidence for changes in vegetation communities within organic and inorganic deposits as proxy data for changes in the altitude and salinity of the watertable.

6. To use ^{14}C dating to establish an absolute chronology for the pattern of Holocene watertable and sea-level movements in the study area.

7. To analyse the evidence for Holocene crustal movements in Southeast England.

8. To study the evidence for tendencies of sea-level movements in Southeast England.

1.3. The study area.

The field area studied in this thesis is defined by the tract of unconsolidated sands, silts, clays and peats which now infill the former Wantsum Channel (Fig 1.1). This extends from the outer Thames Estuary at Minnis Bay, southwards to Sandwich Bay, and includes the adjoining valleys of the Little and Great Stour. Analysis of the data collected from this area involves a comparison with other sites on the south coast extending as far west as the East Sussex coast, and as far north as the Essex coast.

1.4. Operational definitions.

Altitude - Altitude refers specifically to measurements made relative to Ordnance Datum (OD). This is the UK altitudinal datum and is defined as the average mean sea-level recorded at Newlyn in Cornwall between 1921-1925. Altitudinal determinations are quoted in metres OD.

Depth - Depth refers specifically to the local datum, which in this thesis is the groundsurface. Depths are expressed as cm. below surface (BS).

Radiocarbon date - These are quoted in radiocarbon (^{14}C) years before present (BP), i.e. before 1950. The error quoted is one standard deviation about the mean, and all dates are based on a ^{14}C half-life of 5570 yrs.

Calibrated dates - These are ^{14}C dates which have been calibrated to calendar years on an AD/BC timescale using the CALIB program of Stuiver and Reimer (1986).

Sea-level - Sea-level refers to a calculated value which in theory is the Mean Sea-Level of the ocean if no tidal forces operated. Mean Tide Level is the average of the low and high water over time, varying from place to place, and is normally used in the construction of sea-level curves. It is common practice (Jardine 1975) to assume that Mean Sea-Level and Mean Tide Level are the same, given the resolution possible in past sea-level research.

Transgression and regression - The terms transgression and regression have been used in a wide variety of contexts, and as identified by Shennan (1980, 1982) and Tooley (1982b), inconsistencies in the use of these terms have lead to much confusion. Accordingly, following Shennan (1980) they are used in a purely descriptive manner to describe a change in lithology from a semi-terrestrial to a brackish or marine deposit (transgressive overlap), and the replacement of a marine or brackish deposit by a semi-terrestrial deposit (regressive overlap). Their usage does not imply the operation of any vertical movement of sea-level.

Eustasy - This term is taken to include all water-based variables which affect the absolute altitude of the sea, including glacial-eustasy, tectono-eustasy, geoidal-eustasy as well as the operation of meteorological effects, and other local hydrological and oceanographic effects.

Isostasy - This term is taken to include all land-based variables which affect the absolute altitude of the land, including glacio-isostasy, tectono-isostasy, hydro-isostasy and compaction.

1.5. Approaches to the analysis of sea-level movements.

The following sub-Sections review the two main approaches used in the analysis of Holocene sea-level movements. This forms the context for a discussion of the methodology adopted in this thesis (Section 1.5.3). This is designed to give a general overview of the methodology adopted, and does not contain an exhaustive description of the approach to data collection and analysis adopted at each stage in the completion of this thesis.

It is rare that a defined methodology can be established at the outset of a piece of research such as this, and it will become clear that some of the decisions concerning the nature of data collection and subsequent analyses evolved in response to the nature of the sediments recorded in the field, and a growing understanding of the potentialities and limitations of the techniques of data collection and analysis.

1.5.1. Time/altitude analysis.

Sea-level investigations have been characterised by the pursuit of three main variables, - altitude, age and indicative meaning. Early attempts to determine how sea-level has varied during the Holocene typically used the time/altitude approach, with the plotting of data points on a scatter plot with depth as the dependent variable. Commonly this scatter was summarised by a single line, usually drawn by eye. One of the earliest of such diagrams completed in the UK was by Godwin (1940), who constructed a relative sea-level diagram for the East Anglian Fenlands during the Holocene.

Godwin (1940) was careful to stress that his data illustrated only relative changes in sea-level, but observed that the establishment and comparison of relative sea-level curves from all parts of north-western Europe and Britain was "the direct route by which a resolution of land- and sea-level movement into isostatic and eustatic components" could be made (Godwin 1940 :290).

Godwin (1945) later used sea-level data from the southern North Sea to calculate rates of differential crustal uplift and subsidence, as well as changes in the rate of eustatic sea-level changes. Following the advent of radiocarbon dating, Churchill (1965) extended the work of Godwin (1945), and also attempted to determine rates of crustal uplift and subsidence in the UK. By comparing the altitude of sea-level index points which formed c. 6500 BP, Churchill (1965) concluded that Britain was tilting on an axis from the Tees to Pembroke, with Southeast England undergoing net subsidence, and Scotland net uplift. However, the limited data used, and their unequal spatial distribution, restrict the use of Churchill's conclusions. In addition, the datum used in this study was based on deposits observed in Southern Africa, and following Morner's discussion of the concept of geoidal eustasy (Morner 1976), the conclusions of Churchill (1965) can no longer be accepted.

Flemming (1982) analysed a database of 143 sea-level index points to determine the pattern of UK crustal movements. Although the analysis involved a different methodology to that adopted by Churchill (1965), the resulting calculations supported Churchill's general conclusions, with net uplift in Scotland of +2.5mm a^{-1}, and net subsidence in Southwest England of -0.5mm a^{-1}. However, Flemming (1982) assumed a linear geological component (rate of crustal movement), whereas geological theory predicts a more complex curvilinear function for glacio-isostatic recovery. Shennan (1987, 1989) has further refined these studies, using a database of 429 sea-level index points from around the UK to re-examine the pattern of crustal movements. Shennan (1989) used the "regional eustatic curve" proposed by Morner for the North Sea region (eg Morner 1984) to calculate first estimates of uplift and subsidence, and concluded that there has been a difference between Scotland and the Thames Estuary of c. 2.40mm a^{-1}. These data are discussed more fully in Chapter Eight.

The discussion above has illustrated how sea-level data have been used to determine differential rates of crustal uplift and subsidence in the UK. Refinement of these data have been in part dependent on an understanding of the form of the eustatic sea-level curve. However, debate concerning the form of this curve has characterised sea-level studies for many years.

Daly (1934) argued that eustatic sea-level had oscillated during the Holocene, and presented evidence for a eustatic fall in sea-level of 6.00m at about 5000 years BP. In addition, Fairbridge (1958, 1961) presented sea-level data derived from a wide range of materials collected from around the world, and identified evidence for a number of eustatic falls in sea-level during the Holocene. However, Jelgersma (1961, 1966) and Shepard (1963) disagreed, and believed that there was no evidence for an oscillating rise in eustatic sea-level. Instead they proposed a smoothly rising Holocene eustatic sea-level curve. In particular, Jelgersma (1961) argued strongly against the poor quality of data used by Fairbridge (1961), which was derived from Australia, New Zealand, the Netherlands, the United States, Alaska, Algeria and the Gulf of Paria. Jelgersma (1961) observed that all the evidence for the high sea-level stands proposed by Fairbridge were derived from material collected in areas of known isostatic uplift, and therefore likely to have been elevated above their original depositional altitude.

However, Jelgersma has also been criticised, most notably for her acceptance of a fall in sea-level during the Eemian period, whilst at the same time rejecting any data suggestive of a fall in sea-level during the Holocene (Jelgersma et al 1979). In addition, Jelgersma (1961) and Jelgersma et al (1979) have argued for the use of organic sediments which have accumulated directly over permeable and non-compressible pre-Holocene deposits, as a result of rising groundwater conditions caused by a rise in sea-level. These data, it is argued, provide the clearest indicators of any rise in sea-level, and avoid altitudinal problems caused by post-depositional compaction. However, through ignoring the litho-, bio- and chronostratigraphic data associated with intercalated organic and inorganic sediments of Holocene age, Jelgersma (1979) has effectively ensured the determination of a smoothly rising sea-level.

More recently, through the application of detailed litho- and biostratigraphic techniques in the analyses of intercalated inorganic and organic sediments, clear evidence for an oscillating sea-level has been established. For example, following the careful presentation of litho-, bio- and chronostratigraphic data from Northwest England, Tooley (1978 :182) concluded that

> "pronounced sea-level oscillations have occurred: low amplitude oscillations undoubtedly register local effects, such as consolidation, and high amplitude oscillations include a large eustatic component".

Whilst debate concerning the form of the eustatic sea-level curve lessened with the acceptance of an oscillatory form, (although Kidson and Heyworth (1978) continued to argue in favour of a smoothly rising sea-level), the quest for a global eustatic sea-level curve still dominated sea-level research for much of the 1970s. Indeed, the main aim of IGCP Project 61 (1974-82) was to "establish a graph of the trend of mean sea-level during the last 15,000 years" (Tooley 1978 :66).

However, concern over the large differences between sea-level curves from different parts of the world (eg Bloom 1977), led to growing doubts about the validity of a global eustatic sea-level curve. Furthermore, following Morner's (1976) discussion of the impact of possible changes in configuration of the geoid on the altitude of the sea, attention shifted towards the determination of detailed local sea-level histories.

More recently there has been a recognition of the need for the realistic appraisal of errors inherent in the determination of both former altitudes and former ages. Whilst Godwin (1940) proposed both age and altitude error bands for the sea-level curve which he presented, Shennan (1982) has applied rigorous and defined techniques to data collection and appraisal from the East Anglian Fenlands, and rejected the use of a single sea-level line. Instead Shennan (1980) has presented a sea-level band, with an altitudinal accuracy of ± 2m at best. Although Shennan's (1982) sea-level band clearly illustrates an oscillatory form, the number and amplitude of these oscillations are far fewer than those proposed by conventional single line sea-level curves. Shennan (1982) has concluded that

> "With the limitations of present research methods the simple plotting of the data, with their associated errors, on time-depth graphs cannot be expected to reveal mutually exclusive "rises and falls" in past sea-levels, but careful chronostratigraphic and lithostratigraphic correlations indicate definite periods dominated by negative tendencies of sea-level movement and others dominated by positive tendencies. These cannot be interpreted from, or presented by a single line called a sea-level curve".
>
> (Shennan 1982 :59)

1.5.2. Tendency analysis.

Since the late 1960s a number of investigators chose to ignore altitude altogether in the analysis of sea-level changes, instead adopting "an approach based primarily on direct investigation of the timing of changes in marine influence" (Morrison 1976 :163). In part this was because of a recognition of the difficulties inherent in the use of altitudinal data, but also it was due to a growing interest in the application and potential of statistical techniques of data analysis in sea-level studies.

For example, Geyh (1969, 1971) and Geyh and Streif (1970) used this type of approach in the analysis of shoreline movements in the North Sea. Using frequency histogram analyses of dates, Geyh identified evidence for periods of increased or decreased rates of peat growth. In this early analysis no classification of the data was attempted, and only periods of maximum or minimum "ingression" were identified.

Roeleveld (1974) attempted a basic form of data classification in an analysis of the frequency distribution of ^{14}C dates collected from the base and top of peat layers from the coastal sequences of the northern Netherlands. Peaks in the histograms for the former were interpreted as being indicative of "maxima of regression", and peaks in the histograms of the latter were interpreted as "maxima of transgression". The time interval between a maxima of regression and the next younger maxima of transgression was described as the "regressive interval". Roeleveld (1974) concluded that there was a good correlation between the alternation of transgressive and regressive intervals in the northern Netherlands compared with other areas in the country.

Classification of ^{14}C dates was extended by Morrisson (1976), who established a computer database of 1200 dates from the western European seaboard, which he then screened according to their quality as sea-level index points. 700 dates were rejected, and the remaining 500 dates were divided into four classes : transgressive (T) or regressive (R) dates, and basal (W) or isolation (I) dates. Morrisson (1976) followed the approach of Roelevald (1974) by presenting the combined frequency of TW and RI dates on a single time axis, with the latter data inverted on this axis.

Morrisson (1976 :168) argued that changes in "the amounts of transgression and regression evidence could be expected to have an inverse relationship", and that alternative patterns might suggest the operation of local sedimentary processes or errors inherent in the radiocarbon technique. Morrisson (1976) did indeed observe that classes T and W, and R and I fluctuated in a saw-tooth manner, suggesting periods dominated by an increase or decrease of the marine influence. Accordingly, Morrisson (1976) was able to identify a regional sea-level signal for the western European seaboard. The methodology developed by Morrisson (1976) of establishing a database of ^{14}C dates, screening them, and subsequently analysing them through the use of the tendency approach has formed the basis for subsequent analyses of large sea-level databases.

Shennan (1982) and Tooley (1982b) for example, have applied this approach to the analysis of a ^{14}C database of sea-level index points established in the Sea-level Research Unit at the University of Durham. Rigorous screening and classification of these data have enabled these authors to identify evidence for local and regional tendencies of Holocene sea-level changes in the U.K.. Shennan et al (1983), for example, have applied this approach to a comparison of the evidence for tendencies of sea-level movement from the East Anglian Fenlands, Northwest England and the Tay Estuary.

One of the greatest advantages of the tendency approach is that it allows the incorporation of a range of sea-level index points collected from a variety of palaeoecological environments. This flexibility was recognised by Morrisson (1976) as being desirable, and is a reflection of the non-requirement of an indicative altitudinal range for each data point. Thus, Shennan (1982) for example, has noted that

> "Transgressive and regressive contacts are just two types of sea-level index points (which can be used); others include palaeobotanical evidence, morphological and archaeological data, palaeosols and other lithostratigraphic changes".

Despite the flexibility of this approach, at present the type of data used in tendency analyses is overwhelmingly dominated by the traditional transgressive and regressive contacts. There are two reasons for this imbalance;

i. Firstly, chronological and altitudinal data derived from archaeological or geomorphological contexts are less amenable to statistical analyses and absolute age determinations than conventional ^{14}C dates from transgressive and regressive contacts, despite recent developments in thermoluminescence dating techniques.

ii. Secondly, sea-level studies are largely dependent on a database of costly ^{14}C dates established over the last c. 30 years. For much of this time ^{14}C dating has been required to satisfy the dual role of providing both a chronology and an altitudinal context for sea-level studies. This altitudinal context was provided by the use of transgressive and regressive contacts, which are two of the few points in the stratigraphic column which have formed at a known altitude with respect to a former sea-level (the indicative altitudinal range of a sample). This is generally accepted as being the position of Mean High Water Spring Tides (MHWST), although Kidson and Heyworth (1982) have argued that the indicative altitudinal range of a sea-level index point may be affected by the rate of sea-level movements at the time of sediment accumulation.

1.5.3. Discussion.

It is important to realise that the development of sea-level studies has meant that it is no longer sufficient to use a single database of litho-, bio- or chronostratigraphic data to analyse the various components of the sea-level equation. Clearly the nature of data collection must realistically reflect the nature of the initial research objectives.

In order that the nature of data collection described in Chapters Four and Five is understood, the methodology adopted is explained in full below. This thesis has a number of aims, each of which require data collection and data analysis at a variety of spatial scales. These can be divided conveniently into site-scale and regional scale methodologies.

Chapters Four, Five, Six, and Seven present data from the site scale (the East Kent Fens), and the methodology employed is designed to establish a chronology for watertable and sea-level movements in the study area. Through a re-appraisal of the tendency approach this thesis re-examines the value of using transgressive and regressive overlaps, and in so doing argues that the methodological advances made over the last twenty-five years with the development of the tendency approach have not been matched by similar advances in the initial process of data collection.

Thus, pollen and diatom data are used to determine the nature of sedimentary changes associated with the transgressive and regressive contacts, as well as to determine the evidence for within-stratum changes in water depth and water quality. The radiocarbon dating sampling strategy reflects this research methodology, dating the traditional transgressive and regressive contacts, as well as levels indicative of an increase or decrease in water depth and water quality. This methodology is discussed in more detail in Chapter Six.

An additional research objective has been to analyse the detailed sedimentary response of a small depositional basin to changes in the height and quality of the watertable through time. Therefore, following an initial large scale lithostratigraphic survey of the Holocene sediments designed to establish the general nature of Holocene sedimentation in the area, a detailed three-dimensional analysis of the sediments in a small defined sedimentary basin is attempted. Emphasis is placed on assessing the degree of variability in age, altitude and indicative meaning recorded at this small spatial scale. It is believed that this type of appraisal is the necessary preliminary stage before comparing the evidence observed at this study area with that from other sites in Southeast England.

At a regional scale the methodology of data acquisition and data analysis changes. Following the critical review of published and unpublished sea-level index points from Southeast England, these data are combined with new data from the East Kent Fens in order to analyse the evidence for crustal movements and tendencies of sea-level movements at the regional scale. Thus the scale of data analysis increases through this thesis, from the scale of the individual hand-core, through to a regional comparison of crustal movements and sea-level tendencies.

1.6. Structure of thesis.

Chapter Two provides an introduction to the East Kent Fens, placing it within the context of selected published sea-level data from the Essex, Kent and East Sussex coasts. One of the main aims of this Chapter is to establish a chronological context for the current study. Chapter Three describes the techniques used in data collection, with an emphasis placed on the problems involved in using the different techniques with specific reference to the current study.

Chapters Four and Five present the lithostratigraphic, seismic, biostratigraphic and elemental data collected from the East Kent Fens.

Chapters Six and Seven interpret the evidence for watertable and sea-level movements at a variety of spatial scales, beginning in Chapter Six with the individual core, and then in Chapter Seven assessing the degree of intra- and then inter-site variability. This enables the proposition of a continuous chronology of watertable movements and sea-level changes in the study area.

Chapter Eight incorporates the new data from the East Kent Fens with those from the rest of Southeast England described in Chapter Two, in order to analyse the evidence for Holocene crustal movements in the area. Chapter Nine analyses the evidence for tendencies of sea-level movements in Southeast England, and Chapter Ten concludes the thesis by considering to what extent the initial research objectives outlined in Section 1.2. have been met, and by proposing some themes for future research.

Chapter Two: A Review of Previous Sea-level Research in Southeast England.

2.1. Introduction.

This Chapter has two objectives. The first is to describe briefly the geology of the East Kent Fens, and to review previous sea-level research completed in the area. This geological description provides information concerning the nature of pre-Holocene sediments in the study area, which were commonly encountered whilst hand-coring. In addition it provides information concerning the palaeogeography of the area, which is necessary for reconstructing the former relationship of the study area to the sea.

The second objective of this Chapter is to review critically and to classify published and unpublished sea-level data which provide information concerning the chronology of sea-level movements from the Essex, Kent and East Sussex coasts. This forms a chronological context and basis for discussion for the current study. The radiocarbon dates collected during the course of this thesis are not discussed here, but are presented in Section 6.2. Discussion of the crustal history of Southeast England is made in Chapter Eight.

2.2. Classification of radiocarbon dates.

All ^{14}C dates in the following Sections have been classified according to their quality and indicative meaning. This screening procedure is the necessary preliminary stage before subsequent analyses. Each date has been classified into one of five groups and two sub-groups. Whilst it is not possible to discuss each date individually in this Chapter, the criteria used in the classification of these data are outlined in Table 2.1. below.

Table 2.1. Classification of ^{14}C dates.

Group	Indicative meaning
Group 1	Dates obtained from organic sediments which have accumulated directly overlying the pre-Holocene surface. Must have formed under a rising ground watertable. Require supporting pollen data.
Example	Devoy (1977), Isle of Grain, Lab Code Q1286 8510±110 BP, -26.30 to -26.43m OD *Laminated clayey-Limus detrituosus, overlying gravel.* Pollen data indicates accumulation under a rising fresh watertable, with frequencies of Typha angustifolia/ Sparganium >25% Total Land Pollen.
Group 2	Dates obtained from transgressive contacts. Require supporting biostratigraphic data (normally pollen and diatoms) to confirm sedimentary change from a fresh terrestrial to a brackish/ marine depositional environment. Lithological contact must not be eroded.
Example	Devoy (1977), Tilbury, Lab Code Q1429 6575± 90 BP, -10.10 to -10.14m OD *Felted turfa with some Phragmites and Alnus roots.* Pollen data indicate an increase in frequencies of Gramineae and saltmarsh pollen below contact. Diatom data above contact illustrate change to brackish/marine depositional environment. Lithological contact diffuse (lim. sup. 0).

Group 3 Dates obtained from regressive contacts. Require supporting biostratigraphic data (normally pollen and diatoms) to confirm sedimentary changes from a marine/brackish to a fresh terrestrial depositional environment.

Example Devoy (1977), Tilbury, Lab Code Q1428 7050±100 BP, -10.38 to -10.42 m OD

Felted turfa with some Phragmites and Alnus roots.

Pollen data indicate increase in frequencies of saltmarsh indicators below and across contact. Diatom data indicate the replacement of a brackish/marine depositional environment by an increasingly fresh terrestrial depositional environment.

Group 4a Dates obtained from within organic deposits which have no direct biostratigraphic relevance to the direction of watertable movements, and no defined altitudinal relationship to a former sea-level. These dates only indicate a time when organic sedimentation was occurring. No supporting biostratigraphic data required.

Example Greensmith and Tucker (1976, 1980), St Peter's Flats, Lab Code SRR58 4959± 65 BP. c. -1.50m OD

Thin peat seam.

No supporting litho- or biostratigraphic data presented. Altitude only approximate.

Group 4b Dates obtained from within inorganic deposits which have no direct biostratigraphic relevance to the direction of watertable movements, and no defined altitudinal relationship to a former sea-level. These dates are often based on allochthonous material included within inorganic brackish/ marine sediments, and provide a maximum age for the deposition of that deposit. No supporting biostratigraphic data required.

Example Wilkinson and Murphy (1985), Crouch 29, Lab Code HAR 5735 3250± 90 BP. Altitude not known.

Sample of wooden platform set in head and contained within grey estuarine middle clay.

No supporting litho- or biostratigraphic data. Altitude not known.

Group 5a Dates obtained from within organic deposits which are indicative of a rise in the relative height of the watertable. Require supporting biostratigraphic data.

Example Waller (1987), Pannel Bridge, Pett. Lab Code SRR.2890 7000± 90 BP, -6.14m OD

Sample of peat.

Pollen analysis from within an organic deposit indicates a rise in fen and then reedswamp taxa, caused by an increase in the watertable.

Group 5b Dates obtained from within organic deposits which are indicative of a fall in the relative height of the watertable. Require supporting biostratigraphic data.

Example Marsh Lane ML-9. Lab Code H.v. 17333 5825±80 BP. -6.28 to -6.24m OD.

Slightly laminated Phragmites-rich well-

humified brown peat.
Pollen analysis demonstrates a reduction in the height of the watertable.

2.3. The East Kent Fens.

2.3.1. Geology of the area.

The geology of the East Kent Fens has been described in detail by Smart et al (1966) and more recently by Shephard-Thorn (1988). In much of the area the near-surface geology consists of Middle and Upper Chalk, Thanet and Woolwich Beds, and recent Brickearth deposits. Deep boreholes associated with coal mining in the area have provided information concerning the stratigraphy of the Carboniferous Limestone, Coal Measures, Jurassic, and Lower Cretaceous strata which underlie the Chalk, as well as on the occurrence of faults in the area.

The Chalk escarpment of the North Downs forms the eastern end of the Wealden anticlinorium, and in the study area forms an undulating surface, dipping below Palaeocene and Eocene strata in the Richborough (or Wantsum) Syncline, and re-appearing in the Isle of Thanet as the Thanet Anticline (Shephard-Thorn 1988). During Lower Eocene times the Lower London Tertiaries were deposited in the north of Kent, which consisted of Thanet, Woolwich and Reading and Oldhaven Formations (Cooper 1976). The Thanet Beds are exposed in the cliffs at Pegwell Bay where they have been described by Whitaker (1872), and also at Reculver Bay (Gardner 1883). The Thanet Beds attain a maximum thickness of c. 30m in the centre of the Richborough Syncline, and consist of a sequence of clays, marls, silts and fine sands.

Woolwich Beds outcrop in the area as a series of small outliers around East Stourmouth (TR 2600 6400). They have been described by Whitaker (1872) and White (1928), and typically comprise fine- to medium-grained glauconitic sands which are heavily bioturbated with iron-stained burrows. Deposits resembling the description of both the Thanet and Woolwich Beds were recorded in the base of many hand-cores completed in the Sandwich area.

Drift deposits recorded in the area consist of weathered Chalk, gravel deposits and Brickearth. Weathered Chalk was recorded in a number of hand-cores completed in the Lydden Valley (Fig.1.1.), where it comprised a soft deposit with flints. Gravel was encountered during hand-coring beneath fine-grained organic and inorganic sediments in the Little Stour Valley, where the gravels lie unconformably over Brickearth and/or Thanet Beds (Smart et al 1966).

Brickearth deposits are the most widespread drift deposits in the area, commonly occurring on the lower dip-slope of the Chalk. Two ages of Brickearth exist, an older deposit restricted to the plateau surfaces and associated with outcrops of the Thanet Beds, and a younger deposit recorded on the southeast and northeast facing slopes of the Chalk dipslope (Shephard-Thorn 1988). The deposit is described in the Soil Survey Memoir (Fordham and Green 1973) as a brown, finely porous, unbedded silty loam. The coarse fraction commonly contains small amounts of local material from the Thanet beds, and varies in thickness between 0.30m and 4.00m. The type locality for this deposit is at Pegwell Bay, where Pitcher et al (1954) have defined the deposit on the basis of grain size (>50% silt), colour (yellow/brown), and structure (strong vertical jointing).

It has generally been accepted that the Brickearth deposits have a loessic origin (Catt 1977, 1978, 1985, Jones 1981, Pitcher et al 1954, Weir et al 1971). However, Dangerfield (1973, in Shephard-Thorn 1988) has suggested that some of these deposits may have been reworked and mixed with other material under periglacial conditions, and therefore to assume a solely loessic origin for the deposit is incorrect. A deposit resembling Brickearth was encountered during hand-coring at Hacklinge, Marsh Lane, Stewart's Folly and Deerson Valley (Fig.1.1.). The deposit was only ever recorded close to the valley margins, and was only rarely penetrated.

2.3.2. Palaeogeography of the Outer Thames Estuary and Strait of Dover.

In order to establish the former relationship of the study area to the sea, it is important that the palaeogeography of the area is defined. The palaeogeography of the Outer Thames Estuary and the Strait of Dover are described below. This provides information peculiar to both the development of the Wantsum Channel and its associated sediments, as well as to other coastal sites discussed in the remaining Sections of this Chapter.

D'Olier (1972, 1975) has used seismic reflection techniques and 140 borehole logs to reconstruct the late Pleistocene/ Early Holocene palaeodrainage system of the River Thames, and has suggested that the Great Stour formerly flowed northwards, across the now submerged area offshore of the north Kent coast to join the Thames palaeodrainage system in the position of the present Knock Tidal Deep. D'Olier (1972) has combined his own palaeogeographic data with Jelgersma's (1961) relative sea-level data to illustrate the progressive inundation of the Outer Thames.

D'Olier has proposed that by 9600 BP high tide level was at approximately -45m, and that the sea had advanced up through the Strait of Dover and along the flood plain of the Rhine-Meuse-Thames river complex via the Lombourg or Channel valley. By 8600 BP the final land bridge with Europe had been breached, and the sea had penetrated up the Thames valley as far as Canvey Island and the Isle of Grain. However, it was not until 8300 BP that the sea began to invade the valley system of the Northern Stour, by which time sea-level was believed to have risen to -22m. Therefore, the palaeogeography of the River Thames and its tributary valleys indicates that the River Stour debouched into the Thames Estuary from as early as c. 8300 BP. Data concerning the palaeogeography of the Channel and the Strait of Dover are discussed below.

Although the floor of the English Channel is generally recognised as being smooth and flat (King 1948, Larsonneur et al 1975), beneath a thin sediment cover are a series of narrow valleys cut into bedrock. These valleys are infilled with fluvial and marine gravels, sands and clays, and have been described by Dingwall (1975) and Destombes et al (1975). Material collected from one of these valleys has been analysed by Morzadec-Kerfourn (1975). Pollen analyses on sediments recorded between -58.80m and -15.40m below sea-bed have indicated that the valley became infilled during Eemian or early Weichselian times, whilst the presence of two types of Picea pollen suggests a Brorup interstadial age for the pollen spectra.

Dingwall (1975) and Smith (1985) have shown that these offshore-valleys are interlinked, forming a buried palaeovalley system of anastomising valleys formed during periods of lowered sea-level. The Lombourg Valley can be followed in a southerly direction from the Outer Thames Estuary through the Strait of Dover, until it joins the Fosse Dangeard described by Destombes et al (1975). None of these maps illustrate the presence of a southerly offshore extension of the Wantsum Channel. However, a smaller valley of pre-Holocene age, now infilled with organic and inorganic sediments identified in this thesis, has been recorded extending offshore from Deal into the Lombourg Valley (D'Olier pers comm).

The absence of any major palaeovalley feature extending from the southern exit of the Wantsum Channel, confirms the early-Holocene exit of the River Stour into the Thames Estuary proposed by D'Olier (1975). However, offshore extensions of smaller valleys similar to that recorded at Deal are recorded at Dover, Folkstone, and Dungeness. At Dover, detailed geological investigations associated with the Channel Tunnel construction (Destombes and Shephard-Thorn 1972), have revealed the offshore extension of the Dour Valley. In addition, a buried valley identified by sparker profiles has been defined to the east of Folkstone, its base 140m below sea-level. Finally, Greensmith and Gutmanis (1990 Fig.8.) have used data compiled from British Geological Survey Maps (1988, 1989) to present a generalised palaeogeography of Dungeness at c. 3000 BP. This is central to their proposed model concerning the development of the Dungeness foreland since this time (Section 2.6.1.).

2.3.3. Previous Holocene sea-level research and ^{14}C dates from the East Kent Fens.

Previous sea-level investigations in the East Kent Fens are limited. Detailed litho-, bio-, or chronostratigraphic investigations in the area are restricted to Godwin's analysis of the shallow Holocene sediments recorded at Wingham (Godwin 1962). This analysis was only indirectly concerned with sea-level changes. Other research in the area has been based on archaeological and historical data, with only very limited lithostratigraphic analyses.

Considerable discussion has focused on the development of shingle and gravel deposits found at the eastern mouth of the Wantsum, which are believed to have had an important effect on the pattern of sedimentation in the area. Two shingle spits exist near Sandwich, - an inner "Stonar Spit" around which the present River Stour meanders, and an outer shingle spit which extends northwards from Deal to Sandwich (Fig.1.1.). Whilst it is generally accepted that these spits were responsible for the eventual closure of the Wantsum Channel in post-Roman times (combined with land reclamation), the processes involved in their formation have been the subject of considerable debate.

White (1928) has suggested that "eddy drift" was responsible for the growth of the Stonar Spit, whereby the northwards travelling tidal currents of the Strait of Dover would be deflected from the Isle of Thanet. This process would have gradually extended the Stonar Spit in a southerly direction from Ebbsfleet. An alternative hypothesis has been proposed by Hardman and Stebbing (1940), who suggested that the Wantsum Channel was a precursor to the Strait of Dover, and that prior to the opening of the latter the dominant tidal direction was southwards through the Wantsum Channel. They have suggested that these tides transported the reworked Thanet Sands and gravel deposits, and deposited them across the southern mouth of the Wantsum at Stonar. Following the opening of the Strait of Dover, Hardman and Stebbing (1940) have suggested that the dominant tidal direction switched to the north, and the outer shingle spit was deposited.

Robinson and Cloet (1953) agreed that the outer spit accumulated under a northerly dominated wave regime, but favoured longshore drift as opposed to tidal-stream action. However, they argued that the suggestion that the Wantsum Channel predated the opening of the Strait of Dover was untenable, as it would mean that the Stonar Spit must have been subject to several eustatic changes in sea-level of considerable, but unknown magnitude. More recent palaeogeographic data discussed above (D'Olier 1972, 1975) supports the conclusion reached by Robinson and Cloet (1953).

Robinson and Cloet (1953) argued that the Stonar Spit originated as an offshore bar which migrated onshore from the Brake Bank (Fig.1.1.), and which was subsequently overlapped by the outer spit described above. The Brake Bank has been described by Robinson and Cloet (1953) as a shoal, four miles in length and 300-1200m in width, positioned 2-3 km offshore in Sandwich Bay. In composition the Bank resembles the Stonar Spit. Robinson and Cloet (1953) have presented bathymetric data collected over the last 50 years and demonstrated the onshore movement of a limb of gravel and sand which had become detached from the Brake Bank. During this period the Bank was recorded as having moved a distance varying between 300-600m in a west-south-west direction.

Dating the formation of both spits is difficult. Robinson and Cloet (1953) have noted the presence of Roman artifacts in the Stonar Spit, and tentatively attributed a pre-Roman but not pre-Neolithic date for its formation, whilst admitting that conclusive evidence for this age is lacking. At what date the outer spit began to form is uncertain. Redman (1854) has suggested that in the late sixteenth century the head of the spit was located at Sandown Castle, to the immediate north of Deal, whilst Ward (1943) believed that the spit began to form some time after the Saxon Period. However, Roman artifacts discovered at Dickson's Corner and elsewhere south of this point, suggest that part of the outer spit must also have been in place by pre-Roman times (Parfitt 1980).

Details concerning the nature of the unconsolidated sands, silts, clays and peats which infill the former Wantsum Channel are limited, and no detailed lithostratigraphic investigations have been made. One ^{14}C assay has been determined by Shepherd-Thorn (1975) from a sample of organic material collected during the construction of the Sandwich by-pass near Richborough. This sample was collected from between -4.00 and -4.30m and lay directly over Thanet Sands. It has been dated to 5315±100 BP, although Shephard-Thorn (1975) has presented no supporting litho- or biostratigraphic data.

The author has obtained the bore-hole logs collected during the construction of the Sandwich by-pass from the Roads Division of Kent County Council (Section 4.2.2.). Copies of these were supplied to Dr A. Haggart at the Polytechnic of North London, and were subsequently used by Harmer (1990), who attempted to re-sample the organic sediments dated by Shephard-

Thorn (1975).

Harmer (1990) sampled one of the two organic deposits indicated by these borehole logs. This was recorded between -4.53 and -4.77m OD, and was underlain by an impenetrable blue-grey clay which extended to -5.64m OD, and was clearly not the same organic deposit dated by Shephard-Thorn (1975). Pollen analysis between -5.50m and -4.30m OD (Harmer 1990) indicated high frequencies of saltmarsh pollen in the lower clay. Following the end of inorganic sedimentation, frequencies of Tilia, Corylus and Quercus pollen dominated the early period of organic accumulation, and later frequencies of Alnus, Salix and Cyperaceae pollen increased. During the final stage of organic accumulation there was a decline in frequencies of Alnus and Salix pollen, and a sharp increase in those of Chenopodiaceae and Quercus.

Two other sites have been analysed for their pollen and/or macrofossil content in the northern part of the Wanstum Channel (Godwin 1962, Worsfold 1943). At the head of the Little Stour Valley at Wingham, Godwin (1962) recorded a blue-grey silty-clay overlain by a brown clay-mud with occasional flints. This was overlain by a detritus mud which contained remains of Equisetum, Cladium, and Menyanthes. The Phragmites component increased towards the top of this stratum. Overlying this stratum was a fine mud with some clay and then topsoil. The surface altitude was not levelled to OD, and was estimated to be c. +12ft OD (c.+3.65m OD) (Godwin 1962). Two ^{14}C dates were obtained from the sequence, one from the fine detritus organic mud between c. +1.80 to +1.90m OD dated to 3105±110 BP, and a second from the upper coarse detritus mud between +2.65m and +2.75m OD dated to 2340±130 BP.

Whether these dates can be used as sea-level index points is debatable. Godwin (1962) noted that Plantago maritima is recorded in low frequencies throughout the diagram, and has interpreted this as evidence for the proximity of tidal water during sediment accumulation. Godwin (1962) speculated whether the earliest occurrence of this taxon at c. +1.8m OD was a possible reflection of

> "a marine transgression about the opening of the Bronze Age that initiated peat formation in the valley"

and noted that

> "Whether the cause was increased activity of springs from the Chalk, or rising sea-level, there can be little doubt that the site became more water-logged not long after Neolithic "A" people had occupied the valley floor".

Therefore, it would appear that the oldest of the two dates can be classified as a Group 5a ^{14}C date, as it clearly indicates an elevation of the watertable, which may be related to an increase in sea-level. The younger of the dates provides no clear evidence of a directional change in the altitude of the watertable, or an increase in the marine influence, although low frequencies of Plantago maritima pollen are still recorded. This date is therefore classified as a Group 4a ^{14}C date.

At Minnis Bay, Worsfold (1943) has identified a Late Bronze Age site which had two stages of occupation. The first was sealed beneath a dark brown silt, and the second under a blue-grey silt deposited by the floodwaters which caused the final abandonment of the site. Plant macrofossil analysis was completed from the site, although no detailed information concerning sea-level changes is presented.

Evidence for coastal occupation in the Lydden Valley have been described by Halliwell (1981), Parfitt and Halliwell (1983) and Halliwell and Parfitt (1985). The earliest occupation site identified in the area is of Mesolithic age located at Finglesham (TR 25 3383 5377), where a dense concentration of struck and burnt flint was recorded (Parfitt and Halliwell 1983). The site is c. +3m OD, and the material derived from a relatively thin zone of orange-brown clay resting on Brickearth. Hence relative sea-level during this period must have been less than c. +3m OD.

Evidence of later occupation in the area has been presented by Halliwell (1981), who has described struck and burnt flints from a number of sites in the Lydden Valley. Halliwell (1981) has suggested that the flint assemblages recorded to the northeast of the coal tip (TR 25 3560 5460) are of later Neolithic or Bronze Age, and that

> "the marshy area between Deal and Worth and to the west of Sandwich was capable of being settled and regularly traversed in prehistoric times".

In addition, Parfitt (1980) has stated that the presence of a Roman occupation site at Dickson's Corner, and the extensive evidence for prehistoric occupation in the Lydden Valley

> "should finally dispel the long-held belief that this site was under water in prehistoric and Roman times".

A more detailed summary of these finds has been presented by Halliwell and Parfitt (1985), who have described the prehistoric land surface of the Lydden Valley. Sixteen areas producing flint-work have been identified in the Lydden Valley, and preliminary analysis of this material has suggested that it originated from a single general industry. Halliwell and Parfitt (1985) have identified two distinct layers of clay which underlie the surface peat in the Lydden Valley. The most extensive of these is a hard light grey silty-clay which to the west of the Lydden Valley is sealed directly by the surface peat. Shephard-Thorn (in Halliwell and Parfitt 1985) has interpreted this deposit as a waterlogged extension of the Brickearth which covers the adjacent Chalk downlands.

On the Minnis an intervening layer of soft grey, greasy clay is recorded, which increases in thickness from 0.10m to 0.40m towards the railway. Although some prehistoric material was recovered from the greasy clay, most of the material was derived from the lower grey silty-clay. At one site to the north of the coal tip (TR 25 3451 5495) a spread of carbon and "pot boiler" was located resting on top of the flint layer, and partially sealed by the greasy clay under the peat. A sample of this material was ^{14}C dated to 3030±90 BP, indicating a Middle Bronze Age for the deposit. This date has been classified as a Group 4b date, and gives a maximum age for the deposition of this deposit. This date combined with the Later Neolithic, Beaker, Early Bronze Age and Iron Age pottery suggest more than one period of occupation in the Lydden Valley.

The presence and spatial extent of these occupation sites is of some importance in the interpretation of the Holocene sediments of the Lydden Valley described in this thesis. The shallow nature of the pre-Holocene surface in many areas of the Lydden Valley, and the evidence for Neolithic and Bronze Age occupation, suggest that much of this area was land before c. 3000 BP.

Finally, reference is made to two deep ^{14}C dates obtained from trial bore-holes during the Channel Tunnel excavations. These were collected from a thick peat deposit recorded beneath c. 1.5m of gravel directly below the sea bed at a depth of c. -35m OD (Callow et al 1966). The peat was recorded in the base of a shallow sinuous valley on the submerged dipslope of the Middle Chalk. Pollen analysis supported the ^{14}C age determinations, and indicated that the younger of the dates (9920±120 BP) accumulated during Flandrian Zone IV, with high frequencies of birch and pine pollen recorded. The older of the dates (10,530±120 BP contained higher frequencies of herbaceous pollen taxa, suggesting a Zone III date for the deposit.

Pollen analysis failed to find any indicators of marine or estuarine conditions (Callow et al 1966). This, and the the eroded nature of the upper peat contact to the overlying gravel, make the use of these dates in this study inappropriate, although they do indicate that relative sea-level rose by at least c. 35m since c.10,500 BP in this area.

Table 2.2. below summarises the ^{14}C dates in existence in the East Kent Fens prior to this study. In Chapters Eight and Nine these data are not included in the "East Kent Fens" data set. This is because it was felt preferable to maintain the data collected during the completion of this study as a unique data set, collected under a consistent and defined research methodology. The relationship of the dates listed in Table 2.2. to those collected during the course of this study, are discussed where appropriate in Chapters Eight and Nine.

Table 2.2. List of ^{14}C sea-level index points from the East Kent Fens.

Site	Lab. Code	Date	Altitude
Material			
Group 4a			
Channel Tunnel	NPL 101	9920±120	-36.50m OD
Wood peat, top eroded.			
Channel Tunnel	NPL 103	10,530±120	c. -37.60m OD
Peat from layer 3ft (0.90m) thick below NPL 101.			
Sandwich	IGS 115	5315±100	-4.00 to -4.30m OD
Peat.			
Wingham	Q106	2340±130	c.+2.65 to +2.75m OD

Coarse detritus mud with remains of <u>Equisetum</u>, <u>Cladium</u>, and <u>Menyanthes</u>.

Group 4b

Lydden Valley	HAR 6213	3030±90	Not Known

Pot boiler beneath greasy clay.

Group 5a

Wingham	Q110	3105±110	<u>c</u>.+1.80 to +1.90m OD

Fine detritus organic mud.

<u>2.4. The Essex coast.</u>

<u>2.4.1. Sea-level index points from the Essex Coast.</u>

Sea-level index points from the Essex coast have been collected from the Blackwater and Crouch Estuaries, as well as from Mar Dyke. These data have been presented by Greensmith and Tucker (1969, 1971a, 1973, 1976 and 1980), and more recently by Wilkinson <u>et al</u> (1983, 1988), Wilkinson and Murphy (1984, 1985, 1986), as well as Murphy and Wilkinson (1982).

Greensmith and Tucker have identified six transgressions and five regressions which have affected the Essex coast during the Holocene, and presented two sea-level curves for the area (Greensmith and Tucker 1973, 1980). The authors have suggested that this pattern of Holocene sea-level changes compares closely with the evidence from the Lower Thames Estuary presented by Devoy (1979). In addition, Greensmith and Tucker (1980) have identified significant altitudinal differences between dated surfaces in the area, which they believe "provide strong support for differential subsidence of at least 4.3m since Neolithic times" between the Blackwater and Foulness.

However, careful analyses of the data presented by Greensmith and Tucker cast doubt over the quality of their original data, and hence their conclusions concerning the pattern of Holocene relative sea-level changes on the Essex coast.

Material used in their construction of the relative sea-level record from the Essex coast has included ^{14}C dated shells from relic cheniers, intercalated organic horizons, as well as the altitude of overconsolidated layers believed to represent periods of lowered sea-level (Greensmith and Tucker 1971b, 1973). These latter lithological indicators cannot be dated, and are therefore of limited value as sea-level index points. Their proposed chronology for sea-level changes is based on thirteen ^{14}C dates from shells and thin peat seams (eight and five dates respectively).

The shell samples have been collected from buried cheniers, and these cheniers are discussed in detail by Greensmith and Tucker (1969). However, the quality of these sea-level index points is debatable for a number of reasons;

i. Firstly, establishing the former relationship of these shells to a past sea-level is difficult, for as Greensmith and Tucker (1969) noted, they may form at any altitude between +0.50m and +3.00m above the altitude of the adjacent tidal flats. Indeed their maximum altitude is believed to represent the maximum altitude of storm waves at their time of deposition.

ii. Secondly, these sediments are highly mobile and storm events can have a considerable affect on their morphology and structure. Thus, following extreme storms contemporary cheniers have been observed to be "deflated" to a sheet-like form (Greensmith and Tucker 1969).

The variable preservation of these cheniers can have a large effect on the altitude of the samples dated. For example, a thick chenier deposit is recorded in borehole 5 from the Churchend-Foulness Point Ridge between -5.5m and -8.3m OD. Shells from this have been dated to 3912±114, 3936±110, and 3580±175 BP. In contrast, a buried sheet-like chenier is recorded in borehole 19 from the same area at -5.75m OD. A shell from this has been dated to 4350±210 BP (both in Greensmith and Tucker 1971a, Fig.5.). This latter date is c. 400 - 750 ^{14}C years older than the former dates, and yet is recorded at up to c. 2.50m above those dates from borehole 5.

iii. Thirdly, Greensmith and Tucker (1969) have noted

> "short periods of shell influx associated with the mass mortality of molluscs at the mouth of the estuaries"

caused by severe climatic conditions. The authors have illustrated this with an example of a contemporary chenier in the Foulness area which doubled in height within 2-3 years following the severe winter of 1962-3. Thus shell production and deposition is not only controlled by changes in sea-level through time, but also by climatic conditions.

iv. Finally, no adjustment is made for the reservoir effect inherent in the dating of marine shells, which may result in dates being up to 400 ^{14}C years too old (Mook and van de Plassche 1986).

In addition to the dating of shell deposits, Greensmith and Tucker have presented five dates from intercalated lenses of peat. Although the authors suggest that these sediments accumulated at approximately mean high water (Greensmith and Tucker 1971a), no palaeobotanical data are presented to support this contention. In addition, the lithostratigraphic context of these dated organic horizons is poor, with no indication given of their spatial extent.

A comparison of data presented in the different papers of Greensmith and Tucker illustrates unexplained discrepancies which are of some importance in data interpretation. For example, Greensmith and Tucker (1971a, Fig.5.) have presented the lithostratigraphy of borehole 19 on the Churchend-Foulness Point Ridge. Here a thin peat seam found at -18.30m OD has been dated to 7516±250 BP. Overlying this deposit is a thick silty-clay which extends to approximately -5.75m OD, where a thin shell band is recorded at the base of a medium to fine sand which extends to the present surface. In Greensmith and Tucker (1973, Fig.5.) the same dated peat is this time recorded in borehole 10 (White City), where it is overlain by a different lithostratigraphic sequence consisting of a clayey-silt which extends to -7.50m OD, where a sand extends to the present surface.

Furthermore, Greensmith and Tucker (1973) have recorded a date from borehole 10 (White City) of around 4350-4260 BP

> "derived from an assemblage of partly broken shells of Cardium edule and Nassarius at a depth of -7.50m OD",

which was collected from the base of a shell unit which rested with a sharp contact on clayey-silts. In Greensmith and Tucker (1976) this date (4350±210 BP) is described as being derived from shells recorded between -5.00 to -7.50m OD, whilst in Greensmith and Tucker (1980) this date is described as being sampled from a degraded chenier at -7.60m OD.

These altitudinal discrepancies are of importance, as the 4350±120 BP date is used by Greensmith and Tucker (1980) as evidence to support differential subsidence of 4.30m between the Blackwater Estuary and Foulness since this time (see above). If the original altitude of the deposit described in Greensmith and Tucker (1971a) is used (-5.75m OD), the altitudinal discrepancy between the Blackwater and Foulness dates is reduced to approximately 2.5m. Since the authors have stated that the peat lenses have accumulated at approximately the height of mean high water, and the maximum altitude of a chenier bank as being equivalent to that of a storm wave, the difference in the altitude of the two respective samples (and therefore the amount of differential subsidence) may not be as great as the authors propose.

In summary therefore, Greensmith and Tucker have concentrated their analyses of sea-level changes on the investigation of deep boreholes collected from the coastal plain of Essex. The absence of detailed litho- and biostratigraphic data mean that the ^{14}C dates presented by Greensmith and Tucker can only be used to establish a first approximation of the chronology of sea-level changes from the Essex coast. Of the ^{14}C dates used by Greensmith and Tucker, only three ^{14}C dates from peat samples are used in this study, and these are all classified as Group 4a dates.

In contrast to the research completed on the outer coastal plain, Wilkinson and Murphy have analysed the sediments recorded within the estuaries of the Crouch, Blackwater, as well as Mar Dyke. Their findings have been summarised by Wilkinson and Murphy (1986) and Wilkinson <u>et al</u> (1988), where an absolute chronology for sea-level change and human coastal occupation of the Essex coast has been presented. The lithostratigraphy of the area is briefly outlined below in order to provide a context for the ^{14}C dates presented in Table 2.3. below.

The general lithostratigraphy of the Crouch Estuary consists of a pre-Holocene "head" deposit, overlain by a "lower clay" which passes into a "lower peat". This head deposit forms part of the so-called "Lyonesse Surface", a Neolithic to Bronze Age occupation surface first described by Hazzledine Warren (1912) and Reader (1911). The lower peat is overlain by a thick "middle clay" and an "upper peat", which to the west of the

Estuary is overlain by an "upper clay".

The lithostratigraphy of the Blackwater appears to differ from that of the Crouch in that whilst in the latter two freshwater episodes are recognised (lower and upper peats), in the former only one estuarine episode (the lower peat) is recorded. Wilkinson and Murphy (1986) have suggested that the lower peat in the Crouch Estuary may have developed behind the coastal shell barriers (cheniers) proposed by Greensmith and Tucker (1980). In addition, Wilkinson et al (1988) have suggested that the absence of an upper peat in the Blackwater Estuary may be due to the lack of shell barriers during the period of peat formation in the Crouch Estuary.

This suggestion is not supported by lithostratigraphic data which indicate that the shell deposits on the coastal plain accumulated to a maximum altitude of -5.75m OD, some 3.75m below the altitude of the lower peats recorded in the Crouch Estuary.

Lithostratigraphic studies from face exposures in Mar Dyke have indicated three organic deposits, which intercalate with estuarine inorganic sediments to a depth of c. -6.00m OD (Wilkinson and Murphy 1986). These organic sediments have been correlated with the organic deposits Tilbury II, III and IV found in the Lower Thames Estuary (Devoy 1977). Although pollen and diatom data are presented for the sequence of sediments recorded, the ^{14}C dates have not been obtained from the transgressive and regressive contacts but from within the organic deposits themselves. These dated levels do not provide any information concerning the depth or quality of the watertable, and have therefore been classified as Group 4a dates.

The absence of a defined research methodology by Wilkinson and Murphy has resulted in the collection of a large ^{14}C database which provide only poor quality sea-level data.

Frequently depths have not been reduced to OD, and only limited supporting bio- and lithostratigraphic data have been presented. Where lithostratigraphic data have been presented, the use of an objective procedure for sediment description and presentation such as the Troels-Smith scheme (Troels-Smith 1955), is lacking. This is also a criticism of the work of Greensmith and Tucker, and severely restricts the opportunity for the objective comparison of lithostratigraphic data.

Therefore, these data provide only a first approximation of the evidence of sea-level changes, and of the thirty ^{14}C dates presented by Wilkinson and Murphy, all are classified as either Group 4a or Group 4b dates.

<u>**Table 2.3. List of ^{14}C sea-level index points from the Essex coast.**</u>

^{14}C dates from peats in the Blackwater Estuary (after Greensmith and Tucker 1976, 1980).

<u>Group 4a</u>

Site Material	Lab. Code	Date	Altitude
Foulness *Peat.*	BIRM242	7516±250	-18.30m OD
St Peter's Flats *Peat.*	SRR58	4959± 65	<u>c</u>. - 1.50m OD
Colne Point *Peat.*	SRR970	4277± 45	<u>c</u>. - 3.28m OD

^{14}C dates from the Blackwater and Crouch Estuaries and Mar Dyke. BL=Blackwater Estuary, CR=Crouch Estuary, MD=Mar Dyke. BS= depth below surface (after Wilkinson and Murphy 1985, 1986).

Group 4a.

Site Lab. Code Date Altitude
Material

CR8 HAR 5227 4100± 70 -1.65 to -2.03m OD
Wood sample from tree stool growing in lower peat.

CR12 HAR 5226 3760± 70 233 cm BS
Dark greyish brown amorphous peat with some monocotyledonous plant remains.

CR23 HAR 5737 3680± 70 Not known
Wood sample from lower peat.

CR2 HAR 5223 3660± 70 221 cm BS
Wood from the top of the lower peat.

CR29 HAR 5734 2950± 70 Not known
Brushwood resting on head/lower clay interface.

CR1 HAR 5222 2730± 60 Not known
Brushwood platform resting on gently dipping surface of head.

CR11 HAR 5221 2620± 70 Not known
Tree roots collected from remnants of lower peat.

CR4 HAR 5225 1610± 70 -1.33 to -1.44m OD
Straw coloured monocot peat with a minor clay component overlying the middle clay.

CR9 HAR 5224 1500± 70 +1.06 to +1.25m OD
Reed/monocot peat above a grey silty-clay containing drifted plant remains.

CR56 HAR 5732 180± 80 +1.18m OD
Dark grey brown fibrous peat.

BL8 HAR 6617 4690± 70 Not known
Charcoal from below lower peat.

BL8 HAR 6618 4000± 70 Not known
Charcoal from below lower peat.

BL3 HAR 6623 4190± 80 c. -1.12m OD
Stool of Quercus, apparently in situ on top of lower peat, possibly in head.

BL18 HAR 7056 4030± 80 Not known

In situ wood stool in lower peat.

BL7 HAR 6604 3990± 70 Not known

Charcoal of Quercus and Prunus collected from head/lower peat interface.

MD575 HAR 4523 4650± 90 c. -3.75m OD

Wood from lower part of peat.

MD575 HAR 4524 3580± 70 c. -2.70m OD

Wood from top of peat.

MD575 HAR 4525 1540± 80 c. -1.15m OD

Piece of wood from within reddish-brown fibrous peat.

MD575 HAR 4526 1470± 80 c. -0.25m OD

Humified peat with blocky structure.

Group 4b.

CR29 HAR 5735 3250± 90 Not known.

Sample of wooden platform set in head and contained within grey estuarine middle clay.

CR2 HAR 5733 3020± 90 Not known.

Sample of charcoal collected from a clay loam below the upper peat and within the middle clay.

CR56 BM 2339 2900± 70 +0.32m OD ±0.15m

Paddle, collected from within a soft and creamy clay below the upper peat.

CR22 HAR 5736 2800± 70 Not known.

One of five posts found above the lower peat in firm blue-grey estuarine clay, believed to be part of a wattle or hurdle fixture, which subsequently collapsed into intertidal muds and was inundated by later sediment deposition.

CR52 HAR 6581 1420± 70 Not known.

Brushwood located in depression of monocotyledonous upper peat. Appears to overly the upper peat.

CR45 HAR 5550 300± 90 Not known.

Post and twigs believed to be from prehistoric fish weir.

CR44 HAR 5549 270± 90 Not known.

Post and twigs believed to be from prehistoric fish weir.

BL18	HAR 7055	2730± 60	-2.86m below MHWM

Brushwood found in estuarine clay.

BL28	HAR 7051	2410± 80	Not known.

Hurdle in estuarine clay.

BL8	HAR 7054	2350± 70	Not known.

One of a group of twelve oak posts.

MD575	HAR 4522	5740± 80	c. -4.90m OD

Drifted wood in estuarine silt.

Finally, Lake and Shephard-Thorn (1987, Table 6) have presented a number of ^{14}C dates collected from the Essex coast, all of which are derived from shells deposited in contemporary beach ridge deposits, or from buried tidal flat sands at between -13.8m OD and +1.4m OD. Given the problems in determining either an indicative meaning, or a former altitudinal relationship between these deposits and a former sea-level, there are not included in the current analysis.

2.5. The Thames Estuary and North Kent coast.

2.5.1. Introduction.

Detailed analysis of the Holocene sediments recorded in the Thames Estuary began in the late nineteenth century with the work of Whitaker (1889) and Spurrell (1889). Both authors analysed large face exposures of Holocene sediments exposed during the excavation of the London Docks. The authors recorded one peat towards the western end of the Estuary and three peats east of Woolwich, but were unable to establish the detailed upstream/downstream relationship of these sediments (Devoy 1977).

The earliest ^{14}C dated sea-level index points from the Thames Estuary were presented by Churchill (1965) and Godwin et al (1965). These dates were based on material collected from boreholes near to the sections at Tilbury previously analysed by Whitaker (1889). Six radiocarbon dates were presented by Godwin et al (1975), and a further three by Welin et al (1974, 1975), which provided a general chronology for Holocene sedimentation. These dates were not collected from transgressive or regressive contacts, nor were they presented with any supporting litho- or biostratigraphic data. Therefore, these dates have been classified as Group 4a dates.

Lake et al (1975) have published a number of ^{14}C dates from the Thames Estuary, but once again no litho- or biostratigraphic data has been presented. As these ^{14}C dates are not from transgressive or regressive contacts, they are also classified as Group 4a dates.

In a summary paper of the evidence for subsidence in southern Britain, Akeroyd (1972) noted the absence of any interdisciplinary studies of the Thames Estuary deposits comparable with investigations completed in East Anglia, Somerset and the Netherlands. Devoy (1977, 1979 and 1982) was the first to present detailed litho-, bio-, and chronostratigraphic data in order to determine the evidence for past vegetation and sea-level changes in the Lower Thames Estuary. This study remains a benchmark for the study of Holocene sea-level and vegetation changes in the Thames Estuary and Southeast England, and is discussed in more detail below.

Devoy (1977) has presented palaeoenvironmental data collected from seven sites within the Thames Estuary - Crossness, the Dartford Tunnel, Stone Marsh, Littlebrook, Broadness Marsh, Tilbury and the Isle of Grain. Devoy (1977) identified five organic horizons (Tilbury I-V), intercalated between inorganic sediments (Thames I-V), and adopted Tilbury as the "type site" for the Lower Thames Estuary.

Serious data anomalies exist within the data presented by Devoy, and a coherent pattern of sedimentation is still to be established for this area. The following two Sections discuss the altitudinal and compositional variability, and then the chronological variability recorded in the data presented by Devoy (1977).

2.5.2. Altitudinal and compositional variability recorded in the Lower Thames Estuary.

One of the most striking aspects of the lithostratigraphic data presented by Devoy (1977) is the large altitudinal range for the main organic or inorganic deposits identified. This is illustrated in Table 2.4. below.

Table 2.4. Altitudinal range of the organic deposits in the Thames Estuary (after Devoy 1977 :148, Table 4.).

Type site code	Height taken to top of each level
TV	+ 0.40 to - 0.90m OD
TIV	- 0.80 to - 1.80m OD
TIII	- 1.90 to - 5.20m OD
TII	- 6.80 to -10.07m OD
TI	-13.23 to -25.53m OD (Isle of Grain)

This large altitudinal range for each deposit makes correlation of specific horizons difficult on altitudinal data alone. In addition, significant changes in the lithostratigraphy were identified in a west/east manner, "increasing the difficulty of a purely visual and altimetric correlation" (Devoy 1977). For example, TIII changes in composition from a uniform detrital wood peat at Crossness to a monocot Phragmites peat with a high gyttja element at Broadness or Tilbury. Devoy has suggested that this compositional and altitudinal variability may be due to a number of local factors such as topography, erosion and deposition, consolidation and compaction, as well as changes in sea-level.

Some of this altitudinal and lithostratigraphic variability may be a reflection of the fact that most of the stratigraphic data presented were collected from commercial drilling logs, a problem recognised by Spurrell (1889). Devoy (1979) recognised this and suggested that this kind of sampling error may explain the impersistent nature of TIV and TV, for example.

In contrast to this lithostratigraphic variability, Devoy has argued that biostratigraphic similarities have enabled "clear lithostratigraphic correlation on the basis of pollen assemblages" (Devoy 1977 :150). However, the effect of local factors, and in particular the variable influence of the River Thames, complicate litho- and biostratigraphic interpretation, so that clear correlation is not always possible.

For example, evidence for river inwashing was recorded throughout the sedimentary record, and commonly manifests itself as thin inorganic horizons intercalated within the main organic deposit, such as those recorded at Stone Marsh (Devoy 1977 :70). In addition, river inwashing was often recorded in the pollen data (eg Devoy 1977 :86, 106), and pollen analysis from the inorganic deposits frequently demonstrated a strong freshwater influence with only the local presence of saltmarsh taxa. This has important implications when attempting to determine the indicative meaning of each dated sample to a former sea-level, especially when diatom data are only available for the Tilbury "type site".

At Broadness Marsh, for example, the relationship between the transgressive contact recorded at -8.57m OD and dated to 6620±90 BP, and former MHWS is uncertain, as the pollen data suggest the replacement of a fresh water peat by a largely freshwater organic clay. At this site Devoy (1977 :106) has noted that

"The expansion of aquatic pollen taxa notably Typha angustifolia/ Sparganium and Typha latifolia during these transitional phases, supports the interpretation of a shallow, slow-moving water environment...(and)...the development of local saltmarsh communities".

This illustrates the difficulties in interpreting the regressive and transgressive contacts in a complex riverine/estuarine palaeoenvironment such as the Thames Estuary.

2.5.3. Temporal variability recorded in the Lower Thames Estuary.

With respect to the ^{14}C dates from the Lower Thames Estuary, Devoy (1977 :150) has noted that

"the radiocarbon dating of transgression and regression contacts of the biogenic levels can be confusing",

and suggested that anomalies may be the result of errors in fieldwork, errors in the position of samples for ^{14}C analysis, or in the dating process itself. In addition, Devoy (1977) proposed that the age anomalies may be explained as a function of local factors and the variable site-reaction to the form of sea-level rise.

An absolute chronology for the formation of distinct lithostratigraphic horizons remains incomplete. For example, Table 2.5. illustrates the transgressive and regressive ^{14}C dates (Group 2 and 3) for the main organic deposit recorded (TIII) in the Thames Estuary.

Table 2.5. ^{14}C dates of the transgressive and regressive contacts of TIII.

Site	Age of regressive contact ^{14}C BP	Age of transgressive contact ^{14}C BP
Crossness	Basal date (Bore 3)	4195±100
Stonemarsh	4930±110	Eroded contact
Broadness Marsh	5410±85	Not dated
Tilbury	6200±90	3850±80

Only at Tilbury (The World's End) is the full duration of organic sedimentation associated with TIII established at a single site. Indeed, Devoy (1977 :149) selected Tilbury as the "type site" of the Lower Thames Estuary, stating that the site was the "most fully developed and representative of the area". However, although Tilbury contains the most number of transgressive and regressive contacts, and has the most complete chronological record, Tilbury is anomalous with respect to the other sites on the basis of chronological, and lithostratigraphic data.

Table 2.6. presents the age of the transgressive and regressive contacts for the organic deposit TI-V in a West/East manner. Where the ^{14}C dates presented by Devoy (1977) are not from transgressive or regressive contacts, or where these contacts are eroded, no data are presented.

Table 2.6. Inter-site variation in the transgressive and regressive contacts in the Lower Thames Estuary.

C=Crossness, S=Stonemarsh, BM=Broadness Marsh, T=Tilbury. TI-TV refer to Tilbury I-V. t/c=transgressive contact, r/c=regressive contact. * denotes basal peat (Group 1).

West				East
	C	S	BM	T
TI				
r/c	No data......................			8170±110*
t/c	No data......................			7830±110
TII				
r/c	No data	6970± 90*	6882± 90*	7050±100
t/c	No data	6680±100	6620± 90	6575± 90
TIII				
r/c	5640± 75*	4930±110	5410± 80	6200± 90
t/c	4195± 70			3850± 80
TIV				
r/c	No data.........		2836± 85	3240± 75
t/c	No data.........			3020± 65
TV				
r/c	No data..................................			
t/c	No data..................................			

In all cases, the regressive contacts are recorded earlier, and the transgressive contacts later at Tilbury compared with the upstream sites. Moreover, if one considers the duration and thickness of each of these organic deposits (Table 2.7.), Tilbury is again anomalous in comparison with the other sites. Data limitations restrict this comparison to an analysis of TII and TIII.

Table 2.7. Thickness of organic deposits TII-TIII, and duration of sediment accumulation.

Duration of sediment accumulation ^{14}C years (ignoring standard errors) in italics, thickness in cm. Other abbreviations as for Table 2.6.

West				**East**
	C	**S**	**BM**	**T**
TII		*290*	*262*	*475*
	No data	26	22	32
TIII	*1444*	No data	No data	*2350*
	202	164	170	123

Once again Tilbury appears anomalous when compared with the other sites. In particular, the duration of TIII at Tilbury is double that recorded at Crossness, whilst the duration of TII compared with that recorded at Stonemarsh and Broadness Marsh is also notably longer. In addition, the thickness of TIII recorded at Tilbury is markedly less than that recorded at the other sites.

Devoy (1977 :150) has stated that the age anomalies observed at Tilbury, and in particular those associated with TIII, may be explained as a result of local factors and the differential response of the sedimentary system to sea-level rise.

> "Thus at Tilbury peat growth in TIII would have initially begun upon a rise in the freshwater table following a period of regression, but consequent upon a rising sea-level, unless the site is topographically peculiar, for example a hollow (Jelgersma (1961, 1966)). During the phase of regression local erosion and re-deposition of the sediments may have taken place throughout the area with greater riverine activity, (Postma 1967). Sites further upstream at Broadness and Stone, for

> example, lying at greater relative altitudes and above the immediate freshwater table, would probably not have begun peat growth until a later date."

The deposit below TIII at Tilbury is described as a light blue/grey cohesive and plastic very sticky clayey-silt with an irregular upper profile. The irregular profile of this upper contact (Lim. sup. 3) supports the suggestion that a period of erosion preceded the formation of TIII. The absence of a distinct transitional zone between the silty-clay and TIII, which is recorded at Broadness Marsh, Dartford Tunnel and Stone Marsh (and characteristic of regressive contacts in general), also suggests very rapid peat growth over the eroded surface of Thames II. However, this still fails to explain the early date for the regressive contact of TIII at Tilbury (6200±90 BP), which is between c. 1270 ^{14}C years and 560 ^{14}C years older than the regressive contacts for the same deposit recorded at Stonemarsh and Crossness.

The younger transgressive contact of TIII recorded at Tilbury is also difficult to explain, and Devoy (1977 :151) has stated that

> "what is apparent here rather than an anomaly in submergence times, is the beginning of a much larger scale downwarping of the sediments as the outer estuary is approached, with its increased volume of sediment deposition."

However, if Tilbury had undergone differential subsidence relative to the other sites within the Estuary (making it anomalous as a type site), then the date of submergence would be expected to be earlier relative to the other sites. The opposite is the case.

In conclusion, no single explanation for the anomalous altitudinal and age data at Tilbury or elsewhere within the

Thames Estuary is apparent. The variability appears to reflect the complex interaction of local factors, and in particular the variable fluvial influence (which in itself may not reflect sea-level changes). The large altitudinal range of the transgressive and regressive contacts suggest that altitudinal data collected from this type of sedimentary palaeoenvironment should be used with care. Furthermore, the adoption of a single "type site" such as Tilbury, where the altitude, composition and age of the sediments is inconsistent with other sites in the Estuary is questionable.

2.5.4. The North Kent coast.

Sea-level investigations from the North Kent coast are limited to that of Evans (1953) in the Medway Estuary, and the more recent work of Breslin (1990) from the Graveney Marshes. In excavations at Chatham dockyard, Evans recorded three distinct organic deposits. The deepest was recorded overlying gravel at -10.51 to -10.61m OD. The silts overlying this basal deposit are believed to have begun to form about 6000 years ago. A second organic deposit was recorded between -6.10 and -5.49m OD, and a final upper peat was recorded at 0.00m to +0.30m OD. No ^{14}C dates have been collected from these deposits.

More recently, Breslin (1990) has presented litho- and biostratigraphic data from the inner Graveney Marshes to the east of Faversham. Two organic deposits were recorded in the area, with a lower dark brown crumbly peat recorded between -7.40 and -6.40m OD. Overlying this was recorded a thick clay which extended between -6.82m OD and +1.20m OD, on top of which was recorded the upper organic deposit. This upper organic deposit varied in altitude between +0.80m to +3.6m OD, and was overlain by a light orange/brown silty-clay which extended to the present surface. Very limited pollen analysis of the lower organic deposit has illustrated high frequencies of Gramineae and Cyperaceae pollen, which suggests that the deposit accumulated under reedswamp conditions.

Table 2.8. List of ^{14}C dated sea-level index points from the Thames Estuary.

^{14}C dates from the Thames Estuary (after Godwin and Switsur (1965) and Welin et al (1974, 1975)).

Group 4a.

Site / Material	Code	^{14}C Date	Altitude (m OD)
Tilbury 8185	Q790	6940±120	-10.67
Phragmites peat.		7120±120	
Tilbury 8185	Q791	5790±120	- 8.23
"Lens" of Phragmites peat and twigs.			
Tilbury 8180	Q811	5530±100	- 7.92
Sandy wood and sedge peat containing charcoal.			
Tilbury 8180	Q810	4920±120	- 5.49
Sedge peat.			
Tilbury 8182	Q792	3940±110	- 4.88
Phragmites peat.		3916±110	
West Thurrock	IGS 152	4975±120	- 3.40
Peaty clay with wood.			
West Thurrock	IGS 151	3795±115	- 1.35
Peaty clay with wood.			
Tilbury 8182	Q793	2467±110	- 2.59
Phragmites peat.		2390±110	

<u>**^{14}C dates from the Lower Thames Estuary (after Devoy 1977).**</u>

Site / Material	Code	^{14}C Date	Altitude (m OD)
Group 1			
Isle of Grain	Q1286	8510±110	-26.30
Laminated clayey-<u>Limus</u> <u>detrituosus</u>.			
Isle of Grain	IGS 146	8250±100	-26.36
Gyttja, 3m thick.			
Tilbury	Q1426	8170±110	-13.37
Laminated detrital woody peat with some <u>Limus</u> <u>detrituosus</u>.			
Stone Marsh	Q1281	6970±90	- 8.82
Crumbly wood peat with <u>Alnus</u> branches.			
Broadness Marsh	Q1283	6882±90	- 8.75
Compact wood peat.			
Crossness	Q1282	5640±75	- 3.65
Yellow/brown woody clay with monocots.			
Group 2			
Tilbury	Q1427	7830±100	-13.23
Laminated detrital woody peat with some <u>Limus</u> <u>detrituosus</u>.			
Stone Marsh	Q1335	6680±100	- 8.62
Crumbly wood peat with <u>Alnus</u> branches.			
Broadness Marsh	Q1339	6620±90	- 8.57
Compact wood peat.			
Tilbury	Q1429	6575±90	-10.10
Felted <u>turfa</u> with some <u>Phragmites</u> and <u>Alnus</u> roots.			
Crossness	Q1333	4195±70	- 1.96
Wood peat with monocots and <u>Phragmites</u> and prominent clay fraction.			
Tilbury	Q1431	3850±80	- 5.21
Fibrous <u>turfa</u> with some <u>Phragmites</u>.			
Tilbury	Q1433	3020±65	- 1.82
Felted <u>turfa</u> with monocots and <u>Phragmites</u>.			

Stone Marsh Q1388 2850±65 - 0.89

Compact, well-humified herbaceous peat with clay.

Group 3

Tilbury Q1428 7050±100 -10.38

Felted turfa with some Phragmites and Alnus roots.

Tilbury Q1430 6200±90 - 6.42

Fibrous turfa with some Phragmites.

Broadness Marsh Q1342 5410±80 - 4.81

Organic-rich silt/clay with bedded and in situ Phragmites.

Stonemarsh Q1336 4930±110 - 2.99

Clay/silt with high herbaceous component.

Tilbury Q1432 3240±75 - 2.00

Felted turfa with monocots and Phragmites.

Broadness Marsh Q1340 2836±85 - 2.73

Clay/silt with in situ Phragmites.

Group 4a

Dartford Tunnel Q1334 7140±110 -10.64

Turfa with some Detrituosus lignosa.

Littlebrook IGS 74 6820±55 - 8.00

Wood peat.

Littlebrook IGS 72 5464±60 - 5.15

Wood peat.

Littlebrook IGS 73 5372±60 - 4.60

Wood peat.

Broadness Marsh Q1341 5220±65 - 4.66

Monocot peat with in situ Phragmites and Cyperaceae.

Littlebrook IGS 71 4549±55 - 3.95

Wood peat.

Littlebrook IGS 76 4220±50 - 1.88

Fibrous crumbly peat, finely divided with wood and bark found.

Littlebrook IGS 70 2651±50 - 1.70

Fibrous monocot peat with Phragmites and Cyperaceae.

Littlebrook	IGS 75	2610±50	- 1.88

Fibrous monocot peat.

2.6. The West Kent and East Sussex coasts.

This section describes the sea-level index points from Dungeness, Romney Marsh, Walland Marsh and the associated valleys, as well as from the Combe Haven Valley and the Levels in East Sussex.

2.6.1. Sea-level index points from Dungeness, Romney Marsh and Walland Marsh.

The high energy sub-surface and surface shingle deposits of the Dungeness foreland and adjacent marshland, and the fine-grained inorganic and organic sediments which form Romney Marsh and Walland Marsh, provide a complex environment from which to collect sea-level data. In order to interpret ^{14}C sea-level index points from this area it is necessary to appreciate the complex interaction of these two sedimentary systems through time.

The author was first introduced to the sediments and morphology of the Dungeness foreland in 1988 during a geomorphological assessment of Denge Beach (Long and Fox 1988). This work involved mapping the surface and sub-surface form of the shingle beach ridges, adding detail to earlier comprehensive surveys completed by Lewis (1932) and Lewis and Balchin (1940). Dowker (1897) had suggested that altitudinal changes in the shingle ridges of Dungeness may reflect changes in former sea-level, and Lewis (1932) and Lewis and Balchin (1940) substantiated this initial suggestion with their detailed levelling survey. Systematic changes in the altitude of the beach ridges identified from their levelling led Lewis and Balchin (1940) to conclude that these changes reflected changes in relative sea-level from the Romano-Bronze age period to the Middle Ages.

Long and Fox (1988) identified five populations of ridges within the Denge Beach area, defined on the basis of ridge altitude, amplitude and orientation. However, concern over the large number of factors responsible for beach ridge formation (discussed by Lewis and Balchin 1940), and the problems in establishing an absolute chronology for beach ridge construction, cast doubt on the use of these data for the direct reconstruction of changes in past sea-level.

Understanding the general development of the shingle foreland and its relationship to the fine-grained sediments of the protected marsh areas is probably of greater value, albeit complementary, than any direct evidence from the analysis of altitudinal changes of the shingle ridges themselves.

Various models have been proposed for the development of the Dungeness foreland and associated marsh sediments. Gulliver (1897) suggested that Dungeness accumulated as a migrating cuspate foreland. Since then Lewis (1932), Lewis and Balchin (1940), Green (1968), Eddison (1983), Lake and Shephard-Thorn (1987) and Greensmith and Gutmanis (1990) have all proposed different models for the development of the foreland.

Eddison (1983) suggested that the early development of the area saw a combination of the Midley Sands (described by Green 1968) and shingle forming a low-level barrier beach, some 800m in width and with a maximum altitude of +1.5m OD extending in a southwest/northeast direction between Fairlight and Hythe. It was suggested that this barrier beach formed approximately 4500 BP, and that behind this and subsequent shingle beach ridges a sequence of intercalated fine grained inorganic and organic sediments accumulated.

Lake and Shephard-Thorn (1987) supported the general nature of this hypothesis, and suggested that the marsh stratigraphic sequence described by Green (1968) of blue clay, peat and young alluvium accumulated behind this protective feature.

More recently, Greensmith and Gutmanis (1990) have used new borehole data from the Dungeness power station to propose a further model of development. They agreed with previous models which suggested early barrier formation by the Midley Sands, but from about 3400 BP have suggested that a prograding subtidal sedimentary apron formed to the east of Lydd. Greensmith and Gutmanis (1990) proposed that periodic fluxes of fluvial sediments were deposited on this apron during storm events, and that the most recent shingle deposits have accumulated on the surface of this apron. Five shell samples collected from the base of boreholes near the Dungeness power station between -32.1m and -34.2m OD have been ^{14}C dated to between 3140±80 and 1370±80 BP, indicating that more than 30m of sediments have accumulated in approximately the last 1400 and possibly 750 years (Greensmith and Gutmanis 1990).

Rapid rates of sedimentation have also been suggested from other depositional environments in the area during the late Holocene. For example, lithostratigraphic and palaeobotanical data, as well as archaeological and preliminary luminescence dates from Broomhill (Tooley 1990), indicate recent sedimentation rates of c. 1 to 2mm a^{-1}. Tooley (1990) has stated

> "that considerable quantities of fine-grained sediment of marine origin were fed into the shingle valleys, overlapping and concealing the ridge crests from the twelfth century onwards".

To the east of Lydd, in the area described by Greensmith and Gutmanis (1990) as being the sub-tidal apron of silts and sands, other data supporting rapid rates of sedimentation are forthcoming from the litho- and biostratigraphic analyses of the inorganic sediments which overlie the shingle sub-crop.

Both Long and Fox (1988) and Plater (1990) failed to locate any in situ organic material during their lithostratigraphic investigations of the fine-grained deposits of Denge Marsh. The sediments recorded were characteristically laminated silts and fine sands, and both granulometric and diatom analyses have suggested that the sediments accumulated under tidal flat conditions with a strong marine influence (Plater 1990).

No simple model can adequately explain the evolution of Dungeness and Romney Marsh, although general agreement, however speculative, exists concerning the existence of an early low altitude barrier of Midley Sand and gravel, behind which quiet-water sedimentation occurred. However, recent research in the Broomhill area (Tooley 1990) now questions the origin of the Midley Sand. Stratigraphic and pollen analyses in the area of Midley (Tooley pers. comm.) have identified a stratified sequence with two deposits of Midley Sand intercalated between organic and inorganic sediments. In addition, at Broomhill the Midley Sand is recorded overlying gravel between two gravel ridges (Tooley 1990, Fig.1.11. Bore 9), suggesting that the deposit post-dates the deposition of shingle in this area.

Although Green (1968) has defined the granulometric character of this deposit, it is possible that mis-interpretation of this deposit has occurred in the past. Further analyses of the nature and spatial extent of this deposit are required before its geomorphic significance can be established.

The discussion above has illustrated the complexity of the Dungeness foreland, and its relatively poorly understood evolutionary history. This has formed a necessary context for the discussion of the limited sea-level data collected to date from the marsh sediments themselves.

Analyses of the Holocene sediments recorded at Broomhill (Tooley and Switsur 1988) have illustrated the importance of the gravel beach complex in influencing the pattern of subsequent fine-grained inorganic or organic sedimentation.

At Broomhill-1, Tishy's Sewer, high energy shingle deposits with a ridge and swale topography are buried beneath fine-grained quiet-water organic and inorganic sediments. Tooley and Switsur (1988) have suggested that the onset of organic accumulation at this site may have reflected either continuing ridge construction to the east of the site, or a regressive overlap. Establishing the time lapse between shingle deposition and the onset of organic sedimentation is not possible, as the relationship between shingle deposition and organic accumulation is not known.

Two ^{14}C dates from Broomhill Church from a different lithostratigraphic context (a tidal flat environment with no shingle) are significantly younger than the two dates from Broomhill-1, Tishy's Sewer. Tooley (pers. comm.) believes that the organic sediments from Broomhill Church may have accumulated following a breaching of the coastal shingle at Jury's Gut Sewer, which allowed quiet-water sedimentation to occur at this location, thereby explaining the age anomalies. Recent ^{14}C dates from Broomhill Level confirm the earlier chronology, giving strength to the argument that the sediments recorded at Broomhill Church are a manifest breach.

Everett (1984) used pollen, diatom and rhizopod analyses in an investigation of the organic and inorganic deposits recorded at Old Cheyne Court near Lydd. Everett (1984) described a blue grey silty-clay underlying an extensive organic deposit similar to the main marsh peat described by Green (1968). One sample of this clay analysed for its diatom content was found to contain a marine or marine/brackish assemblage, with high frequencies of <u>Rhaphoneis</u> <u>surirella</u> and <u>Paralia</u> <u>sulcata</u>. The overlying organic deposit was recorded between <u>c</u>. 0.00 and +1.00m OD and could be divided into a lower detrital wood peat and a thin upper herbaceous peat. Frequencies of <u>Betula</u>, <u>Corylus</u>, <u>Alnus</u>, and Filicales were high in the lower part of the peat, whilst in the upper part of the peat <u>Salix</u>, <u>Corylus</u>, <u>Calluna</u>, and <u>Sphagnum</u> pollen were most commonly recorded.

Overlying this organic deposit was recorded a silty-clay which became orange-brown towards the surface. No ^{14}C dates were forthcoming from this study, so an absolute chronology for peat formation is unavailable.

Cairns (1988) has presented litho- and biostratigraphic data collected from Shirley Moor. Here a similar lithostratigraphic sequence to that identified at Cheyne Court by Everett (1984) was encountered. Unconsolidated sediments were observed to a depth of -4.00m OD overlying a gravel or sandstone base. Overlying this base was a clay which in turn was overlain by peat, silty-sand and sandy-silt. The lower clay illustrated a fining-upwards sequence, and passed into the peat at between c. -2.50m and -0.20m OD. The altitude of the transgressive contact varied between c. -1.20m and +0.30m OD. Frequencies of Alnus, Quercus, Corylus, and Salix pollen were found to dominate the lower part of the peat, and towards the transgressive contact an increase in the frequencies of Gramineae, Cyperaceae and a number of saltmarsh pollen taxa were recorded. The overlying inorganic sediments were found to contain high frequencies of Gramineae and Cyperaceae pollen. Again, no ^{14}C dates were forthcoming from this study and therefore an absolute chronology for sedimentation at this site is not known.

Tooley and Switsur (1988) and Tear (1990) have presented litho-, bio- and chronostratigraphic data collected from Horsemarsh Sewer. Unconsolidated Holocene sediments were recorded here by Tooley and Switsur (1988) to a depth of c. -4.30m OD, and a maximum thickness of 5.70m. It has been suggested that three transgressive and three regressive overlaps are recorded at the site, although only two overlaps have been dated.

Overlying the basal silty-sand with some grit and gravel in HM-4 was recorded a fining-upwards sequence and an increase in organic content (Tooley and Switsur 1988, Fig.3.3.). A transgressive contact was recorded at -3.42m OD and dated to 5500±70 BP. The diatom content of the overlying clayey-silt indicated high frequencies of Diploneis interrupta, which is characteristic of supratidal conditions (Vos and der Wolf 1988) or brackish water lagoons (Van der Werff and Huls 1958-1974). Overlying this inorganic deposit was the main peat recorded in this valley and elsewhere in the Romney Marsh area (Section 2.4.2.). The regressive contact was recorded at -3.33m OD and dated to 5150±70 BP. This organic deposit was recorded between c. -3.30m to +0.20m OD, and was overlain by silty-clays with iron-staining.

Pollen analysis from the lower part of the sequence described above illustrated high frequencies of Quercus, Tilia, Alnus, Corylus, and Gramineae pollen. Saltmarsh indicators such as Chenopodiaceae and Glaux pollen were associated with the transgressive and regressive contacts described above. Both an elm (Ulmus) and a lime (Tilia) decline were recorded within the main organic deposit, and these were used to confirm the ^{14}C dates.

In conclusion, although considerable debate concerns the evolution of the Dungeness foreland, there remains a profound lack of detailed and systematic analyses of the Holocene fine-grained inorganic and organic sediments. To date no deep coring has been carried out in large areas of the marsh, and only a very limited database of ^{14}C dates exists. It is probable that through the analysis of the marsh sediments many of the outstanding questions concerning the development of the Marsh and shingle foreland may be resolved.

2.6.2. Sea-level index points from the valleys of the Pannel, Brede, Tillingham and Rother.

Woodcock (1984), Marlow (1984), and Waller (1987) have presented extensive litho-, bio-, and chronostratigraphic data collected from the Pannel and Brede Valleys, as well as from

Pett Level and Walland Marsh. These and other data from the valleys of the Rother and Tilingham have been summarised by Waller et al (1988).

Waller (1987) has presented a ^{14}C dated pollen diagram of the valley-fill sediments from borehole 19 at Pannel Bridge in the Pannel Valley, which provides the most complete history of Holocene vegetation and watertable movements in the area. Here, local conditions have meant that organic sedimentation has persisted for much of the Holocene.

The deepest deposit recorded here was an organic-rich clayey-silt, which accumulated between 9960±110 and 9380±100 BP between -8.42m and -7.61m OD. This was overlain by a thick sequence of organic sediments which were characteristically detrital woody peats with macrofossil remains of Alnus. Pollen analysis of this deposit illustrated that between c. 9300 and 7000±90 BP a slow accumulation of organic sediments occurred, independent of changes in sea-level.

The only early-Holocene ^{14}C date from the area which is related to sea-level changes was collected by Welin et al (1974) from the base of a trial bore-hole at Tilling Green near Rye. Here a sample of laminated silty-peat was recorded at -22.50m OD and dated to 9565±120 BP. Because of the absence of biostratigraphic data this date has been classified as a Group 4a date.

The proximity of estuarine conditions to the site at Pannel Bridge was first recognised at c. 7000 BP where a rise in fen followed by reedswamp taxa occurred. Waller (1987 :276) has suggested that

> "With the arrival of the latter at the site immediately prior to 7000 BP this basin appears to

have come under the direct influence of regional base levels for the first time".

Therefore, this date is classified as a Group 5a date.

Immediately following 7000 BP there was a local decline in the marine influence, but between c. 6500 and c. 6000 BP (-5.62m to -4.98m OD) estuarine conditions approached close to the site once more. Reedswamp communities were re-established and the proximity of open coastal communities suggested by low frequencies of saltmarsh taxa. This suggestion is supported by the presence of intercalated blue clay layers which were recorded between -5.57m and -4.32m OD slightly downstream.

Whilst peat formation dominated the early- and mid-Holocene at Pannel Bridge, at many other sites in the area the deepest deposits recorded were inorganic silts and clays. The deepest estuarine deposit was commonly a widespread bluish grey sand, which passed into a bluish grey clay deposit which thickened in a down-valley direction. This bluish grey clay was similar to that recorded by Green (1968) on the adjacent marshland, and on the basis of its foraminiferal content is believed to be of marine/estuarine origin (Waller 1987).

This deposit was commonly overlain by the most lithostratigraphically continuous phase of organic sedimentation recorded in the area. A similar regressive overlap has been recorded in the valleys of the Brede, Tillingham and Rother Valleys, as well as in Horsemarsh Sewer and the adjacent area of Walland Marsh where it can be correlated with Green's (1968) main marshland peat. Waller (1987) has noted that only on Pett Level is this deposit subdivided, where two laterally persistent layers of hypersaline clay have been recorded (Marlow 1984).

This regressive overlap has been dated at Brede Bridge to 5970±150 BP, where pollen data suggested a progressive change from a saltmarsh to alder-carr environment. This date cannot be definitively correlated with other dates in the area, due to the absence of suitably dated material. Moreover, Waller (1987) has recognised that the date of peat initiation was probably diachronous, with the regressive contact generally recorded at a lower altitude (and therefore possibly at an older date) in up-valley locations.

During this period of organic sedimentation, Waller (1987) has suggested that the dominant trend of sea-level was upwards, but noted that other factors such as changes in sediment supply, changes in the rate of sea-level rise, and the presence of coastal barriers may also have affected the rate of peat growth. At Brede Bridge organic sedimentation slowed following the Tilia decline at c. 3700 BP, and this has been interpreted as evidence for

> "an alteration in the rate of base-level change and that possibly a fall in relative sea-level occurred" (Waller 1987 :287).

Meanwhile, the continuing fast rate of peat growth at Pannel Bridge has been attributed to local factors such as valley constriction and the presence of springs.

This thick organic deposit was recorded by Waller (1987) as passing into an estuarine clay, and this transgressive contact has been dated at Old Place to 1830±80 BP (Waller 1987). Although this is the only date for this transgressive overlap, it provides a maximum date for the change in sedimentation. Not only was the contact eroded, but the pollen data suggested "no clear indication of the approach of estuarine conditions" (Waller 1987 :139). Therefore, this date is classified as a Group 4a date. Foraminiferal analysis of the overlying inorganic sediments have suggested an intertidal saltmarsh and then sand/mudflat depositional environment. Laminations and a limited species diversity have been interpreted as ecological stress, high and variable sedimentation rates with fluctuating salinity conditions. Other evidence for rapid rates of sedimentation during this period have been discussed above (2.6.1.).

Waller (1987) has observed that similar "post-peat" inorganic deposits are recorded in the Brede valley, on Pett Level, as well as in the Lower Rother Valley and on Walland Marsh. The spatial extent of this deposit is restricted to the western side of Walland Marsh, and the deposit was seen to thin in an easterly direction as well as in an up-valley direction. Green (1968) has suggested that these sediments were deposited because of a gap in the shingle barrier at Rye, allowing a marine influence to penetrate inland. Waller (1987) has stated that the widespread erosion of the transgressive contact in the lower Brede Valley, and the absence of any indication of approaching estuarine conditions in the pollen record from Old Place, suggest that this switch in sedimentation occurred suddenly as a result of barrier breaching near Rye.

A chronology for sea-level changes in the area is incomplete, and at present is dependent on the incorporation of a wide range of sea-level index points from diverse palaeoenvironments. The most recent attempt to establish a chronology for sea-level changes in the area is by Tooley and Switsur (1988, Fig.3.15.). Here both transgressive and regressive contacts, supported by lithostratigraphic and landform evidence, were combined to establish a provisional partial chronology of tendencies of sea-level movements in the area. The data used in this study are listed in Tooley and Switsur (1988, Table 3.1.), and of these one ^{14}C date defined by Tooley and Switsur (1988) as a transgressive overlap date (Lab code NPL.25, Callow et al 1964) is not used in further analyses because of the lack of lithostratigraphic control and absence of supporting palaeobotanical data. These data are listed in Table 2.9. below.

Table 2.9. List of ^{14}C dated sea-level index points from Romney Marsh, Walland Marsh and adjacent river valleys of the area.

References : 1= Waller (1987), 2= Tooley and Switsur (1988), 3= Welin et al (1971), 4= Welin et al (1974), 5= Callow et al (1964), 6= Welin et al (1972).

Site / Altitude	Source / Material	Code	^{14}C Date
Group 2			
Horsemarsh Sewer	2	Q.2647	5500±70
-3.42m OD	*Silty Limus detritus.*		
Tishy's Sewer	2	Q.2652	3160±60
c. +0.90m OD	*Silty Limus detritus.*		
Tishy's Sewer	2	Q.2650	3060±60
+1.40m OD	*Silty Limus detritus.*		
Broomhill Church	7	Q.2753	2160±50
+1.35 to +1.33m OD	*Black sandy silty-limus with some detrital herbaceous material.*		
Group 3			
Brede Bridge	1	SRR.2646	5970±150
-5.35m OD	*Clayey peat.*		
Horsemarsh Sewer	2	Q.2648	5150±70
-3.33m OD	*Silty Limus detrituosus.*		
Tishey's Sewer	2	Q.2649	3520±60
+1.20m OD	*Silty Limus detrituosus.*		
Tishey's Sewer	2	Q.2651	3410±60
c. +0.80m OD	*Limus detrituosus with flints.*		
Broomhill Church	7	Q.2752	2600±50
+1.16 to +1.14m OD	*Laminated silty limus.*		

<u>**Group 4a**</u>

Tilling Green, Rye	4	IGS/C14/116(St.3835)	9565±120
-22.5m OD	*Laminated silty-peat.*		
Pett Level	6	IGS/C14/56(St.3405)	5300±100
c. 0m OD	*Peat from beneath tree stump.*		
Pett Level	6	IGS/C14/55(St.3400)	5205±105
c. 0m OD	*Wood from in situ tree stump.*		
Blackwall Bridge	3	IGS/C14/14(St.3069)	4845±100
-5.89 to -5.97m BS	*Peat from within peat bed -3.66 to -6.70m BS.*		
Pannel Bridge, Pett	1	SRR.2889	5540±80
-4.22m OD	*Peat.*		
Pannel Bridge, Pett	1	SRR.2888	5040±180
-3.42	*Peat (Ulmus decline).*		
Blackwall Bridge	3	IGS/14c/13(St.3068)	3560±100
-4.27m BS	*Peat from within peat bed -3.66 to -6.70m BS.*		
Pannel Bridge, Pett	1	SRR.2887	3700±70
-0.76m OD	*Peat (Tilia decline).*		
Brede Bridge, Brede	1	SRR.2645	3690±70
+0.40m OD	*Peat (Tilia decline).*		
Old Romney, Court Lodge	5	NPL.24	3340±92
c. +3.00m OD	*Tree-trunk in peat.*		
Appledore Dowels	1	NPL.23	3020±94
c. +3m OD	*Wood in peat.*		
Pannel Bridge, Pett	1	SRR.2886	2980±80
+0.38m OD	*Peat.*		
Scotney Farm, Lydd	5	NPL.92	2740±400
c. +3m OD	*Roots.*		
Scotney Farm, Lydd	5	NPL.91	2050±90
Not known	*From 2" thick peat layer overlying clay with roots.*		
Old Place, Icklesham	1	NPL.25	1830±120
-1.16m OD	*Peat.*		

Group 5a

Pannel Bridge, Pett 1 SRR.2890 7000±90
-6.14m OD *Peat, pollen indicate rise in groundwater table.*

2.6.3. Sea-level index points from the Combe Haven Valley, Pevensey Levels, Lottbridge Drove and Langney Point.

2.6.3.1. Sea-level index points from the Combe Haven Valley.

Litho-, bio- and chronostratigraphic data collected from the unconsolidated Holocene sediments recorded in the Combe Haven Valley in East Sussex have been presented by Smyth (1986), Jennings and Smyth (1987), Smyth and Jennings (1988a, b, 1990). A combination of commercial and hand-cores have determined four lithostratigraphic units of Holocene age in the area: river gravels, a lower blue silty-clay, peat deposits and an upper silty-clay (Smyth 1982).

River gravels were recorded in the centre of the valley at a depth of c. -15m OD, and were overlain by a blue silty-clay. This deposit contained roots, decayed organic material, and shell bands. Pollen analysis and occasional remains of Scrobicularia indicated that the deposit accumulated under estuarine conditions. Two peat beds, called the "lower" and "upper" peat, were recorded between -5.0m to -5.60m OD and +0.30m to -4.0m OD, whilst a basal peat overlying gravel has been recorded at -16.52m OD, at -14.72m OD and at -14.29m OD. These deeper peats have not been sampled (Smyth 1982).

The lower peat was recorded at greater depths in the most seaward sites (c. -6.00m OD), and in general was 0.70 to 0.80m thick and composed of wood fragments. Pollen analysis from this peat showed an Alnus-Quercus-Tilia-Corylus association, with high frequencies of Alnus pollen. Three ^{14}C dates have been determined for this deposit. The regressive overlap recorded at -6.56m OD in CH2 has been dated to 6020±70 BP and the transgressive contact at -6.15m OD to 5780±80 BP. In CH1 the regressive contact at -5.02m OD has been dated to 5900±50 BP (Smyth and Jennings 1988b).

The upper peat was recorded throughout the Combe Haven, and was overlain by an upper silty-clay at between c. +0.30m and +1.00m OD. The regressive overlap of the upper peat has been dated in CH2 to 5170±70 BP at -3.45m OD. Pollen analysis has indicated that Alnus, Quercus and Corylus pollen dominated the biostratigraphic record at both CH1 and CH2 during the formation of the upper peat. During the final phase of organic accumulation arboreal pollen frequencies fell, and were replaced by high frequencies of Cyperaceae and Gramineae pollen.

Overlying the upper peat was recorded a silty-clay which varied in thickness between 0.65m and 1.05m, and accumulation of this deposit was diachronous within the valley. In CH1 the onset of inorganic sedimentation has been dated to 2930±50 BP, and at Buckholt Farm to 2730±70 BP. In CH2 this contact has been dated to 2170±60 BP, at Upper Wilting 1 to 2180±70 BP, and at Upper Wilting 2 to 2160±70 BP (Smyth and Jennings 1990). These dates cluster in two age groups, with inorganic sedimentation commencing at an earlier date at upstream compared with the downstream sites. Pollen analysis has shown that in the down-valley locations the silty-clay was deposited under estuarine conditions, contrasting the fresh depositional conditions under which the deposit accumulated in the up-valley locations.

Smyth and Jennings (1988b) have explained this contrast between up- and down-valley sites by the time transgressive forest clearance in the Combe Haven Valley during the Late Bronze Age or Iron Age. Smyth and Jennings (1988b) have suggested a chain of events whereby upstream woodland clearance resulted in the downslope movement of inorganic sediments onto the valley floor. This colluvium was not reworked by the Combe Haven river, and later forest clearance in the down-valley locations, combined with a reduction in evapotranspiration and increased run-off may have resulted in the widening of the river mouth and the extension of estuarine conditions up-valley.

If this model is accepted, then the quality of these most recent transgressive and regressive contacts for sea-level research is equivocal. It is clear for example, that the up-valley contacts at CH1 and Buckholt Farm represent a change from fresh terrestrial/semi-terrestrial organic sedimentation to fresh inorganic sedimentation, and therefore these dates are omitted from the summary of dates from this area presented in Table 2.10.

2.6.3.2. Sea-level index points from Willingdon Levels, Lottbridge Drove and Langney Point.

Extensive litho-, bio- and chronostratigraphic analyses have been completed by Jennings (1985) on the unconsolidated sands, silts, clays and peats recorded on Willingdon Levels, Lottbridge Drove and at Langney point. In general these depositional environments differ from the Combe Haven Valley, containing less organic and more inorganic sediments.

A combination of commercial and hand-cores have established the nature of Holocene sedimentation in this area (Jennings 1985). Four main lithostratigraphic units have been identified: valley gravels, a lower silty-clay, the Willingdon peat, and an upper clay. The altitudinal range of these units is summarised below (after Jennings and Smyth 1987);

Unit 4	Upper silty-clay	+3.15 to +1.40m OD
Unit 3	Willingdon peat	+1.40 to +0.40m OD
Unit 2	Lower silty-clay	+0.40 to -6.08m OD
Unit 1	Valley gravels	-6.08 to -8.19m OD

Unit 1 is described as a late-glacial soliflucted deposit whose surface altitude is highly variable. A conductivity survey completed by Morey (1985) has defined the pre-Holocene surface in the area, and this indicated the presence of two drainage channels cut into the pre-Holocene surface, which join to the south of Lottbridge Drove.

Overlying this basal deposit were recorded the lower silty-clays of Unit 2, which are of estuarine origin. The Willingdon peat was recorded overlying Unit 2, and consisted of an organic clay with numerous remains of Phragmites. The Willingdon peat was never greater than 1.70m thick, and had occasional interleaved thin inorganic horizons. Pollen analysis has been completed from two sites on Willingdon Levels, - Lottbridge A, where the complete sedimentary sequence was analysed (Units 1-4), and Lottbridge B, where only the Willingdon peat was studied.

The litho- and biostratigraphy at both sites have indicated a prolonged period of fine-grained estuarine sedimentation, interrupted by the formation of the Willingdon peat. The regressive contact for this peat has been dated at +1.65m OD to 3750±40 BP and the transgressive contact at +1.92m OD to 3390±40 BP. During the accumulation of this deposit a reedswamp environment with aquatic communities developed, with saltmarsh communities in close proximity.

At the seaward end of Willingdon Levels at Langney Point, Jennings (1985) used a drilling rig to sample the Holocene stratigraphic record to a depth of approximately -33m OD. Four lithostratigraphic units were recognised in this core overlying the Lower Greensand (Jennings 1985). The altitude and thicknesses of these units are described below:

Unit 1	Crumbles shingle	+ 4.30m to -3.70m OD
Unit 2	Upper minerogenic sequence	- 3.70 to -24.70m OD
Unit 3	Crumbles peat	-24.70 to -24.82m OD
Unit 4	Lower minerogenic sequence	-24.82 to -29.10m OD

Unit 4 has been described as a clay with some sand, and pollen analysis has suggested that it accumulated under initially fresh and then estuarine conditions. A sample of Unit 4 at -29.08m OD was ^{14}C dated to 11,290±170 BP, but Jennings (1985) has rejected this date because of the probability of a hard-water error affecting the age determination. This date is not used in the current analysis.

Pollen analysis of Unit 2 has indicated high frequencies of Juniperus pollen, which have been interpreted as evidence for coastal sand-dunes in close proximity at the time of sediment accumulation (Jennings 1985). Indeed, it has been suggested that the onset of organic accumulation may have been in response to the emplacement of a barrier behind which freshwater became empounded and peat accumulation occurred (Jennings and Smyth 1985).

The Crumbles peat was recorded above Unit 4 between -24.82m and -24.70m OD. The deposit recorded by Jennings (1985) was thinner than that sampled by Shephard-Thorn at a site only 10m from that of Jennings (1985). Shephard-Thorn recorded the Crumbles peat being approximately 3.50m thick and lying directly on the Greensand surface. Two samples of this deposit from -27.30m and -24.90m OD were dated to 9510±75 and 8760±75 BP (Shephard-Thorn 1975). The transgressive contact of the Crumbles peat sampled by Jennings (1985) has been dated to 8770±50 BP, which is in close agreement with the determination made by Shephard-Thorn (1975).

Overlying the Crumbles peat was recorded a thin sandy layer, which passes into the upper minerogenic sequence. Particle size analysis of this deposit has illustrated a coarsening-upwards sequence, with the replacement of clay by sand at -14.20m OD, and sand by shingle at -3.70m OD. This sequence was interpreted by Jennings (1985) as a reflection of the shoreward movement of barriers and shoals which progressively over-ran the site, and which also affected the pattern of sedimentation on Willingdon Levels.

Considerable debate has arisen from the suggestion of Jennings and Smyth that the sedimentary changes described above owe themselves to the operation of local factors, and in particular to barrier breaching (eg Carter 1982, Burrin 1982). An absolute statement concerning the possibility of barrier beaches affecting past sedimentation cannot be made. It is only possible to propose a series of hypotheses based on carefully collected empirical data to explain the patterns observed.

For example, in Wallers' (1987) discussion of the upper peat recorded in the Brede valley, the suggestion that barrier breaching may have been responsible for the change in sedimentation observed was supported by several lines of evidence:

i. The presence of a widespread eroded transgressive contact.

ii. The lack of any pollen succession indicating a gradual change in sedimentation.

iii. The probable existence of shingle and/or sand deposits at the coast at a time of relatively slow sea-level rise.

Local processes should only be invoked as being responsible for the patterns of sedimentation observed at any single site when the data analysed have been conclusively shown to be incompatible with data from other areas. Only then should possible non-regional processes be discussed.

Table 2.10. List of ^{14}C dated sea-level index points from the East Sussex coasts

References: 1= Jennings and Smyth (1987), 2= Smyth and Jennings (1990), 3= Shephard-Thorn (1975).

Group 2

Site / Altitude	Source / Material	Lab.code	^{14}C Date
Langney Point -24.7m OD	1 *Peat.*	SRR-2452	8770±50
Combe Haven -6.15m OD	1 *Peat.*	SRR-2682	5780±80
Lottbridge Drove +1.92	1 *Peat.*	SRR-2454	3390±40
Combe Haven (CH2) +0.43m OD	1 *Peat.*	SRR-2680	2170±60
Upper Wilting (UW1) Not known	2 *Peat.*	SRR-3212	2180±70
Upper Wilting (UW2) Not known	2 *Peat.*	SRR-3213	2160±60

Group 3

Combe Haven (CH2) -6.56m OD	1 *Peat.*	SRR-2683	6020±70
Combe Haven (CH1) -5.02m OD	1 *Peat.*	SRR-2685	5900±50
Combe Haven (CH2) -3.45m OD	1 *Peat.*	SRR-2681	5170±70
Lottbridge Drove +1.65m OD	1 *Peat.*	SRR-2455	3750±40

Group 4a

Langney Point	3	SRR-380	9510±75
-27.30m OD	*Peat.*		
Langney Point	3	SRR-379	8760±75
-24.90m OD	*Peat.*		

Chapter Three: Techniques.

3.1. Introduction.

This Chapter describes the field and laboratory techniques used in the collection of sea-level data in this thesis. General descriptions of the techniques employed in this thesis (levelling, lithostratigraphic analysis, pollen and diatom analysis, and ^{14}C dating) have been made elsewhere (eg. Tooley 1978, Devoy 1977, Shennan 1980, Haggart 1982, Sutherland 1984, Simmons and Tooley 1984, Lowe and Walker 1984, Jennings 1985, van de Plassche 1986, and Ireland 1988). Whilst the techniques employed in different research projects may be broadly similar, the reasons for their application can vary widely. Therefore, this Chapter concentrates on why each technique was used in this study, and on possible sources of error arising from their usage. One new technique for the collection of sea-level data (shear-wave seismic refraction), and one seldom used technique (elemental analysis) are discussed in more detail.

3.2. Levelling.

Levelling was completed using a Sokkisha automatic level. All levels were reduced to a common datum (Ordnance Datum Newlyn (OD)). In all cases levelling lines were closed, and a maximum closure error of 0.08m was recorded over a distance of c.4 Km.

3.2.1. Sources of error.

A major concern in the levelling was the accuracy of the benchmarks used. Coal mining activities in the Hacklinge area have lead to some concern over the possibility of mining-related subsidence. Three main benchmarks were used in the Hacklinge/Deal area:

	NG Ref	Altitude (m OD)	Geodetic Survey	Year levelled
1.	TR 25 3407 5446	+1.90	3rd	1975
2.	TR 25 3596 5257	+6.81	3rd	1975
3.	TR 25 3729 5408	+3.78	3rd	1975

Levelling between benchmarks 1, 2 and 3 resulted in a maximum closing error of 0.08m. Allowing for the distances between these benchmarks there does not appear to have been significant differential land movement between the three benchmarks since 1975, although this does not rule out the possibility of mining-related subsidence prior to this date. Attempts to establish information concerning the possibility of mining-related subsidence failed, due to the closure of Bettshanger Colliery and the loss of relevant data.

3.3. Lithostratigraphic analysis.

Lithostratigraphic data were collected employing a gouge auger (Eijkelkamp 1990), and the description of the sediments sampled was made employing the Troels-Smith scheme (1955). In this thesis the scheme is used in a purely descriptive manner, so that Substantia humosa is used to describe decomposed organic material lacking macroscopic structure, and the term Limus detrituosus is not used. Once understood, the scheme allowed the accurate and objective description of samples. Data presentation in the text follows that of Tooley (1978), whilst that in Appendix 1 follows a slightly abbreviated form, which lacks stratum number and altitude (m OD).

Graphical presentation of these data is made through the use of the computer programme STRAT (Everett and Shennan 1987), which utilises a simplified version of the Troels-Smith lithostratigraphic symbols (Appendix 6). Purely to aid in the visual interpretation of the lithostratigraphic data, solid and dashed lines have been used to correlate deposits between cores. It is stressed, however, that these correlations do not assume that the deposit necessarily formed at the same time, or even under the same sedimentary conditions.

Undisturbed cores for laboratory analyses were collected using a modified Livingstone piston corer and percussion drill (Merkt and Streif 1970). This corer provided largely contamination-free samples. In order to ensure that the required sedimentary sequence had been sampled, piston-cores were extruded in the field. Samples were returned to Durham for cold storage in sealed plastic tubing according to standard practice (Moore and Webb 1978). A total of six 0.048m diameter piston-cores were collected from the area under study. The equipment proved extremely effective in obtaining undisturbed samples to depths in excess of 10m. The detailed lithostratigraphic description of each piston-core is presented in full in Chapter Five, and a full listing of all hand-cores in Appendix 1.

3.3.1. Sources of error.

Shennan (1980, 1982) has identified a number of largely unavoidable errors arising when using the auger, including angle of borehole, curvature of sampling rods, identification of boundary, measurement of depth, and compaction. Similar errors are expected in the current lithostratigraphic investigations, although all efforts to reduce such errors were made. More serious altitudinal errors occur in the use of the piston-corer, and these are related to compaction during sampling and extrusion.

Some material (such as fine-grained wet clays and silts, or soft well humified turfas) are prone to substantial compaction during both sampling and extrusion. The only known depth for each sample tube collected is its base, and accordingly any altitudinal error consequential upon extrusion will be unequally distributed through each sample. A simple correction based on the ratio between known depth sampled and extruded sample length is therefore inappropriate. In addition, where an intercalated inorganic and organic deposit is recorded within a single sample tube, the different characteristics of each deposit is likely to result in differential compaction upon extrusion.

3.4. Shear wave seismic refraction.

Devoy (1982) noted the need to establish the relationship of any sea-level site to the former coast, but that palaeogeographic information at the site scale is rarely available. Shennan (1980) defined the form of the pre-Holocene surface of the Fenlands on the basis of coring-data, but this study provided only limited information on the detailed palaeogeography at the site scale. Morey (1985) employed a resistivity survey to define the form of the pre-Holocene surface in Willingdon Levels, East Sussex. This survey formed the basis for the interpretation of the Holocene sediments from this area (Jennings 1985). More recently borehole data have been used to establish the Holocene palaeogeography of the Delaware Estuary, USA (Knebel et al 1988a), which also formed the context for the subsequent interpretation of overlying Holocene sediments (Knebel et al 1988b).

Following the initial hand-coring programme in the Hacklinge area, it became apparent that the Holocene sediments had accumulated within a small valley of pre-Holocene age incised into Cretaceous Chalk. Hand-coring failed to reach Chalk in a number of hand-cores at Hacklinge, Marsh Lane, and Sandfield Farm. An accurate determination of the form of the pre-Holocene surface at the site scale was therefore not possible on the basis of hand-coring data alone. In order to resolve this problem, a collaborative research project with Dr. N. Goulty of the Department of Geophysics, University of Durham, was begun, which attempted to use seismic refraction techniques to resolve the form of the pre-Holocene surface.

This represented the first reported attempt to use shear-wave refraction in a study of this kind. The full results of the survey are to be found in Gunn (1990) and Long et al (in press) and a summary of these results are described in Chapter Four. An example of the application of this technique was given in the field during the 1990 IGCP Project 274 U.K. Working Group Annual Meeting in the East Kent Fens (Long 1990). Grateful thanks are expressed to Dr N.Goulty, C.Gunn and D.Bedlington for their help and involvement in this project.

3.4.1. The seismic refraction method.

Although the seismic refraction method is a well established method for determining the thickness of unconsolidated sediments overlying bedrock, its application in coastal areas where the pre-Holocene surface is overlain by saturated sediments of Holocene age, has not previously been reported. A basic description of the seismic refraction method is found in the introductory geophysics textbook by Kearey and Brooks (1984); a fuller treatment is given by Sjogren (1984).

Within the context of this study it was necessary for there to be a seismic velocity contrast between the unconsolidated Holocene sediments and the Cretaceous Chalk bedrock. The velocity of compressional waves (P-waves), in which the direction of particle motion is parallel to the direction of wave propagation, is determined by the bulk modulus as well as the rigidity modulus and density of the medium through which they propagate. The bulk modulus of water is rather high, and therefore P-waves travel faster through a water-saturated medium. As a result there is a large P-wave velocity contrast at the watertable within the Holocene sediments, but there is only a small velocity contrast between the water-saturated Holocene sediments and Chalk bedrock.

This was confirmed by a test profile in the study area using P-waves (Gunn 1990). However, the velocity of shear waves (S-waves), in which the direction of particle motion is perpendicular to the direction of wave propagation, depends on the rigidity modulus and density of the medium through which they propagate. Because the rigidity of fluids is zero, S-wave velocities are not affected by the presence of the watertable. Furthermore, the rigidity of unconsolidated sediments is much less than that of rocks, so it was to be expected that there would be a large S-wave velocity contrast between the Holocene sediments and the Chalk bedrock. Such large velocity contrasts have been exploited in previous applications of the S-wave seismic refraction method where unconsolidated sediments overlay sedimentary rocks (Hasbrouck and Padget 1982, Brabham and Goulty 1988, Goulty et al 1990).

Fig.3.1a. is a schematic diagram showing source and receiver positions at the ground surface, with a homogeneous upper layer (corresponding to the unconsolidated Holocene sediments) overlying a thick lower layer (corresponding to the Cretaceous Chalk). Supposing that the source emits an impulsive waveform in all directions, which propagates into the ground obeying Snell's law of refraction. For a receiver close to the source, the first seismic arrival picked up by the receiver after the source is initiated will be the direct wave, which has travelled directly from the source to the receiver. At a receiver which is sufficiently far from the source, the first arrival will be the headwave, which has been refracted along the interface (corresponding to the pre-Holocene surface). Raypaths for the direct and headwaves are shown in Fig.3.1a.

The downward raypath for the headwave is incident on the interface at the critical angle, and the critically refracted wave travels along the interface at the higher seismic velocity of the lower layer. As it does so, it continuously radiates the headwave back into the upper medium, with the raypaths also leaving the interface at the critical angle. At a certain distance along the surface from the source, the direct wave and the headwave will have the same traveltime. This distance is called the crossover distance, and the first arrival at a receiver positioned beyond the crossover distance will be the headwave.

The most common method used in the interpretation of seismic refraction data is the plus-minus method of Hagedoorn (1959). This method utilises the headwave arrival times at each receiver from two separate source points on either side of the receiver, as shown in Fig.3.2. These arrival times are referred to the instant of source initiation and are called traveltimes. The traveltime of the headwave from a source at A to a receiver at B is defined as t_{AB}, etc. Then the plus time at receiver B is defined as

$$t_{+} = t_{AB} + t_{CB} - t_{AC}$$

whilst the minus time is defined as

$$t_{-} = t_{AB} - t_{CB}$$

Using Snell's law the perpendicular distance Z_B between the pre-Holocene surface and B is related to t_{+} by

$$Z_B = \frac{t_{+} V_0 V_r}{2\sqrt{V_r^2 - V_0^2}}$$

where V_0 is the seismic velocity in the upper layer and V_r the seismic velocity in the lower layer. V_0 may be calculated from graphs of the traveltime against distance for the first arrivals recorded closest to the source, as these will be the direct wave. V_r may be calculated from a graph of the minus times against distance, as the gradient of the graph is equal to $2/V_r$. Thus, the depth to the interface may be determined at any geophone position B from the set of headwave traveltimes t_{AB}, t_{CB}, t_{AC} and the velocities V_0 and V_r.

3.4.2. Field technique.

In order to generate S-waves, a steel stand was struck horizontally, with the direction of hammer strike perpendicular to the line of the profile. Horizontal geophones were used as receivers, and were orientated in the transverse direction to detect the horizontally polarized S-waves generated by the source.

The geophones were connected to an EG&G Geometrics ES-1210F enhancement seismograph with twelve recording channels, each with its own gain and filter settings. The enhancement feature enabled successive blows to be summed into the digital memory. Seismograms were displayed on the cathode-ray tube screen and paper records were played out on the integral printer. The gains were adjusted to equalise the first arrival amplitudes recorded on each channel, whilst the filters enabled high frequency noise to be suppressed. Power to the seismograph was supplied by a 12 volt car battery, and the recording system was triggered by a geophone located close to the source, so that the start of the seismograms correspond to the instant of source initiation (the impact of the hammer).

For the main survey lines, the geophone spacing was chosen to be 5m with an offset of 20m from the source to the nearest geophone. Thus most of the first arrivals on the geophone spread were refracted headwaves from the pre-Holocene surface. It was necessary to sum the signals from several hammer blows, as the energy generated from a single blow was insufficient to provide an adequate signal-to-noise ratio (SNR) at the furthest geophones. Even so, the SNR deteriorated beyond 60m, so the source and geophone spread were moved along the line together in increments of 20m to extend coverage. Each line was profiled in both forward and reverse directions in order to acquire the data needed to calculate the plus and minus times at each geophone station.

In addition, it was necessary to make separate recordings to estimate the seismic velocity in the unconsolidated Holocene sediments. For this, geophones were spaced at intervals of 2.5m with source points 2.5m beyond the geophones at each end. These short spreads were deployed at intervals of approximately 150m, but where the stratigraphic data suggested a change in the nature of the Holocene sediments (e.g. localised coarsening), additional short spreads were deployed. It was generally not possible to observe seismic velocity contrasts within the Holocene, so the velocities determined from the short spreads were (for the most part) assumed to be appropriate for the whole Holocene section in converting plus times to depths.

3.4.3. Data example.

Fig.3.2. shows a 12-channel S-wave record from the southwest end of line 9003 at Marsh Lane (Fig.4.24.) and is of typical signal quality. The SNR deteriorates with distance from the source and depth to the refractor boundary. For the geophone closest to the source, the first arrival is the direct wave travelling through the topmost unconsolidated sediments. Beyond the crossover distance (between 20 and 25m in this example), the first arrivals are headwaves refracted along the pre-Holocene surface. First arrival traveltimes are read at the first clear down-break on the traces.

The first arrival times for line 9003 are shown in Fig.3.3a. Plus times were calculated for each geophone position where headwave first arrivals were recorded from profiling in each direction. Using the appropriate values of V_0 and V_r, obtained as described above, plus times were converted into the profile of the pre-Holocene surface shown in Fig.3.3b. Depth coverage is not complete because the first geophones at the start and end of the line record direct waves as first arrivals.

3.4.4. Accuracy of the seismic method.

Lithostratigraphic control for the area under study, established by hand-coring, meant that it was possible to assess the accuracy of the seismic refraction method. Before the main survey was carried out, three trial lines were profiled using S-waves at places where the pre-Holocene surface was known to be 2-4m deep. The S-waves did not show a significant velocity contrast either at the watertable or within the Holocene sediments themselves, but did show a large contrast between the unconsolidated Holocene sediments and the Chalk bedrock.

Following the completion of the main survey an attempt to assess the accuracy of the seismic method was made at places where the pre-Holocene surface was deeper than 4m. Line 9014 (Fig.4.24.) was selected for detailed comparison with hand-coring data. The line was chosen because the seismic profile suggested that the pre-Holocene surface dipped from approximately 2m to 9m below surface in depth. This covered the maximum range possible by hand-coring, over a lateral distance which was sufficient to permit the establishment of a number of control points.

The results showed remarkably close agreement to depths of 9m (Fig.3.4.). Whilst there are insufficient data points in this study to make a statistical estimate of errors, it is probable that the errors in depths determined through the seismic refraction method are rarely greater than ± 20%, and in most cases considerably less. The key factor affecting the accuracy of the method is whether the values for V_0 obtained using the short spreads are valid for the whole thickness of sediments overlying the Chalk.

3.4.5. S-wave velocities and lithology.

The velocity contrast between the unconsolidated Holocene sediments and the Chalk bedrock was far greater than any contrast within the Holocene. It is for this reason that the S-wave technique was so useful in defining the depth to the Chalk. The S-wave velocities measured in the various unconsolidated sediments and the Chalk bedrock are given below in Table 3.1.

Table 3.1. S-wave velocities for unconsolidated sediments and Cretaceous Chalk (metres per second).

Material	Line	
Surface peat		
	9001	32
	9010	37, 52
	9011	46
	Mean velocity = 41.75 ± 9.96 m/sec	
Intercalated peats, clays and silts		
	9003	92, 86
	9014	73
	9015	76
	9016	83
	9018	81
	9019	85
	Mean velocity = 82.29 ± 6.37 m/sec	
Sand		
	9012	162
	9013	168
	Mean velocity = 165.00 ± 4.24 m/sec	

Brickearth

9002	108
9004	114

Mean velocity = 111.00 ± 4.24 m/sec

Chalk

9001	448
9002	502
9003	744
9004	680
9010	549
9012	505
9014	447
9015	533
9019	547

Mean velocity = 550.55 ± 100.11 m/sec

Hand-coring showed that the surface of the Chalk was commonly weathered to a depth of c. 0.50m, and variations in the extent of Chalk weathering are almost certainly the main cause of the wide range of S-wave velocities in the Chalk bedrock. It is not necessary for weathering to break down the Chalk matrix to cause a reduction in velocity. Partial dissolution of the cements in a sedimentary rock matrix is sufficient to reduce substantially its rigidity modulus and hence its S-wave velocity. Some weathering of this nature will almost certainly have taken place for tens of metres down into the Chalk.

The results of the shear-wave refraction survey are presented in Chapter Four. The technique has enabled a first approximation of the form of the pre-Holocene surface in the Hacklinge/Marsh Lane/Sandfield Farm area to be made, and provided the necessary context for the accurate interpretation of litho-, bio-, and chronostratigraphic data collected from the area.

3.4.6. Sources of error.

The main source of error in the method lies in the calculation of the seismic velocity for the Holocene sediments. Therefore, the method must be used in conjunction with a programme of hand-coring, in order to assess the degree of stratigraphic variability in the Holocene record. This in turn affects the number of V_0 determinations which must be calculated. Once established, however, the method has the advantage of providing data points at a 5m (or less) interval, and therefore ensuring the fine resolution definition of the pre-Holocene surface to depths of up to 18m.

3.5. Pollen analysis.

Pollen analysis was completed on samples collected from Hacklinge, Marsh Lane and Sandfield Farm. Samples were taken from either piston-cores or in one case a monolith tin, and prepared according to well established techniques (Appendix 4). Counting was carried out on a Zeiss photomicroscope, with magnification up to 12.5 x 63 (eye-piece x objective), although most identification was made at a magnification of 12.5 x 40. Pollen identification was made with reference to the texts of Faegri and Iversen (1964) and Moore and Webb (1978), as well as an extensive type-slide collection.

Taxonomic nomenclature was made with reference to Clapham *et al* (1962). *Corylus* and *Myrica* pollen were not differentiated (grouped as *Corylus*), nor was *Phragmites* pollen from that of Gramineae, and *Sparganium* pollen were included with *Typha angustifolia*. Sampling interval varied between approximately 0.01m and 0.06m, and reflected the changes in the pollen record as well as the nature of pollen preservation.

3.5.1. Aims of pollen analysis.

It is possible to identify eight applications of pollen analysis in sea-level research:

i. To determine the nature of sedimentary changes associated with transgressive and regressive contacts.

ii. To establish changes in groundwater conditions during the accumulation of organic and inorganic sediments which may be related to sea-level changes.

iii. To identify local and regional vegetation changes.

iv. To support lithostratigraphic correlation.

v. To ensure that a sedimentary hiatus has not occurred.

vi. As a relative dating technique, and in particular to confirm ^{14}C dating of sediments older than c. 5000 BP.

vii. To assess the relative importance of sedimentary processes through the analysis of reworked pollen grains and spores.

viii. To determine approximate rates of sedimentation through the calculation of absolute pollen frequencies.

Within the context of the current research project, pollen analysis was used for the first five of these applications.

3.5.2. The pollen sum and count.

There are various ways of calculating the pollen sum depending on the type of material analysed and the aims of the study (Moore and Webb 1978). The exclusion of aquatic pollen and ferns from the pollen sum is common practice because the former are produced in a different environment to terrestrial pollen, and because the latter are formed in a different way to pollen grains. Within the context of this study frequencies of aquatic taxa, and those of Filicales for example, are of great significance as indicators of wetting and drying episodes. Accordingly, diagrams were initially calculated on the basis of % total pollen and spores, and then compared with those calculated on the basis of % total land pollen (TLP). Major differences in the interpretation of the diagrams were not observed, and thus all diagrams were calculated on the basis of %TLP less aquatics and spores.

Where possible a minimum of one hundred and fifty land pollen were counted at each level. This pollen sum was chosen because it was found to be sufficient to enable an adequate assessment of environmental changes associated with transgressive and regressive contacts, as well as being able to identify discrete changes in the height of the watertable.

3.5.3. Diagram zonation.

In order to aid in the description and correlation of the biostratigraphic data, all diagrams were divided into a series of Local Pollen Assemblage Zones (LPAZs). These are of local significance only and are therefore numbered, and not named after significant taxa (Birks 1970).

All diagrams presented in this thesis are produced using the computer program TILIA (Grim 1990). This program has a number of advantages over the alternative program available NEWPLOT10 (Shennan 1980). These include ease of data entry (spreadsheet format), flexibility in data manipulation, within-program statistical analysis, ease of access (PC-driven), and finally of plotting (to a laser printer or plotter). However, the absence of a facility for the calculation of confidence limits is a serious weakness and warrants further discussion.

Shennan (1980) has noted the need to calculate confidence bands in order to identify limitations in pollen data from coastal sites not otherwise obvious, and also as a way of identifying the influence of low pollen counts. In addition, confidence limits may be used as a basis for constructing Local Pollen Assemblage Zones (LPAZs). However, as noted by Shennan (1980 :77),

> "There are no set rules for the construction of LPAZs 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)."

More recently, Ireland (1988) applied a number of numerical zonation techniques proposed by Gordon and Birks (1972). These included constrained single link cluster analyses (CONSLINK), constrained divisive analysis using information content (SPLITINF), constrained divisive analysis using sum of least squares deviation (SPLITLSQ) and principal component analysis (PCA).

Gordon and Birks (1972) have noted the general similarity in results obtained by zonation of a single diagram with any one of these techniques. Although TILIA lacks an ability to calculate confidence limits, it does possess an option allowing the analysis of each data set with either cluster or ordination techniques. Of the former, constrained incremental sum of squares cluster analysis (CONISS) was used as an aid in the definition of LPAZs. Thus, as an aid to zonation, all pollen diagrams were initially divided into LPAZs on the basis of the highest splits calculated by this technique. Similar statistical zonation of coastal pollen sequences has been used by Smith and Morgan (1989) in the zonation of two pollen diagrams from the Gwent Levels. The number of zones which were selected varied between datasets. All diagrams were zoned first by computer and then checked by eye, and in all cases a close agreement between the zonation suggested by CONISS, and that of the author was found.

The pollen taxa have been plotted in their respective groups with trees on the far left, followed by shrubs, herbs, aquatics and ferns and spores. In addition, on the right of each diagram, summary curves for these groups are plotted. Within all groups except herbs, taxa have been sorted alphabetically. Within the herb group, saltmarsh taxa are plotted first, followed by Graminae and Cyperaceae, followed by damp and then dry herbs.

3.6. Diatom analysis.

Diatom analysis was completed on samples collected from Hacklinge and Sandfield Farm. Samples were collected from piston-cores, and prepared according to well established techniques (Appendix 5). Counting was carried out on a Zeiss photomicroscope, and identification made at a magnification of 12.5 x 40. Diatom identification was made with reference to the texts of Van der Werff and Huls (1958-74), and Hendey (1964).

3.6.1. Aims of diatom analysis.

Within this study, diatom analysis was completed with the same four main objectives as those for the pollen analysis (Section 3.5.1.), but with the obvious concentration on the inorganic sediments. Despite completing diatom preparations within the organic deposits, insufficient diatoms for counting were recorded.

3.6.2. The diatom sum and count.

As in pollen analysis, no single method for the counting and subsequent presentation of diatom data exists. The diatom sum may be determined according to relative abundance (Andrews 1972), according to absolute concentration techniques (Battarbee 1973), or by relative percentage techniques (Battarbee 1979, 1986). Each of these techniques has been described in full by Ireland (1988), who concluded that the first is too subjective, and that the second too restrictive to allow its widespread application.

In the context of the current study the method selected had to enable the statistical analysis of data, which is something that Andrews' (1972) approach does not allow. The absence of detailed ^{14}C dating, made the calculation of concentration techniques inappropriate. Within this study all diatom data have been collected according to the relative method (Battarbee 1979, 1986), and diatom frequencies presented as a % Total Valves (%TV).

Within the current study some elongate species, such as Synedra capita, were never recorded intact. However, most broken diatom valves were still identifiable, and were therefore counted. Where necessary a counting procedure designed to avoid counting the same diatom twice was adopted so that for example, at least half a valve of a centric diatom was required to constitute a single count. In this study two hundred valves were counted at each level. A similar sum has been adopted by Shennan (1980), Haggart (1982), Sutherland (1984) and Ireland (1988).

3.6.3. Diatom classification.

Diatoms may be classified according to a number of different salinity and life-form groupings. For example, Hustedt (1927-66), Miller (1964), and Van der Werff and Huls (1958-66) have each produced different classification schemes. Of these the latter is adopted in this study, and diatoms are classified into marine (M) >17000 mg. Cl^-/l: marine-brackish (MB) 1000-17000 Cl^-/l: brackish-marine (BM) 5000-10000 Cl^-/l: brackish (B)

1000-5000 Cl^-/l: brackish-fresh (BZ) 500-1000 Cl^-/l: fresh-brackish (ZB) 100-500 Cl^-/l and fresh (Z) <100 Cl^-/l.

Diatom assemblages can also be classified according to life-form, and an analysis of life-form assemblages can provide information on the autochthonous and allochthonous component of any assemblage (Beynes and Deneys 1982). Three life-forms have been recognised:

i. Benthonic or benthic (attached to the substratum).

ii. Epiphytic or epontic (attached).

iii. Planktonic (free floating).

This tripartite classification of diatoms by life-form has been adopted by Miller (1964) and Shennan (1980). However, Round (1971) has noted that the term epiphytic has been used in the description of species attached to a substratum (eg. Miller 1964). Accordingly in this study the terms benthonic and planktonic describe all benthonic and epiphytic species, and all free-floating species respectively (Round 1971). Taxonomic nomenclature is made with reference to Hartley (1986).

3.6.4. Problems in diatom classification schemes.

The use of this classification scheme has two problems. The first is that the Van der Werff scheme does not provide information on life-form for all species. Accordingly reference was made to Miller (1964), Round (1971), du Saar (1969), and Lebour (1930) in order to obtain additional life-form information.

Secondly, the life-form classification of a number of species by Van der Werff differs from that made by other authors. The most important of these to this study is in the classification of Paralia sulcata, which in the two sites analysed in this study commonly constituted > 30-40% TV. Both Van der Werff (1958-66) and Vos and de Wolf (1988) have classified Paralia sulcata as planktonic. However, Brockmann (1937 in Round 1971) has recorded Paralia sulcata in bottom samples collected from the North Sea at a depth of 46m, whilst Bordenau (1946 in Round 1971) and Von Stosch (1956 in Round 1971) have recorded Paralia sulcata in bottom samples from the Black Sea and North Sea respectively. Miller (1964) did not classify Paralia sulcata according to life-form, although du Saar (1969) classified the taxa as benthonic and possibly planktonic. Cleve-Euler (1951-55) noted that Paralia sulcata is benthonic and becomes planktonic in autumn. Ireland (1988 :38) has classified Paralia sulcata as planktonic "because such valves are likely to be transported over greater distance in a water body than true benthic forms". Finally, Kjemperud (1981) has recorded frequencies of Paralia sulcata in comparable frequencies with those in the current study (45% TV), and concluded that the consistent preponderance of the species suggested that it was "no doubt mostly autochthonous".

Whilst recognising that Paralia sulcata can be transported during storms and high energy wave conditions, and that it can possess both an epithetic and benthonic life-form, in this study it is classified as benthonic. The reasons for this classification are:

i. The taxon was recorded continuously in predominantly fine-grained unlaminated sediments suggestive of low-energy depositional conditions.

ii. Whilst Paralia sulcata is recorded throughout much of the sequences studied, other truly planktonic forms (eg. Auliscus sculptus, Actinoptychus undulatus, Thalassiosira decipiens, Biddulphia alternans and Triceratium favus (Vos and de Wolf 1988)), are recorded in lower frequencies and far more sporadically. In general, fluctuations in Paralia sulcata appear to result from changes in the salinity of the entire assemblage, and not simply possible changes in the planktonic/benthonic ratio.

In summary, the diatom data are presented in two forms:

i. Firstly, relative frequencies based on %TV are presented, with taxa grouped according to the salinity classification suggested by Van der Werff and Huls (1958-66). The diagrams are constructed with marine (**M**) taxa plotted to the left of the diagram, and fresh (**Z**) taxa to the right.

ii. Secondly, summary curves for the seven salinity groupings are provided (where approporiate), as well as information concerning the number of diatoms counted.

The dominance of benthonic forms makes the further classification of species according to the ratio of benthonic/planktonic diatoms unnecessary. However, it is recognised that in any level where a combination of **M**, **MB**, **BM**, **B**, **BZ**, **ZB**, and **Z** taxa are recorded, then one or more components of the assemblage must be allochthonous. Where such a situation is recorded, the probability of an allochthonous/autochthonous element is recognised in the text.

3.6.5. Diagram zonation.

In order to aid in the description and correlation of diatom data, all diagrams were divided into a series of Local Diatom Assemblage Zones (LDAZs). These were of local significance only and are therefore numbered and not named after significant taxa (Birks 1970).

The procedures involved in diagram construction, zonation and statistical analysis are similar to those employed in the pollen analysis described above. One exception is in diagram presentation, in which only taxa recorded in frequencies >2%

TV have been plotted in the relative frequency diagrams. The summary diatom data for each diagram has been calculated on the basis of the total diatom count, and a full listing of all counts is found in Appendix 3. This procedure has been adopted in order to aid in the visual presentation of data.

3.7. Elemental analysis.

3.7.1. Aims of the elemental analysis.

Assuming that changes in the composition and altitude of the watertable affect the elemental composition of the plants growing therein, and that this record is preserved under the anaerobic conditions associated with peat formation, it was hoped that elemental analysis of organic deposits could provide an alternative and simple way of establishing changes in water quality and depth through time. In order to test this possibility, the elemental composition of samples taken with a piston-core from Hacklinge was determined. This core was selected so that a comparison with a pollen diagram constructed from the same core could be made.

Previous analyses of the elemental composition of Holocene coastal sediments, in order to determine a record of palaeosalinity, have concentrated on the study of predominantly inorganic sediments (Chapman 1939, 1960, Ericcson 1972, 1973). Analyses of organic sediments in coastal contexts has been rare; it has been more common in non-coastal contexts (eg. Clymo 1983, Walsh and Barry 1958, Hobbs 1986, Ingram 1983, Malmer and Sjors 1955, Mornsjo 1968).

Sculthorpe (1967) identified the main source of nutrients for emergent macrophytes such as Phragmites as being the substrate. However, Hoy (1981) noted that evidence from fieldwork and experimental studies (eg Roman et al 1971 in Hoy 1981) suggested that bathing water may act as an additional supply of nutrient and water to the plant. In particular this will be the case in nutrient-rich waters with a peat substratum. In an analysis of the elemental composition of <u>Phragmites</u> in three Scottish lakes of differing trophic levels Hoy (1981) concluded that "the productivity of the reed is determined by the nutrient content of the water".

3.7.2. Analytical procedure.

The analytical procedure used in this study was adapted from a technique developed by Dr M. Kelly, Department of Botany, University of Durham, whose help is gratefully acknowledged.

Samples (dry weight 30mg) of peat and <u>Phragmites</u> were extracted from the centre of the piston-core so as to avoid any contamination caused during sampling. Samples were stored in soda glass snap top vials (Kelly 1986), and oven dried at 105^0 C. After cooling samples were weighed to determine the working weight. All glassware used was soaked for at least half an hour in 4% nickel chloride, and then washed at least six times with distilled water in order to avoid possible contamination.

Samples were washed twice for 45 minutes in a 10 ml 20 mM nickel chloride solution. This was in order to remove transferable ions from the outer surface of the samples (Kelly 1986). These exchange sites may have been affected by post depositional-changes in the composition of the watertable. Following each wash the nickel chloride was drained into a separate "wash" vial, which was topped up to a 25ml volume with 20 mM nickel chloride.

The remaining plant tissue was digested using 5ml of 2M nitric acid. These "digest" samples were placed in a beaker of boiling water for 30 minutes and left for approximately 12 hours before being topped up with de-ionised water to a 25ml volume. Both digest and wash were then analysed for their calcium, magnesium, sodium and iron content using Atomic

Absorption Spectrophotometry (AAS). All analyses were made on a Perkin-Elmer model 5000 Atomic Absorption Spectrophotometer with a PE model 5000 Automatic Burner Control Unit.

3.7.3. Sources of error.

Inherent in this study are two main assumptions:

i. That the elemental composition of the plant macrofossils, which constitute peat, are an approximation of the elemental composition of the medium (water and substrate) in which they once grew.

ii. That an accurate (and determinable) record of the elemental composition of these plants at the time of death remains preserved in the plant tissue.

Neither of these assumptions are absolute, and accordingly are discussed in more detail below.

3.7.3.1. The relationship between the elemental composition of the growth medium and plant.

The theory underlying tissue analyses as a measure of nutrient availability has been discussed by Gerloff and Krombholz (1966), who observed that the concentration of any element in a plant can be considered a reliable indicator of the availability of that element within the growth medium. This relationship was illustrated by Boyd (1969), and recently applied in the analysis of environmental pollutants (eg Base III and McLaughlin 1984, Whitton 1988, Kelly 1986, Livett et al 1979, Brown and Hummerstone 1973).

However, the relationship between nutrient availability and nutrient uptake is complex, and can be determined by both physiological and environmental factors. For example, both Hoy (1979, 1981) and Boyd (1970) have identified differential nutrient uptake by aquatic plants, and Boyd (1969) concluded that

> "although very few aquatic macrophytes within a community have access to identical nutrient supplies, results ..... indicate comparatively high degree of preferential absorption of particular nutrients by certain species".

Samples of undifferentiated peat are unlikely to contain the remains of a single plant species. Therefore, it was decided to analyse the elemental composition of peat samples as well as that of a specific plant species. The most common plant macrofossil recorded in the organic deposits of the East Kent Fens, and indeed coastal sediments throughout the mid-latitudes and beyond, is Phragmites, and therefore this species was selected for analysis. In addition, samples of Phragmites were collected from the predominantly inorganic deposits for analysis.

Phragmites is often the only identifiable plant macrofossil, and is capable of tolerating a wide range in water quality. For example, it may grow as part of a hydroseral succession in a freshwater lake (Lambert 1951, Walker 1970), or under more saline conditions as part of an upper saltmarsh community (Chapman 1960, Adam 1990).

Not only does the chemical composition of different species of plant growing in the same growth medium vary (see above), but differences also exist in the chemical composition of different organs of a plant of the same species. For example, Chapman (1960) identified considerable variation in the sodium and chloride ions in the nodes of Phragmites "not only from habitat to habitat, but also within a single plant". Mason and Bryant (1975) concluded that the levels of sodium in Phragmites rhizomes were markedly higher than those in the shoots, whilst levels of calcium, magnesium and (to a lesser extent) potassium were approximately the same. Furthermore, in an analysis of seasonal changes in the chemical composition of *Phragmites*, Hoy (1981) concluded that the rhizome had less seasonal variation in the levels of mineral elements investigated than the above ground organs.

In the analyses of bulk peat samples it was hoped that any elemental changes in the growth medium and associated plants would be sufficiently large to exceed any intra and inter-plant variability identified above. Through analysing *Phragmites* it was hoped that some of the problems of inter-species variations in elemental composition would be avoided. Ideally it would have been desirable to analyse consistently the same organ of *Phragmites*, but limitations in the macrofossil record made this impractical.

3.7.3.2. The effects of decomposition.

The second assumption inherent in this study is that an approximate (and determinable) record of the elemental composition of plants at the time of death remains preserved in the plant tissue. Whether this is the case will depend on the effects of decomposition following plant death. Attempts to establish rates of plant decomposition commonly involve the use of litter bags, suspended or lain on a lake bed for variable lengths of time. Regular intervals between the analysis of the litter bags enable time sequences illustrating the pattern of nutrient loss/uptake to be established.

Boyd (1970) has discussed the losses of mineral nutrients during the decomposition of *Typha latifolia*, and observed that aquatic macrophytes decompose more rapidly than terrestrial plants during the initial phase of decay. Thus, weight losses were particularly great during the first twenty days "apparently due to solubilization of substances rather than microbial activity or particle loss from the bags". Boyd (1969) noted that calcium was seen to decrease rapidly for the first 64 days and then remain stable, whilst almost all the magnesium, potassium, and sodium was leached during the first 20 days.

In a comparison of the pattern of decomposition of Phragmites and Typha angustifolia, Mason and Bryant (1975) recorded a similar pattern of rapid nutrient change in the first month due to leaching. However, after the first month there was no significant trend of increase or decrease of any nutrient. Planter (1970) has also observed that the elution of elements from Phragmites in water can occur very rapidly.

Clearly, decomposition of organic material under anaerobic conditions comparable with those associated with peat formation does alter the elemental composition of the plant macrofossils. Furthermore, pollen data from this core have shown that on several occasions the peat surface may have undergone significant drying. It is probable that during these periods decomposition of the peat surface and near-surface will have accelerated.

Finally, a further problem associated with the technique arises when attempting to establish the relationship of the samples to a former peat surface. Phragmites has a highly variable rooting depth with the rhizomes extending to depths of up to 2m (Godwin 1975), although the normal rooting depth is 0.40-1.00m (Haslam 1970). The rooting depth is closely related to the height of the watertable and the nature of the substrate (Haslam 1970). It is known from the pollen data that the altitude of the watertable has undergone significant changes during peat formation. Accordingly no consistent relationship between samples of Phragmites and a former peat surface (where pollen accumulates) can be assumed. This seriously complicates attempts at correlating the pollen data with the elemental content of samples of Phragmites.

3.8. Radiocarbon dating.

Twenty samples collected for ^{14}C dating were taken from four piston-cores and one monolith tin from Hacklinge, Marsh Lane and Sandfield Farm. Samples were selected following the completion of all litho- and biostratigraphic analyses, ensuring that the indicative meaning of each sample was known. The outer layer of the sample was removed to avoid the possibility of contamination as a result of smearing during sampling. All pieces of wood, roots (including *Phragmites*) and shells visible to the naked eye were also removed. Between 50-75 gm wet weight of material was then packed in plastic bags, sealed and sent to Dr Geyh at the *Niedersachsisches Landesamt fur Bodenforschung* for dating.

3.8.1. Aims of radiocarbon dating.

Since the establishment of the ^{14}C dating technique, it has been used extensively in sea-level research as a means of establishing an absolute chronology for sea-level changes. Within the context of this study ^{14}C dating has been used for three specific reasons:

i. ^{14}C dates have been used to establish an absolute chronology for sea-level changes by the dating of transgressive and regressive contacts with a known altitudinal relationship to a former sea-level.

ii. ^{14}C dates have been used to establish a chronology for changes in the watertable identified by pollen analytical techniques. Thus, ^{14}C has been used to date the onset of a rise in the watertable prior to a transgressive contact, as well as to date other episodes of elevated or reduced watertable conditions.

iii. ^{14}C dates have been used to establish a three-dimensional time/space sedimentary history of the area under study.

3.8.2. Sources of error.

Errors involved in the application of ^{14}C dating techniques to coastal organic sediments are numerous and have been widely discussed (eg Tooley 1978, 1981, Mook and van de Plassche 1986). A number of potential errors in the ^{14}C technique which are of particular reference to the current study are discussed below.

3.8.2.1. Natural fluctuations in atmospheric ^{14}C.

One of the fundamental assumptions of the ^{14}C technique, is that atmospheric ^{14}C levels have not varied significantly over time. However, this assumption has been proven incorrect, following the identification of the so-called "Suess effect" (Suess 1955). This effect described the processes responsible for a decrease of the $^{14}C/^{12}C$ ratio in atmospheric CO_2 found in plant matter grown at the end of the nineteenth century. The reason for this dilution was the increased input of fossil fuel CO_2 into the atmosphere. Recent atmospheric measurements have confirmed this effect, in addition to defining its distinct geographical patterns (Levin et al 1989). The importance of this discovery was that it showed that atmospheric ^{14}C has not remained constant through time.

A similar effect was identified by de Vries (1958), who illustrated that wood samples collected in the seventeenth century contained levels of radiocarbon some 2% greater than that expected in a comparison with nineteenth century wood. In addition, he illustrated that there were further differences in radiocarbon ages and calender ages extending back as far as c. 500 yrs BP. Further ^{14}C dating of dendrologically dated tree-rings has shown that the relationship between ^{14}C and calendar years has varied significantly through time.

Suess (1961) extended the record of atmospheric changes in ^{14}C years to 3-4000 yrs BP, and then to 7400 yrs BP on the basis of the Bristlecone-pine tree-ring record (Suess 1970). More recently, ^{14}C dating of dendrologically dated tree-rings from Ireland (Brown et al 1986) has provided independent confirmation not only of the general pattern of the changes in atmospheric ^{14}C during the Post-glacial period, but also the existence of the so-called "Suess wriggles". These are small scale non-random changes in atmospheric ^{14}C which include a 200 year component (see also Suess 1980, de Jong et al 1979). Through the analysis of the tree-ring record it has been possible to establish a calibration curve to convert ^{14}C years to calendar years during the Post-glacial Period.

The principal concern caused by these natural variations in atmospheric ^{14}C is that horizontal parts of the calibration curve, indicating constant atmospheric production of ^{14}C over a period of time, can cause clustering of ^{14}C dated sea-level index points (de Jong and Mook 1981). Van de Plassche (1986) discussed the possible effect of such clustering on calculations of rates of sea-level rise.

With particular respect to the current study, one of the aims of the ^{14}C dating has been the close interval dating of cores. Accordingly, all ^{14}C dates quoted in this thesis were transformed to sidereal years using the CALIB program (Stuiver and Reimer 1986) in order to establish whether any significant interpretational changes were apparent. These calibrated dates are discussed in detail in Chapter 9.

One of the effects of calibrating ^{14}C dates is that the age range of the one or two standard error age calculations, are in general double that of the ^{14}C timescale. For example, a ^{14}C age of 4549±55 BP is converted by CALIB as follows:

Age ranges calculated from probability distribution.

% area enclosed	Cal BC	Relative area under probability distribution
68.3 (one sigma)	3362-3303	.33
	3237-3174	.38
	3166-3131	.19
	3129-3107	.10
95.4 (two sigma)	3495-3470	.02
	3463-3428	.02
	3378-3091	.94
	3063-3044	.02

In selecting the calibrated sidereal age the user must determine the relative area under the probability distribution required. In order to achieve 68.3% of the relative area under the probability distribution, an age range of 3362-3107 BC must be quoted. This is at least double the standard error of a ^{14}C date quoted by the laboratory for this date.

3.8.3.2. Isotopic fractionation.

Olsson (1968) has observed that there are three naturally occurring isotopes of carbon: ^{12}C, ^{13}C, and ^{14}C, which constitute about 98.9%, 1.1%, and 1.18 X 10^{-10} of the total carbon in circulation. However, the masses of each isotope differ, so that ^{14}C has a mass 15% greater than ^{13}C (Ogden 1977), and therefore during photosynthesis ^{13}C will be absorbed differentially by plant matter. Because of this most plant matter is deficient in ^{14}C with respect to the atmosphere. Most radiocarbon laboratories make adjustments for this effect, using the known ^{14}C:^{12}C ratio which is approximately double that of the ^{13}C:^{12}C ratio. The latter can be determined through the analysis of a small subsample of the sample being dated. This ratio is then compared with a standard PDB ratio and values calculated as deviations from this standard. Most samples have a negative ^{13}C value relative to the PDB, and in general each sample is treated as though an average enrichment of -25‰ has taken place. Olsson (1979) has estimated that samples of peat require a correction of c. -30 years due to this effect. However, this is not always the case, and Stuckenrath (1977) has identified that certain saltmarsh plants preferentially uptake ^{14}C and may be too young by 150-200 years compared with wood samples.

3.8.3.3. Hard-water error.

In areas of carbonate rocks, such as the Cretaceous Chalk of the Hacklinge/Deal area, groundwater is often enriched in Dissolved Inorganic Carbons (DICs), thereby diluting the ^{14}C:^{12}C ratio. This problem is known as the "hard-water error". The extent of this problem was recognised by Webb and Moore (1982), for example, who in a study of the late Devensian vegetational history of the Whitlaw Mosses in Southeast Scotland, did not employ ^{14}C dating due to the calcareous nature of the sediments.

Opinions as to the effect of the "hard-water error" vary. Mook and van de Plassche (1986) state that in shallow water the ^{14}C activity is relatively quickly restored through carbon exchange between the atmosphere and the dissolved inorganic fraction to contemporary atmospheric levels. However, in a study of the effects of DICs from a karst limestone area of Yugoslavia, Marcenko et al (1989) observed total DIC ^{14}C activity in spring water 60-84% of modern activity. This hard-water effect resulted in the ^{13}C values for certain aquatic plant types having a greater enrichment of ^{13}C relative to the PDB, such as Phragmites (-28.1‰) and Potamogetonaceae (up to -29.7‰), both of which are probable components of the organic material dated in this study.

Clearly in the current study this is a cause of some concern, as the Lydden Valley is fed by water from two Chalk springs, ensuring a plentiful (but probably variable) supply of hard-water. Through the use of chemical, tritium and radiocarbon techniques Howard and Lloyd (1983) and Howard (1985) have been able to identify water bodies of distinct age in Chalk groundwater. However, in an attempt to quantify the effect on ^{14}C of DICs in spring water, Krajcar-Bronic et al (1986) studied the spring water in a karst aquifer and determined that the recharge system was open to the atmosphere. In this case the authors concluded that

> "atmospheric CO_2 contributes to the ^{13}C content and the ^{14}C activity of groundwater to an estimated extent which varies between 10 and 40% of DIC".

Details of the characteristics of the springs in the Hacklinge /Deal area are not available, although the possibility of changes in the background level of DIC in the groundwater during the Holocene cannot be ignored.

In a recent study of the ^{14}C content of freshwater in Sweden, Olsson (1986) observed that lake water had a mean enrichment of ^{14}C activity of 36‰, and fen water 208‰. Olsson concluded by stating that

> "Since some plants take up the greater part of the carbon dioxide they use from the sediment via their roots, the composition of the sediment and the accumulation rate may be of importance, resulting in various apparent age reservoirs... The present investigation may, however, be taken as a recommendation to date where possible, well-defined plant remains of bulk sediments".

Attempts have been made to avoid the problem of allochthonous carbonate by using AMS dating of recognisable plant macrofossils. For example, Andree et al (1986) have used AMS techniques to date plant macrofossils from lake sediments from the Western Swiss Plateau. In a comparison of the results derived from the AMS dating with those of adjacently sampled bulk samples of sediment, the authors concluded that for gyttjas and carbonates the age determinations of the two were approximately 800 ^{14}C yrs different. Therefore, the hard-water error may be overcome in two ways:

i. Laboratory correction.

ii. Selective dating of plant macrofossils.

Due to the lack of suitable material and resources, only the former technique has been employed in this study.

3.8.3.4. Contamination.

Contamination of a ^{14}C sample can occur because of the incorporation of either older carbon during sediment accumulation, or younger carbon following deposition. The hard-water error discussed above is an example of older carbon contamination, and other forms of old carbon contamination can occur as a result of the incorporation of allochthonous organic material in the sample material. Thus, following Tooley (1978) material with a high inorganic content was avoided, as this may include reworked organic material from estuarine sources, as were samples containing large amounts of *Detritus lignosa*.

Contamination by younger carbon may occur as a result of root penetration or the downward movement of younger humic acids. The deep rooting nature of *Phragmites* has been discussed above, and may result in the contamination of material by up to 845±210 ^{14}C years (Streif 1972), whilst van de Plassche (1980) estimates a possible error of *c*. 400 yrs In the current study much of the material sampled included *Phragmites* rhizomes, and all macroscopic remains of this plant were removed before dating.

The penetration of younger humic acids due to water percolation through the stratigraphic profile is avoided in laboratory preparation through the chemical separation of the acid-soluble fulvic acid and alkali-soluble humic acid from the more resistant cellulose and lignin. The effect of different chemical separation procedures has been illustrated by Williams (1989). In an analysis of a freshwater peat from a coastal site at Place Cove, South Lube, Maine, Williams (1989) applied a series of different chemical pretreatments to the peat, which was known to have formed c. 2000 yrs BP. Multiple dating employing different chemical pretreatments gave a series of dates between 2270+/-60 to 2980+/-80 yrs BP. In this study, Williams (1989) concluded that much of the variance reflected the younging effect of the soluble fractions compared with the bulk peat samples.

3.8.3.5. Laboratory error.

Recent concern over the accuracy of different laboratories has led Long and Kalin (1990) to state that

> "A significant number of users of ^{14}C data are losing the unquestioning confidence they had in ^{14}C dates...Even long-standing, well established laboratories have not been immune to inaccuracy problems".

Quantification of this problem when analysing a dataset of ^{14}C dates obtained from a number of laboratories over a long time period is almost impossible. Recent attempts at inter-laboratory cross-checking through the multiple-dating of tree-ring samples may help identify and correct such discrepancies and go some way to removing the "dark cloud gathering over the radiocarbon community" (Long and Kalin 1990). Within the current study all samples were analysed by the same laboratory which should at least ensure internal consistency.

Chapter Four: Lithostratigraphy and Seismic Survey Results.

4.1. Introduction.

This chapter presents the lithostratigraphic and seismic data collected from the East Kent Fens. The aim of the lithostratigraphic survey was to determine the nature of Holocene sedimentation in the area, and to identify locations suitable for subsequent palaeobotanical analyses. The seismic refraction survey was used to establish the form of the pre-Holocene subcrop in the Hacklinge/Marsh Lane/Sandfield Farm area.

4.2 Site descriptions.

4.2.1. The Little Stour Valley.

In 1962 Godwin described a shallow sequence of late-Holocene sediments overlying the weathered Chalk surface in the upper reaches of the Little Stour Valley at Wingham (Section 2.3.3). In an attempt to establish whether deeper sediments, which might bear a more direct relationship to changes in sea-level were present in the area, a series of cores was sunk in the lower reaches of the Little Stour Valley.

The Little Stour occupies a flat-bottomed valley approximately 800m in width and with a surface altitude between +0.5 and +2m OD. The surrounding valley sides rise gently to approximately +20m OD. In order to determine the nature and spatial extent of the Holocene sediments in the lower part of the Little Stour Valley (Fig.4.1.), two transects and one grid of close interval cores were made.

Following a number of preliminary cores it was found that up to 6m of unconsolidated organic and inorganic sediments were recorded above a gravel deposit which was impenetrable. This gravel deposit was later found to underlie most of the valley deposits in the area under study. Maps of the deposit were analysed at the Seaton gravel works (TR 25 2300 5900). These provided only local information, and described the thickness and composition of the gravel in the location of the works. A variable thickness of gravel, from several decimeters to a maximum of 10m was recorded, which was overlaid by 0-8m of unconsolidated sediments. Bore logs for the area were general and have not been included here, but illustrated the gravel surface over which clays and silts extended to a surface peat. The gravel was described as being clean, with a low sand and chalk content. Beneath the gravels were a series of silts and sands described as Thanet Beds (see Section 2.3.1), whilst to the immediate north of Seaton the gravels lay directly over Chalk.

Transect 1 was completed in order to establish the general nature of sedimentation in the valley. The grid of 13 cores was completed in order to assess the detailed spatial variability in the gravel base, as well as the nature of sedimentary changes at the northerly margin of the valley. Finally, Transect 2 was completed so as to establish the detailed nature of the upper organic deposit encountered in the most southerly bores of Transect 1.

4.2.1.1. Deerson Valley: Transect 1.

Transect 1 consisted of 16 cores, and extended from the foot of the valley slope below Preston Court (TR 26 2425 6070) to the sewage works on the opposite side of the valley (TR 26 2380 6120). The total transect length was 720m, and the sampling interval varied between 30m and 70m. The lithostratigraphy of Transect 1 is illustrated in Fig.4.2. The symbols used in data presentation are listed in Appendix 6.

The deepest deposit recorded in most cores was the gravel described above. Directly overlying this in many of the cores was a thin organic deposit which varied in thickness and composition. In a number of cores the upper part of the deposit had been eroded (cores 16, 17, 19, 23 and 8). In general the deposit was c. 0.10m thick. The transgressive contact had an altitudinal range of 2.13m, between a maximum altitude of -6.01m OD (core 16) and a minimum of -3.48m OD (core 7).

The composition of this deposit was variable, and in those cores where the transgressive contact had not been eroded it could be divided into two parts:

i. Immediately above the gravel surface the was a compact, slightly laminated, black and well humified Phragmites peat.

ii. This passed into a clay-rich turfa with some Phragmites (especially to the south of the transect), which was transitional to the overlying clay or silty-clays. This was well illustrated in cores 15, 18, 21, and 7.

Above the basal organic deposit was a variable sequence of predominantly inorganic sediments, with laminated silts and sands found in the centre of the valley, and finer silts and clays to its margins. The latter were recorded at altitudes above the basal organic deposit from c. -0.5 to -1.5m OD. These finer-grained deposits extended 220m across the valley from the southerly end of the transect, and 190m from the northerly end of the transect. Typically they consisted of soft unlaminated silty-clays with some organic material, and occasional shell remains (Scrobicularia).

In the central part of the valley between cores 20 and 24, was found a sequence of laminated silts and sands. Only in core 22 did these sediments directly overly the gravel surface. The laminated sediments were wedged out towards the valley sides by the finer-grained sediments described above. Above the laminated silts and sands in cores 20-23 were unlaminated silts and clays.

At approximately the same altitude at which the laminated sediments in the centre of the valley gave way to finer-grained sediments, a thin organic deposit was recorded towards the margins of the valley (cores 14-16, 18-19, and 6 and 8). This deposit varied in thickness between 0.08m (cores 8 and 5) and c. 1.00m (core 14), and was generally thicker in the southern part of the transect where it was found at a lower altitude. In most cores towards the centre of the transect clays and silts passed into an upper iron-stained orange-brown silty-clay, which in turn extended to the surface.

Cores 14 and 4-5 were the most landward of the cores in the transect. In cores 4-5 an organic-rich silt or clay (25% turfa) 0.70m thick with some shells (unidentified) was recorded beneath the topsoil. In core 14 a much thicker organic deposit was present. The regressive contact was recorded at -1.64m OD with a transition from a battleship-grey silty-clay to a turfa-rich clay. This transition zone was 0.22m thick, and at -1.42m OD passed into a brown fibrous monocot peat with some Phragmites. The Phragmites content decreased at -0.12m OD where the peat became well humified and compact. This humified peat was overlain by a clay-rich turfa with some Phragmites which passed into a dark grey clay with some Phragmites. This deposit was 0.60m thick and was overlain by a dark grey clay with turfa and Phragmites, which extended to the surface.

4.2.1.2. Deerson Valley: grid of cores.

A grid of 13 cores has enabled the detailed pattern of the pre-Holocene subcrop at the northerly end of Transect 1 to be established (Fig.4.1.). The overlying lithostratigraphy was similar to that recorded in Transect 1, and is recorded in full in Appendix 1. Gravel was not encountered in all cores, and three different lower deposits were recorded:

i. In cores 1, 4, and 5 an impenetrable orange-brown sandy-silt was recorded extending to an altitude of -2.69m OD in core

5. This deposit resembled a Brickearth deposit (Section 2.3.1).

ii. At a slightly lower altitude was recorded a series of impenetrable silts or clayey-silts which were green-blue or khaki-brown in colour, which are tentatively interpreted as the Thanet Beds. These silts were recorded in cores 2, 12, and 13, and extended up to at least -3.12m OD in core 2.

iii. The gravel formed the third lower facies recorded and was recorded in all remaining cores. Nowhere was the gravel surface found above -3.00m OD, and it was recorded at a maximum depth of -4.59m OD in core 6.

Overlying these lower sediments was a similar sequence of sediments to that recorded in Transect 1. A black, well humified Phragmites peat was recorded directly above the gravel in cores 3, and 7-10. Nowhere was the transgressive contact of this deposit eroded. The variable spatial distribution of this peat may be related to the altitude of the gravel base, and the maximum altitude of the transgressive contact was -3.48m OD (core 7).

Silts and clays dominated the rest of the sedimentary record, with the exception of a thin organic-rich clay and the remnants of a surface peat recorded in cores 4, 11, 12, and 13. An organic-rich clay recorded in cores 3, 6, and 8, was similar in altitude and composition to that recorded in Transect 1. The uppermost sediments consisted of either an iron-stained silty-clay or silty-sand (cores 1-3, 5-8). In cores 4 and 10-13 an upper organic deposit was recorded which in cores 10-13 was in turn overlain by a fine orange sand limited to the southwestern edge of the grid.

4.2.1.3. Deerson Valley: Transect 2.

The lithostratigraphy recorded in Transect 1 suggested that any upper organic deposits were restricted to the valley margins. In order to determine the detailed spatial extent of these upper organic sediments, as well as the deeper sediments overlying the gravel, a transect of nine cores was made at close intervals extending northwards from the foot of the valley slope (TR 26 2415 6040) 170m across the valley floor (Fig.4.1.). The first five cores were made at 10m intervals, the remaining four at 30m intervals. The lithostratigraphy of the transect is illustrated in Fig.4.3. The transect was extended beyond core 29 in order to establish the continuity of the organic deposit overlying the gravel, despite the absence of the upper organic deposit in cores 29-33.

As in Transect 1 all cores were stopped by gravel (except core 25 which was underlain by an impenetrable orange sandy-silt). The altitude of this gravel fell from -3.07m OD (core 26) to -4.98m OD (core 33), and was overlain by a lower organic deposit in cores 32 and 33, where the gravel was below -4.80m OD. In core 32 the upper part of the deposit had been eroded, but in core 33 the transition from peat to the overlying silt-clay was gradual.

Above the gravel in the landward cores of the transect were laminated sands and silts. These were thickest in core 29 where they extended between -3.49m and -0.79m OD. The laminated sediments were overlain by a battleship-grey silty-clay in cores 25, 26, 27, 28 and 30. In cores 30 and 31 there was a thin organic deposit at approximately -0.50m OD. As in Transect 1 this was a <u>turfa</u>-rich clay and was 0.10 and 0.24m thick in cores 30 and 31 respectively.

The upper organic deposit recorded in cores 25-28 was very limited in its spatial extent, and beyond 30m from the valley edge was wedged out by the laminated silts and sands recorded in core 29. The nature of the upper organic deposit is discussed in detail below.

The regressive contact to this organic deposit rose in altitude from +0.05m OD in core 25 to +0.85m OD in core 28 over a distance of 90m. The deposit was thickest in core 25 and could be divided into four units:

i. The battleship-grey silty-clay recorded below the regressive contact passed into a transitional deposit with a high Phragmites and clay content, which was 0.16m thick.

ii. This transitional deposit passed into a well humified Phragmites dark brown peat with some clay 0.87m thick.

iii. This in turn was overlain by a clayey-turfa.

iv. Finally this deposit passed into a dark-brown well humified turfa with occasional silt.

4.2.2. North and South Poulders.

In order to determine the nature and spatial extent of the Holocene sediments recorded around North and South Poulders, three transects and a grid of 9 cores at 30m intervals was completed (Fig.4.4.). This site was selected because commercial bore-hole logs of the Kent County Council indicated Holocene sediments in the area extending to a depth of approximately -10 to -12m OD with at least two intercalated peat beds.

The first transect of 12 cores extended from the Sandwich/Deal roundabout (TR 25 3170 5870) parallel to the Sandwich/Ash road towards Each End (Fig.4.4.). At the extreme western end of this transect an additional 6 cores were sunk in order to determine the spatial extent of an organic deposit recorded here. The second transect of cores was completed at

South Poulders (TR 25 3180 5880) running parallel to the Sandwich bypass. The lithostratigraphy recorded in each of these surveys are described below.

<u>**4.2.2.1. North Poulders: Transect 1.**</u>

Transect 1 was 560m long and consisted of 12 cores. The general altitude of the ground surface along the transect varied between +1.69m OD and +2.16m OD. The sampling interval varied between 85m and 25m depending on the degree of lithostratigraphic variability encountered, and the lithostratigraphy recorded is illustrated in Fig.4.5. In the base of all cores was an impenetrable green-blue or brown silt or sandy-silt. This deposit formed an undulating surface between -3.21m OD (core 1) and <u>c</u>. 0.45m OD (core 7). Unconsolidated Holocene sediments up to a maximum thickness of 5.00m were recorded above this surface.

The deepest sediments recorded were in core 1 where a soft battleship-grey silty-clay with a trace of detrital organic material was recorded between -3.21m OD and -2.01m OD. This passed into a soft dark grey clayey-silt, 0.10m thick, which in turn was overlain by laminated grey or dark grey silts which extended from -1.91m OD to +0.67m OD. These were the only laminated sediments recorded in the transect, and to the west of the transect the sediments became finer, and were characteristically very soft grey or grey-blue silty-clays with traces of well humified organic material. In all cores the uppermost inorganic sediments were sticky grey or brown clayey-silts with some iron-staining.

The only significant organic deposits recorded between cores 1 and 7 were in cores 3 and 4. In core 3 a soft organic-rich clay 1.35m thick was recorded intercalating a blue silty-clay. The altitude of the regressive and transgressive contacts were -2.20m and -0.85m OD respectively. In core 4 a well humified dark grey or black <u>turfa</u> with some clay was recorded above a coarse white sandy-silt. The deposit was 0.66m thick, and the organic content decreased from 50% to 25% in its upper part. The altitude of the base of the deposit was -1.18m OD, and the transgressive contact (which was eroded) was at -0.53m OD. The deposit was overlain by a dark grey or black clay with some unidentified shells.

Towards the west of the transect further organic sediments were recorded in cores 10 and 11, intercalated between a lower creamy-white shell-rich clay and a grey or khaki-brown silty-clay. In core 11 the shell-rich clay was directly above the lower impenetrable green-brown silts at -1.49m OD, whilst in core 10 it overlay a dark grey or black clay with some silt at -1.55m OD. In cores 10 and 11 the deposit passed into a brown organic-rich clay with some silt, which was 0.17m and 0.58m thick respectively, and in core 11 could be divided into two units:

i. The lower unit consisted of a soft, light brown and well humified organic-rich clay with some shells (Hydrobia spp.) 0.38m thick.

ii. This passed into an upper unit which consisted of a well humified dark brown peat with some Substantia humosa and turfa 0.20m thick.

The altitude of the transgressive contact recorded in cores 10 and 11 was -0.85m OD and -0.29m OD. In core 12 the shell-rich clay passed into a khaki-brown clayey-silt with some shells and turfa at -0.14m OD.

Above this sequence were further silts and clays which extended to the surface, except in cores 11 and 12 where a localised channel-fill deposit of wet dark grey or black sand was recorded immediately below the surface.

4.2.2.2. North Poulders: grid of cores.

The most significant organic sediments recorded in Transect 1 were to the west of the transect in cores 10 and 11. In order to determine the spatial extent of this deposit a further 6 cores were made in this area with a 30m sampling interval (see additional short transects in Figs. 4.6., 4.7.).

The deepest deposit recorded was the same green-brown or grey compact silt or sandy-silt recorded in the base of all cores described above. The basal organic and shell deposits recorded in cores 10-12 were not recorded in any of these additional cores.

Above these lower silts, was a thick sequence of unlaminated silts and clays with traces of organic material and broken shells. Theses sediments passed into a silty-clay or sandy-silt with iron-staining and extended to the surface in cores 13-18.

4.2.3. South Poulders: Transect 2.

In order to establish further the nature and spatial extent of the Holocene sediments recorded in this area, a second transect of six cores was completed running parallel to the Sandwich by-pass towards Deal at South Poulders (TR 3180 5850) (Fig.4.4.). The sampling interval between cores was 50m and the lithostratigraphy recorded is presented in Fig.4.8.

In all cores a compact green-brown silt with some sand and rare turfa was recorded, over which were recorded Holocene sediments to a maximum thickness of c. 5.00m (core 6). The deepest Holocene sediments recorded were in core 6, where a laminated clayey-silt was recorded between -3.85m OD and -0.90m OD. This was the only laminated deposit recorded in the transect, and passed into a light-brown silty-clay with traces of turfa. Above this deposit was a compact iron-stained silty-clay which was 0.50m thick and which extended to the surface.

The only organic sediments recorded were in cores 5, 3 and 1. In core 5 a black <u>turfa</u>-rich clay was intercalated between a lower clay with a trace of silt and some <u>turfa</u>, and an upper dark grey or brown clayey-silt. The deposit was 0.15m thick, and the altitude of the regressive and transgressive contact was -0.90m and -0.75m OD respectively. In core 3 an organic deposit was recorded at a similar altitude, intercalated between a thin dark-grey silt and an upper organic-rich dark grey silty-clay. The deposit was 0.78m thick and the altitude of the regressive and transgressive contact was -1.11m and -0.33m OD respectively. In composition the deposit could be divided into two units:

i. The lower unit consisted of a dark brown clay-rich peat with some <u>Substantia humosa</u> 0.28m thick.

ii. Above this was a dark grey clay with 25% <u>turfa</u> 0.50m thick.

In core 1 a soft well-humified organic clay intercalated a lower coarse white or grey silt and an upper soft organic clay with some silt. The altitude of the regressive and transgressive contact was -1.04m and -0.97m OD respectively.

4.2.4. Stewart's Folly.

In order to determine the nature and spatial extent of the unconsolidated Holocene sediments recorded to the south of Sandwich, four transects of cores were completed near Stewart's Folly (TR 25 3350 5680 - Fig.4.9.). The general topography of the area consists of a flat plain surrounded by higher land on which the Sandwich/Deal road and Coventon Lane are built. In general the altitude of the land surface in the area under study varied between +0.50m and +2.00m OD. The lithostratigraphy of each of these transects are discussed in turn below.

4.2.4.1. Stewart's Folly: Transect 1.

Transect 1 consisted of 7 cores at 30m intervals extending parallel to Coventon Lane (Fig.4.9.). The altitude of the ground surface varied between +1.92m OD and +1.34m OD, and the lithostratigraphy recorded is illustrated in Fig.4.10. Chalk was recorded in the base of all cores between +1.11m OD (core 7) and -0.10m OD (core 4). The Chalk subcrop was occasionally overlain by flints, and was penetrated to a maximum of 0.20m in core 3. Overlying this surface was a brown or orange silty-sand or sandy-silt with some iron-staining which extended to the surface in all cores.

4.2.4.2. Stewart's Folly: Transect 2.

Transect 2 consisted of 5 cores at 30m intervals and was located 150m to the east of Transect 1 (Fig.4.9.). The altitude of the ground surface varied between +0.81m OD (core 3) and +1.87m OD (core 5), and the lithostratigraphy recorded is illustrated in Fig.4.11. Chalk or flints were recorded in the base of all cores, and above this surface was a sequence of orange or brown silts and sands with some iron-staining, with the exception of cores 3 and 5 in which finer grained inorganic sediments were recorded.

In core 3 a blue-brown-grey silty-clay was recorded between -0.79m OD and -0.49m OD, which passed into a creamy-brown silty-clay with some Phragmites which extended to 0.05m OD. Above this deposit was a 0.36m thick, well humified crumbly dry peat with some sand and flecks of chalk, which in turn was overlain by a light-brown silty-sand with some iron-staining which extended to the present surface. The altitude of this transgressive contact was +0.41m OD. In core 5 a 0.20m thick buttery dark grey silty-clay was recorded between +0.69m and +0.89m OD.

In order to establish the spatial extent of the upper organic deposit recorded in core 3 two further cores were completed to the immediate east of this core (Fig.4.9., Appendix 1). In core 6 a similar lithostratigraphic sequence to that described for core 3 was recorded, with a well humified, dry and crumbly peat with occasional sand grains and detrital wood recorded between a lower silty-clay and an upper iron-stained silty-sand. In core 7 no organic sediments were recorded, and the Chalk subcrop was overlain by a soft orange sandy-silt which passed into an orange-grey silty-sand with iron-staining which extended to the present land surface.

4.2.4.3. Stewart's Folly: Transects 3 and 4.

Transects 3 and 4 were located 350m to the south-east of Transect 2 (Fig.4.9.). The transects consisted of five and six cores respectively made at 25m intervals. The two transects were 90m apart, and to aid in the lithostratigraphic description they are discussed jointly. The land surface in the area varied between +1.62m OD and +1.07m OD, and the lithostratigraphy recorded in the two transects is presented in Figs.4.12. and 4.13.

The deepest deposit recorded in all cores was the Chalk or gravel surface, which varied in altitude between -1.08m OD (core 11), and -3.07m OD (core 4). Unconsolidated sediments were recorded over this surface to a maximum thickness of 4.20m (core 4). Above this surface in cores 3, 5 and 7-9 and 11 was a sandy-silt or silt which was green-blue or grey in colour which resembled the Thanet Sands. In cores 4 and 10, which were approximately in parallel with each other (see Fig.4.9.), an orange sand or silty-sand resembling Brickearth was recorded.

In cores 1, 2 and 6 the Chalk or gravel surface was overlain by a dark grey or black silt with occasional remains of _Scrobicularia_, which was in turn overlain by an organic deposit. This organic deposit was also recorded in cores 7-9, where it overlay above the green or blue silts or sandy-silts described above. The altitude of the regressive contact (or base of the deposit in cores 1, 2, and 6) was between -1.99m OD (core 1) and -0.13m OD (core 6). The deposit varied in thickness between 0.11m (core 6) and 0.86m (core 8). In all cores this deposit was overlain by inorganic sediments and the altitude of the transgressive contact varied between -1.51m (core 7) and -0.02m OD (core 6). In cores 1 and 7 the transgressive contact was eroded, which may explain the steep gradient observed for this contact between cores 1-2, and 7-8. The deposit varied in composition, but was generally a dark brown _Phragmites_-rich _turfa_, with some woody remains recorded in core 8 and core 1.

Where this organic deposit was not recorded, the Chalk or gravel base was overlain by inorganic sediments which extended to an upper organic deposit. In core 3 an iron-stained clayey-silt with some _Phragmites_ was above impenetrable green-grey sandy-silt, and in core 4 the impenetrable orange silty-sand was overlain by a dark grey silt with some _turfa_. In cores 5 and 11 an iron-stained sandy-silt was also recorded above the lower sandy-silts at between +0.14m OD and +0.67m OD, and +0.12m OD and +0.53m OD respectively.

Above the lower of the two organic deposits in cores 1, 2, 6-9 was a battleship-grey silty-clay with some remains of _Phragmites_. This was overlain by the upper organic deposit, which was in turn overlain by further inorganic sediments. The former varied in thickness between 0.10m (core 6) and 0.43m (core 11), and the regressive contact was recorded between +0.28m OD (core 4) and +0.93m OD (core 6). In composition the deposit was typically a well humified _turfa_ with some _Phragmites_ remains. In cores 2, 3 and 5 charcoal remains were recorded, and in core 2 a number of distinct inorganic horizons were recorded within the organic deposit itself. An example of these thin inorganic horizons is illustrated through a description of the deposit recorded in core 2.

Here, the regressive contact was overlain by a 0.07m thick _Phragmites_-rich _turfa_ which was slightly laminated. This in turn was overlain by a brown _turfa_ with some clay and charcoal between +0.64m and +0.72m OD, which passed into a grey silt with some sand and occasional charcoal remains. This unit was 0.04m thick, and was overlain by a moist _turfa_ which extended to the transgressive contact at +0.92m OD. It would appear from the lithostratigraphic data that these represent periods of sediment inwashing.

Above this organic deposit in all cores were inorganic sediments which extended to the present land surface. Typically these were grey or brown silts with some clay and iron-staining.

4.2.5. Hacklinge and the Lydden Valley.

In the following section data from four lithostratigraphic surveys completed in the Hacklinge/Lydden Valley area of the East Kent Fens are described. The area under study was centred around Hacklinge, 2km north of Deal on the A258 Sandwich/Deal road. The topography of the area consists of a flat coastal plain, approximately 3km in width, which extends in an easterly direction from the foot of the Chalk dip-slope towards the coast. At HAcklinge, the Sandwich/Deal road drops to the level of the coastal plain and crosses the South and the North Stream (Fig.4.14.). These streams drain two small valleys, each about 3km in length, both of which have freshwater springs at their heads. These valleys trend parallel to the Sandwich/Deal road and join to cross the Chalk ridge at Hacklinge.

The four lithostratigraphic surveys were as follows:

i. The first survey consisted of two transects of cores which extended from the foot of the dip-slope below Mercer's Farm (TR 25 3375 5430) to the Sandwich/Deal road at Hacklinge (cores H1-H17).

ii. The second survey was a detailed 4 X 4 grid of cores completed near Hacklinge Farm, where material for ^{14}C and palaeobotanical analyses were collected (cores GR1-GR16).

iii. The third survey consisted of a long transect of cores across the Lydden Valley designed to establish the general lithostratigraphy of the coastal plain, and to determine the relationship between the sediments recorded at Hacklinge and those towards the coast (cores LV1-9).

iv. The final survey was also completed in the Lydden Valley and consisted of a series of cores between Roaring Gutter Dyke and the coal tip, and which was completed as part of the seismic refraction survey (cores LV10-14).

4.2.5.1. Hacklinge: Transects 1 and 2.

The initial interest in the lithostratigraphy of the Hacklinge area arose from the a series of cores made in the immediate vicinity of Hacklinge Farm as part of an undergraduate dissertation in 1987/8. This site was first identified by Rose (1953), who recorded a thick surface peat below which were blue inorganic sediments. Rose (1953) only described the lithostratigraphy of one hand-core, and no further lithostratigraphic studies in the area have been recorded.

The cores completed in 1987/8 indicated a sequence of intercalated organic and inorganic sediments to a depth of at least -5.00m OD (Long 1988). A transect of eight cores

(Transect 1, H1-8) was later completed and a piston-core collected and analysed for its pollen and diatom content (Long 1988). This formed the basis for the investigation of the sediments in the area, but was completed at a time when the authors' skills at lithostratigraphic description were comparatively limited. Although the gross lithostratigraphic descriptions are still of some use, the interpretation of the lithostratigraphy using the Troels-Smith scheme is not comparable with lithostratigraphic data collected during the completion of this thesis. In 1991 the site was resampled with a transect of nine cores running approximately parallel with Transect 1 (Transect 2, H9-17).

In the following section Transect 2 is described in detail, and reference made to Transect 1 where appropriate. Figs. 4.15. and 4.16. illustrate the lithostratigraphy recorded in the two transects. Four cores from the grid of cores (see below) have been added to the eastern end of each transect so as to extend the transect across the entire width of the valley.

The composition of the pre-Holocene subcrop was variable, and consisted of either Chalk (cores GR4, GR8, GR12 and GR16) or a sandy-silt, which resembled a Brickearth deposit (H9-13). This subcrop dipped steeply at both valley margins, and was recorded to a maximum altitude of -7.49m OD in core H13. The deepest inorganic Holocene sediments were recorded in core H16, where a battleship-grey silty-clay was recorded between -8.38m and -7.76m OD. This was overlain by an organic deposit at -7.76m OD, which was recorded in cores H11-17 and GR4, although only penetrated in core H16. In cores H11-13 and GR4 this deposit rested directly on the pre-Holocene subcrop, and rose in altitude towards the valley margins as the pre-Holocene subcrop also rose. In cores H14-17 and GR4 the deposit was characteristically a well humified and compact black peat with some Phragmites and occasional woody detritus. To the west of the transect between cores H13-11 the deposit was more variable in composition, with a number of thin intercalated shell deposits. A similar complex sequence of shell marl deposits intercalated within a well humified peat was found in the western cores of Transect 1 (H3-4).

In all cores this organic deposit was overlain by a thick predominantly inorganic deposit, and the altitude of the transgressive contact varied between -8.16m (core H17), and -4.30m OD (core H11). The deposit thinned towards the valley margins, and attained a maximum thickness of 3.46m in core H17 and in all cores was overlain by further organic sediments. The altitude of the regressive contact was deepest in the centre of the valley and rose to the margins, and was recorded at a minimum altitude of -3.77m OD in core H11. In composition the deposit was characteristically a soft battleship-grey silty-clay with some Phragmites. The deposit was laminated, and slightly coarser in the centre of the transect (for example between -6.52m and -5.96m OD in core H16) compared with the margins of the transect (cores 11 and GR4), where it was a clay with no silt.

In core H15 a thick shell marl was recorded between -5.85m and -5.22m OD, which was transitional to the lower inorganic and upper organic deposit. The shell content of this deposit varied between 75% and 25%. Thinner shell deposits were recorded at slightly higher altitudes in cores H16 and H17.

The overlying organic deposit extended to the surface in cores H9-13, and could be divided into two units:

i. A lower unit which consisted of a well humified peat with some Phragmites.

ii. An upper unit which consisted of a fibrous Phragmites-rich peat with some turfa.

In addition, thin inorganic deposits were recorded within this organic deposit to the west of the transect. For example, in core H11 a thin shell marl was recorded between -2.44m and -2.31m OD. In cores H10 and H13 a shell-rich clay was recorded between -1.50 and -1.49m OD and -1.47m and -1.34m OD respectively. Finally, in core H14 a soft grey/brown organic-rich clay was recorded between -1.88m and -1.78m OD. It is probable that these inorganic sediments accumulated under sedimentary conditions associated with the deposition of the inorganic deposits which interleave the organic sediments in cores H15-17 and GR4-GR8.

In core H16 the organic deposit was the thinnest recorded (0.67m), and was overlain by a thick inorganic deposit which was in turn overlain by another organic deposit. The altitude of the transgressive and regressive contacts were -4.03m and c. -1.30m OD. The inorganic deposit was characteristically a battleship-grey silty-clay, and although this was not laminated it appeared to have accumulated in a former channel. This conclusion is drawn on the basis of the configuration of the transgressive contact and the lateral spread of subsequent inorganic deposit from this core.

This deposit was recorded in cores H15, H17, and GR4, and in these cores the organic content of the deposit was 50%. Above this deposit were further organic sediments which were recorded in cores H15, H17 and GR4. These organic sediments were overlain by an inorganic deposit which varied in composition between a clay-rich turfa with some Phragmites (core H15), a light brown clay with some turfa and Phragmites (core H17), and a Phragmites-rich brown turfa (core GR4).

Above this was a thin predominantly inorganic deposit, also recorded in cores H15, H17 and GR4, and which was in turn overlain by an organic deposit. The altitude of the regressive contact was approximately -2.10m OD. In core H15 this inorganic deposit was a battleship-grey clay with some silt and occasional shells, and in cores H17 and GR4 was an organic-rich clay.

In general the overlying organic deposit was a Phragmites-rich turfa, which in core H15 passed into a black well humified turfa peat with some Phragmites. This was overlain by a further thin inorganic deposit which was recorded in cores H14, H15, H17, and GR8. The altitude of the regressive contact varied between -1.88m (core H14) and -1.39m OD (core H17). The deposit was generally an organic-rich clay, although the shell marl recorded in core H13 could have been a western expression of this deposit, as might the thin clay-rich turfa recorded in core H10 at a comparable altitude. The deposit was overlain by a surface peat which was recorded in all cores (except GR8), including core H16.

4.2.5.2. Hacklinge: grid of cores.

Prior to the collection of material for palaeobotanical analyses and ^{14}C dating, a further lithostratigraphic survey was completed at Hacklinge in order to establish the three-dimensional nature of the Holocene sediments. Holocene sediments were sampled to a depth of -11.46m OD, and a maximum of five organic and four inorganic deposits were recorded. In the following description each deposit will be discussed in turn and a graph illustrating the thickness of each deposit as well as the altitude of its transgressive and regressive contacts is presented. The full lithostratigraphic description of these cores are in Appendix 1.

In most cores the subcrop of the pre-Holocene surface was located. The surface was generally of weathered Chalk, in places overlain by coarse green or blue sands and silts. The surface dipped in both a southerly and westerly manner as the valley of the North Stream turned through 90^0 at this point (Fig.4.14.).

The deepest sediments recorded were in core GR2, where an organic deposit overlying Chalk was found at -11.46m OD. The deposit was 0.20m thick and was overlain by a clay containing some turfa and Hydrobia spp. The altitude of the transgressive contact was -11.26m OD. The deposit was a compact and slightly laminated, well humified turfa, with occasional unidentified shell remains. The spatial extent of this deposit is not known as it was only recorded in core GR2.

The clay overlying this organic deposit was 0.20m thick, and passed into a Phragmites-rich clay between -11.26m OD and -11.06m OD. This deposit was in turn overlain by a thick deposit of soft grey silty-clay with some Phragmites which extended from -11.06m OD to -8.80m OD. A similar dark grey silty-clay was recorded in core GR1 extending from -9.44m OD to -9.24m OD. Whilst in core GR1 this silty-clay passed at -9.24m OD into a 0.10m thick organic-rich clay with some Substantia humosa, in core GR2 the silty-clay was overlain by a distinct organic deposit. The altitude of the regressive contact in GR2 was -8.80m OD, and this was in turn overlain by a grey silty-clay with some eroded peat pockets and remains of Phragmites. The transgressive contact was at -8.68m OD, and the deposit was divisible into two distinct units:

i. A lower unit which consisted of a black turfa 0.04m thick.

ii. An upper unit which consisted of a soft yellow clay with some turfa and unidentified shells 0.08m thick.

The overlying silty-clay extended from -8.68m OD to -8.30m OD, where it passed into a further organic deposit.

In core GR2 the regressive contact at -8.30m OD was overlain by an organic deposit 0.84m thick, which was in turn overlain by a battleship-grey silty-clay. The altitude of the transgressive contact was -7.46m OD. The peat was well humified, compact and red or brown in colour with some detrital wood and Phragmites. Due to its compact nature and the fact that in cores GR6, GR9, (and possibly GR4), the deposit rested directly on the pre-Holocene surface, only in core GR2 was the deposit penetrated by hand-coring. The deposit was thickest in core GR2 and thinnest in core GR5 (0.19m), although the transgressive contact in core GR5 showed signs of erosion. The altitude of the base of the deposit (as opposed to the regressive contact) varied between -8.30m OD (core GR2) and -5.53m OD (core GR9). The altitude of the transgressive contact varied between -7.46m OD (core GR2) and -5.53m OD (core GR9). These data are presented graphically in Fig.4.17a.

Fig.4.17a illustrates the large altitudinal range over which this deposit was recorded from an area only $90m^2$. The deposit was only penetrated in core GR2, and therefore it was not possible to establish whether the altitude or gradient of the pre-Holocene surface had exerted any direct control on sedimentation, as the database is too small. The deposit was only recorded in the westerly and southerly edges of the grid where the pre-Holocene surface was below approximately -5.50m OD. The spatial extent of the deposit, combined with the form of the pre-Holocene surface suggested that it has accumulated on the margins of the channel of the North Stream as it turns though 90° at this point.

A thick inorganic deposit was recorded above this peat in cores GR2-7, GR9 and GR13, and was in turn overlain by a further organic deposit. The altitude of the regressive contact varied between -4.64m OD (core GR2) and -3.28m OD (core GR7) and the deposit varied in thickness between 2.82m (core GR2) and 0.65m (core GR7). These data are presented graphically in Fig.4.17b. The deposit was typically an unlaminated clay with some silt and herbaceous material, commonly with Phragmites remains. It was soft and battleship-grey or blue in colour.

Fig.4.17b indicates that as the altitude of the transgressive contact increased, so the thickness of the deposit decreased. The reason for this is the relatively constant altitude of the regressive contact. The deposit was recorded in the westerly and southerly part of the grid to an approximate altitude of -3.30m OD, and appears to have accumulated along the margins of the channel which flowed through 90° at this point. The deepest transgressive contacts were recorded in cores GR2, GR5, and GR3, all on the south-westerly corner of the grid. The transgressive contact gradually rose in cores GR4, GR6, GR13, GR9, and finally GR7 (data from core GR1 are omitted because the thickness of this deposit is not known). As transgressive contacts were recorded at successively higher altitudes, so the thickness of the deposit continued to decrease.

Overlying the regressive contact was a further organic deposit which was recorded in all cores except GR11, GR12 and GR16. In cores GR8, GR10, GR14 and GR15 this deposit accumulated directly on the Chalk surface. The deposit varied in thickness between 0.50m (core GR8) and 1.80m (core GR3), and was in turn overlain by a thin inorganic deposit. The altitude of this transgressive contact varied between -3.35m OD (core GR5) and -1.82m OD (core GR8). These data are presented graphically in Fig.4.17c.

The composition of this deposit was variable. Above the regressive contact in cores GR1, GR2, GR5, and GR9 a thin, soft yellow-brown Phragmites-rich clay with some turfa and occasional shells of Hydrobia spp. were recorded. This deposit varied in thickness between 0.10m (core GR9) and 0.29m (core GR2), and was overlain by a well humified turfa with some Phragmites and occasional woody remains. In those cores where this deposit was not recorded, a Phragmites-rich turfa was found overlying the regressive contact, and in cores GR4, GR6, GR7, GR9 and GR14, woody remains were recorded near this contact.

Fig.4.17c illustrates that as the altitude of the regressive contact became higher, so the thickness of the deposit decreased, although in cores GR6 and GR3 the deposit was far thicker than in adjacent cores. Above -3.28m OD the deposit was only recorded as a basal deposit, and became progressively thinner as the altitude of the Chalk subcrop rose towards -2.30m OD.

The overlying inorganic deposit was recorded in all cores except GR11, GR12, and GR16, and varied in thickness between 0.07m (core GR13) and 0.95m (core GR5). The deposit was in turn overlain by further organic sediments. The altitude of this regressive contact varied between -2.96m OD (core GR13) and -1.76m OD (core GR8). These data are presented graphically in Fig.4.18a. The composition of the deposit was variable, although in most cores it was characteristically a soft blue-grey _Phragmites_-rich clay. In cores GR1, GR2, and GR5, where the deposit was thickest, the organic content was less than 25%.

The deepest transgressive contacts were recorded in cores GR5, GR2, GR4, GR13, GR1, GR9, and GR3, which were all located on the westerly and southerly edges of the grid. Higher transgressive contacts were recorded in the inner cores of the grid (GR7, GR6, GR10, GR14, GR15 and GR8).

Above the regressive contact was a further organic horizon which in cores GR6-8, GR10, GR14 and GR15 extended uninterrupted to the present surface, but in cores GR1-5, GR9 and GR13 was overlain by inorganic deposits. In the latter cores the altitude of this transgressive contact varied between -2.96m OD (core GR13) and -2.04m OD (core GR1). The deposit varied in thickness between 0.10m (core GR2) and 0.60m (core GR4). The data describing this deposit are presented graphically in Fig.4.18b.

The composition of the deposit varied between a clay-rich Phragmites-turfa (cores GR1, GR2, GR9 and GR13), and a Phragmites-rich turfa (cores GR3-5). In cores GR6-8, GR10, GR14 and GR15 the deposit extended to the surface, with a maximum thickness of 1.60m (cores GR6 and GR7). In most cores it consisted of a lower light-brown Phragmites-rich turfa, and an upper turfa with less Phragmites. In cores GR5-8 however, one or two thin inorganic horizons were recorded. These were variable in composition, but in general were coarse sand deposits with small pieces of gravel and chalk flecks. In core GR6 two such horizons were recorded, one between -1.46m OD and -1.39m OD, and a second between -1.26m OD and -1.21 OD. (The presence of two similar horizons in core GR5 above the overlying clay deposit, suggest that they post-date the deposition of this inorganic deposit).

Fig.4.18b illustrates that the deposit extended to the surface in cores GR6-8, GR10, GR14 and GR15, but was overlain by inorganic sediments in those cores on the westerly and southerly edges of the grid. The thickness of the organic deposit increased dramatically in these cores. The regressive contact of this deposit was recorded over a range of altitudes, and above -2.04m OD transgressive contacts were not recorded. The inorganic deposit which was above the transgressive contact in cores GR1-5, GR9 and GR13 varied in thickness between 0.05m (core GR4 and GR13), and 0.34m (core GR5). The altitude of this regressive contact ranged between -2.63m OD (core GR13) and -1.80m OD (core GR1). These data are presented graphically in Fig.4.18c, which illustrates that the deposit was thickest in cores GR2, GR5 and GR1. The spatial extent of the deposit was again limited to the southerly and westerly edges of the grid. The deposit was characteristically a soft blue or grey Phragmites-rich clay. The organic content is 50% or greater in cores GR3, GR4, GR9 and GR13 where the deposit was also at its thinnest. The overlying organic deposit extended to the surface and could be divided into two units, with a lower light-brown Phragmites-rich turfa, and an upper dark brown *turfa* with less *Phragmites*.

4.2.5.3. The Lydden Valley.

In order to determine the general lithostratigraphy of the Holocene sediments in the Lydden Valley, a transect of nine cores was completed extending from Hacklinge Farm in an easterly direction towards the railway (Fig.4.14., cores LV1-9). A second transect of cores (LV10-14) was completed extending from the pumping station near Roaring Gutter Dyke (TR 25 3485 5485) south-eastwards towards the coal tip (TR 25 3575 5440). The sampling interval in both transects was approximately 2-300m which was the coarsest resolution of sampling undertaken. The lithostratigraphy recorded is illustrated in Figs.4.19. and 4.20. The surface altitude of the Lydden Valley varied between approximately -0.70m OD and +0.88m OD. In the immediate vicinity of Hacklinge Farm the ground surface was notably lower than that of the Lydden Valley (for example cores LV1 and LV2).

4.2.5.4. Lydden Valley: Transect 1.

The Chalk subcrop was located in all cores except LV3 and LV4. Intercalated organic and inorganic sediments dominated the lithostratigraphy to the east of the transect (cores LV1-5), whilst to the west of the transect inorganic sediments dominated. In this westerly part of the transect the Chalk formed an undulating subcrop with an altitude of between -1.50m and -2.75m OD. (Fig.4.19.).

The deepest Holocene sediments were recorded in core LV4, where a dark brown, impenetrable and well humified *turfa* with some *Phragmites* was recorded. This deposit was overlain by a thick battleship-grey silty-clay with some *turfa* which was in turn overlain by further organic sediments. The altitude of the transgressive and regressive contacts in core LV4 were -6.46m and -2.76m OD respectively. This inorganic deposit was also recorded in cores LV5 and LV3, where it was a clayey-silt and silty-clay respectively.

The overlying organic sediments varied in composition between a well humified peat with some Phragmites and woody remains (core LV5) and a well humified wet peat (core LV4). The deposit varied in thickness between 1.77m (core LV3) and 0.50m (core LV4). The overlying inorganic sediments also varied in composition between a battleship-grey silty-clay with turfa remains (core LV4), and an organic-rich clay with some turfa in cores LV2,3, and LV5. The altitude of the transgressive contact was between -2.31m OD (core LV4) and -1.36m OD (core LV3).

Above this inorganic deposit was a further organic deposit, and the regressive contact was recorded between -1.64m OD (core LV2), and -1.00m OD (core LV3). In core LV4 this deposit was a thin turfa-rich clay, whilst elsewhere it varied in composition between a detrital peat with some Phragmites (core LV2) and a well humified peat with Substantia humosa (core LV5). Overlying this organic deposit were inorganic sediments, and the altitude of the transgressive contact rose from -1.30m OD (core LV2) to -0.60 (core LV3).

The overlying inorganic deposit extended to the base of a surface peat in cores LV2-5. Typically the deposit was a battleship-grey clay with some silt, although in core LV2 the deposit had a 50% organic component. A dark brown turfa was recorded above this deposit, which extended uninterrupted to the surface in cores LV1-5.

Whilst intercalated organic and inorganic sediments were recorded to the west of the transect, in cores LV6-9 no significant organic sediments were recorded. The spatial correlation of these inorganic sediments is difficult on the basis of altitude and composition. Above the Chalk in these cores was a series of coarse silty-sands and sandy-silts which were frequently olive-green in colour and slightly laminated. In core LV7 these laminated sediments became finer and extended to the surface, whilst in cores LV8 and LV9 they passed into a series of clayey-silts which also extended to the surface. The uppermost sediments in these cores showed strong iron-staining.

4.2.5.5. Lydden Valley: Transect 2.

In addition to the transect described above, five further cores (LV 10-14) were sunk in the Lydden Valley in order to define the form of the pre-Holocene subcrop in the area, as well as to establish the general pattern of Holocene sedimentation. The sampling interval between cores was large (200m+) and therefore lithostratigraphic correlation should be interpreted with care. The lithostratigraphy of these cores are described in Appendix 1 and illustrated in Fig.4.20.

In all cores except LV10 the Chalk subcrop was encountered at between -4.56m (core LV12) and -1.00m OD (core LV13). In core LV10 the deepest deposit recorded was a grey silt which sampled poorly. Above the Chalk in cores LV11-12 was a green or grey silt with some sand which resembled the Thanet Sands. Above this deposit in cores LV11-12 was a dark brown _turfa_ with some sand grains which was overlain by inorganic sediments. The altitude of the transgressive contact was -0.86m and -3.91m OD in cores LV11 and LV12 respectively. A well humified _turfa_ recorded in core LV10 was also overlain by inorganic sediments, and the altitude of the transgressive contact was -2.31m OD.

The overlying inorganic deposit recorded in core LV10 was a battleship-grey clay with some silt, which was overlain by a well humified red or brown _turfa_ which extended uninterrupted to the present surface. The altitude of the regressive contact was -0.67m OD. In core LV11 inorganic sediments extended to the surface, and consisted of a blue-grey silty-clay with some _turfa_ which passed into an orange or brown silty-clay with some iron-staining. In core LV12 the inorganic deposit was a soft grey clay with some silt and a trace of _turfa_ which was overlain by a further organic deposit at -2.26m OD. The latter was a dark brown _turfa_ with some _Phragmites_ which was overlain by inorganic sediments which extended to the surface. The altitude of the transgressive contact was -1.86m OD. The overlying inorganic sediments consisted of a blue-grey silty-clay which became coarser and iron-stained towards the surface.

No significant organic sediments were recorded in cores LV13 and LV14. In LV13 a soft grey silty-clay overlying the Chalk passed into a khaki-brown silty-clay with some iron-staining which extended to the surface. In LV14 the Chalk surface was overlain by a grey sand, and passed into a grey sandy-silt and then a grey or brown sandy-silt with some iron-staining which extended to the present surface.

4.2.6. Marsh Lane.

In order to determine the nature of Holocene sediments recorded in the Marsh Lane area (TR 25 3590 5330), a transect of 16 cores was completed. In addition, observations of face exposures were made during the digging of two fishponds in the southern part of the transect (Fig.4.21.). The transect of cores extended in a north-easterly direction from the foot of the dip-slope (TR 25 3578 5307) towards the coal tip (TR 25 3614 5362). The general altitude of the ground surface varied between +0.13m OD and +1.16m OD, and rose slightly in a north-easterly direction. The sampling interval varied between 30m and 70m depending on the lithostratigraphic variability encountered.

Unconsolidated sediments were recorded to a minimum altitude of -8.81m OD (core 8, Fig 4.22.). The pre-Holocene sub-crop was recorded in cores 1-6, 15 and 16. In cores 1-6 a Brickearth deposit was recorded, the surface of which dipped from -1.19m OD (core 1) to -5.68m OD (core 6). This was not penetrated in any of these cores, and was overlain by a khaki-white clayey-silt which varied in thickness between 1.30m (core 2) and 0.24m (core 4). In cores 15 and 16 the weathered Chalk surface was encountered at -4.25m OD and -2.70m OD respectively

The deepest sediments recorded were soft silty-clays with some turfa and Phragmites found in cores 7-9, 11 and 12. The base of this deposit was penetrated only in core 7, where a clay-rich peat with some Phragmites, turfa and woody remains was recorded. The altitude of this transgressive contact was -7.41m OD. In cores 7-9 and 11-13 the silty-clay was in turn overlain by the lower of the two main organic deposits recorded in this transect. The altitude of the regressive contact (or base of deposit) varied between -7.26m OD (cores 8 and 13) and -6.49m OD (core 9).

The overlying organic deposit varied in thickness between 0.17m (core 13) and 0.57m (core 7), and the altitude of the transgressive contact ranged between -7.09m OD (core 13, which may be slightly eroded), and -6.14m OD (core 9). The components of this deposit were broadly similar, with a lower transitional zone from the underlying silts and clays, which passed into a brown Phragmites-rich turfa. This was overlain by a fine shell-rich turfa with some Phragmites which varied in thickness between 0.02m (core 9) and 0.19m (core 7). This in turn was overlain by a very compact, well humified turfa with some Phragmites and occasional woody remains. In cores 6 and 15 an organic deposit was recorded at between -4.93m OD and -4.53m OD, and -4.25m OD and -3.80m OD respectively. In core 15 this deposit was directly on the weathered Chalk surface, whilst in core 6 it overlay a grey silt with some clay.

Above this organic deposit was a thick inorganic deposit which in turn passed into the upper of the two main organic deposits recorded. The inorganic deposit was recorded in cores

4-9, 11-13 and 15, and varied in thickness between 0.38m (cores 4 and 5) and 4.27m (core 13). The altitude of the regressive contact varied between -3.41m OD (core 11) and -2.53m OD (core 4). The composition of the deposit was variable. In the centre of the transect between cores 7 and 13 it was characteristically a soft battleship-grey silty-clay with some turfa. In cores 9 and 11 it was slightly laminated, probably due to the proximity to the coarse channel-fill deposit in core 10. Similarly, in core 13 the deposit was a battleship-grey silty-clay between -7.10m OD and -4.84m OD, where it passed into a laminated grey silty-sand. This was also probably related to the proximity of the channel-fill deposit recorded in core 14.

This inorganic deposit passed into the upper organic deposit, above which were further inorganic sediments which extended to the surface. This organic deposit varied in thickness between 0.10m (core 15, - where the transgressive contact was eroded), and 0.80m (core 6). The altitude of the transgressive contact varied between -2.91m OD (core 7) and -1.87m OD (core 4), and in general rose in a south-westerly manner as the pre-Holocene subcrop also rose. The composition of the deposit was variable. In core 13, where the deposit was at its highest altitude, it was a crumbly dark brown turfa with some clay and Phragmites. Away from the edge of the valley the peat thickened to a maximum in core 6. Here the deposit could be divided into five distinct units:

i. A finely laminated Phragmites peat with some clay, turfa and rare shells.

ii. A thin grey white clay with some shells, Phragmites and turfa 0.07m thick.

iii. A compact turfa with some woody detrital material and Phragmites 0.38m thick.

iv. A dark brown or black _turfa_ with some _Phragmites_ and detrital wood.

v. A soft grey brown clay-rich _turfa_.

Towards the centre of the transect the deposit became a _turfa_ with some _Phragmites_ and woody detrital material.

Above this organic deposit, and extending to the surface in all cores, was a variable sequence of alternating inorganic sediments with occasional thin and laterally impersistent organic horizons. In cores 2, 4, and 5 the remnants of a surface peat was recorded. Laminated channel-fill sediments of sands and silts were recorded in cores 10, 11, 14 and 15, and these all illustrated an upward fining sequence. The most persistent thin organic horizon was recorded in cores 4, 6, 8-10, and 12 at a variety of altitudes. The deposit varied in thickness between 0.03m (core 8) and 0.19m (core 6), and was commonly a _turfa_-rich clay with approximately 75% clay and 25% _turfa_. The altitude of the regressive contact varied between -2.42m OD (core 12) and -1.00m OD (core 10), and the transgressive contact between -2.35m OD (core 12) and -0.88m OD (core 10). Apart from those cores with the remnants of an upper peat, the uppermost sediments in most cores consisted of a sticky orange-brown iron-stained silty-clay.

4.2.7. Sandfield Farm, Deal.

In order to determine the nature and spatial extent of the unconsolidated Holocene sediments recorded near Deal, a transect of twenty-one cores was completed extending from Penfield Sewer (TR 25 3640 5380) parallel with the Northwall Road towards Sandfield Farm (Fig.4.21.). The general altitude of the land varied along the transect between +1.34m OD and +2.43m OD. Sampling interval varied between 5m and 60m, and unconsolidated Holocene sediments were recorded extending to a maximum depth of -8.89m OD (core 5). Three organic deposits were recorded, intercalated between laminated and unlaminated sands, silts and clays. The pre-Holocene subcrop in the area was Chalk, and was sampled in cores 11-21, where it rose from -7.41m OD (core 11) to 0.09m OD (core 20). The lithostratigraphy recorded in the transect are presented in Fig.4.23.

The deepest organic deposit recorded was in cores 2, 5, and 6. In core 2 this was underlain by a silt; the regressive contact was recorded at -7.61m OD, and the transgressive contact at -7.46m OD. The deposit was a dark grey clay-rich turfa with some Phragmites, detrital wood and unidentified shells. In core 5, where the deposit was not fully penetrated, the transgressive contact was at -8.79m OD. In composition the deposit was a khaki-brown Phragmites-rich clay.

Above this organic deposit was a thick inorganic deposit which was in turn overlain by a second organic deposit. The inorganic deposit attained a maximum thickness of 3.58m (core 5), and whilst in cores 2-6 was a soft unlaminated grey clay, in cores 7 and 8 was a silty-clay with occasional turfa remains. The altitude of the regressive contact varied between -6.45m OD (core 9) and -4.95m OD (core 3).

The overlying organic deposit was recorded in cores 2-10. Its thickness varied between 0.22m (core 4) and 0.50m (core 8), and was in turn overlain by further inorganic sediments. The altitude of this transgressive contact varied between -6.00m OD (core 9) and -4.74m OD (core 2). In all cores except 2 and 10 the upper contact of this deposit had been eroded. The composition of the deposit was variable. In cores 2-6 immediately above the regressive contact was recorded a yellow-brown clay-rich Phragmites peat with some Substantia humosa and broken shells (unidentified). In core 8 this was above a thin dark-brown and laminated Phragmites-rich turfa 0.02m thick. This clay-rich peat varied in thickness between 0.07m (core 5) and 0.14m (core 8). Overlying was a compact slightly black turfa with some Phragmites, which was well humified and slightly laminated. In core 10, where the transgressive contact was not eroded, this passed into a 0.05m thick grey-brown Phragmites-rich peat with some clay.

In cores 2-6 and 7-12 this organic deposit was overlain by a second inorganic deposit, above which was a further inorganic deposit. The latter varied in thickness between a maximum of 3.15m (core 9) and a minimum of 2.24m (core 4). The regressive contact of this deposit was recorded between -2.92m OD (core 7) and -2.23m OD (core 12). In composition it varied between a soft grey clay with some turfa in cores 2-6, and a silty-clay in cores 7, 8, and 10-12. In core 9 the deposit was a laminated sand 3.15m thick.

The overlying organic deposit was recorded in cores 2-12, and varied in thickness between 0.20m (core 9) and 0.50m (core 7). This is in turn overlain by further inorganic sediments, and the altitude of the transgressive contact varied between -2.65m OD (core 9 - where it was eroded) and -1.84m OD (core 12). In cores 2, 3, and 8-10 this transgressive contact was eroded. The composition of the deposit varied, although in general it could be divided into two units:

i. In cores 5, 6, and 8 a thin yellow-brown clay-rich turfa with some Phragmites was found immediately above the regressive contact, which was c. 0.05 - 0.10m thick.

ii. This was overlain by a well humified brown or black turfa with some woody detrital material and humified remains of Phragmites.

In core 14 an organic deposit was recorded at a slightly higher altitude between -1.25m OD and -1.01m OD, which also consists of a lower organic-rich clay and an upper well humified turfa with some Phragmites. This deposit was above a series of compact white, blue and green sands and silts immediately above the Chalk subcrop at -1.21m OD.

Channel-fill deposits of sands and silts were recorded in cores 1, 9, and 13 at the same altitude as this organic deposit, and either prevented the accumulation of this deposit, or were responsible for its subsequent erosion. In core 13 laminated sands extended to the surface, whilst in core 6 they represented part of a much larger channel-fill deposit which was recorded in cores 2 and 4-6, where it was recorded above the organic deposit described above, and extended to the present surface. Overlying the transgressive contact sands, silts and clays extended uninterrupted to the surface in all cores. The uppermost sediments recorded in most cores consisted of an orange-brown silty-sand or sand with iron-staining.

4.3. Seismic Data.

4.3.1. Introduction.

This section describes the results of a shear-wave seismic refraction survey completed in the Hacklinge/Deal area. For a full description of the results from this survey the reader is referred to Gunn (1990) and Long _et al_ (in press). A total of thirteen seismic lines have been completed in the area and each line is discussed in turn below.

4.3.2. Results of seismic survey.

The first aim of the survey was to establish the size of the infilled-valley identified by hand-coring at Hacklinge (Section 4.2.5.). Two seismic lines were completed in this area (lines 9010, 9011 - see Fig.4.24.). Due to the presence of low velocity surface organic sediments, data quality was very poor with a high SNR. For line 9010 the short geophone spread suggested a three layer situation, with the first refractor boundary at between 1.2 and 1.4m below surface (BS). This upper layer had a velocity of 46 m/s and was underlain by a higher velocity deposit (64 m/s), which was above the Chalk subcrop, which had a velocity of 549 m/s. The depth profile (Fig.4.25a) illustrates the Chalk subcrop dipping in a southerly manner from 6.5m BS to 9.5m BS. This would appear to be the northerly edge of the infilled-valley.

A continuous profile across the infilled-valley was not possible due to restricted land access, but line 9011 was completed in an attempt to locate the southerly edge of the infilled-valley identified in line 9010. Data quality was again poor, with a high SNR probably due to the presence of a thick surface peat in this area. A simple two layer case was assumed for data interpretation, although it is probable that higher velocity sediments existed beneath the surface peat. The depth profile is illustrated in Fig.4.25b, which shows the Chalk surface dipping in a northerly direction from 5.00m BS to 11m BS. This is probably the southern edge of the same infilled-valley located in line 9010.

In order to establish the form of the pre-Holocene surface in the area of core LV4, two seismic lines were completed in this area (lines 9015 and 9018). For both lines data quality was poor, and a short geophone spread shot for each of these lines indicated that a three-layer situation exists. The top layer for line 9015 had a velocity of between 37 m/s and 50 m/s, and was between 1.75m and 2.50m thick, below which was a second layer with a velocity of 75 m/s to 80 m/s which in turn overlay the Chalk subcrop. These velocity contrasts were not in agreement with the lithostratigraphy recorded at the start of the seismic lines (core LV4), which indicated a surface peat 0.50m thick overlying inorganic sediments. Accordingly the seismic data was interpreted using a velocity structure in accordance with the lithostratigraphy recorded. The depth profiles for lines 9018 and 9015 are illustrated in Figs.4.25c and 4.25d. The Chalk subcrop at these locations was relatively shallow (<10.00m BS), and rose in both a northerly and easterly direction. These data suggested that a northern boundary of the infilled-valley may exist in this location.

Hand-coring at c. 200m indicated that the pre-Holocene surface to the north and east of the Lydden Valley transect 2 was approximately -3.00m BS to -4.00m BS. Accordingly, the infilled-valley located at Hacklinge must therefore have swung in a southerly direction towards Marsh Lane and Sandfield Farm. Further seismic data were collected from these areas.

The Holocene sediments recorded at Marsh Lane have been described above, and seismic lines 9003 and 9017 were completed along the same transect from which these stratigraphic data have been collected. Data quality for these two lines was good due to the absence of surface organic sediments. Four short geophone spreads were used to determine the seismic velocity of the near surface sediments, and a simple two layer-case was used in data analysis. Depth profiles for these two lines are illustrated in Figs.4.26a and 4.26b, and delineate an infilled-valley at least 400m in width and up to 20m in depth.

From a consideration of hand-coring data from Sandfield Farm it appeared that the sediments recorded here may also have accumulated within the infilled-valley identified at Hacklinge and Marsh Lane. Two seismic lines (9014 and 9016 - See Fig. 4.24) were completed in this area. Once again, the absence of surface organic sediments ensured a low SNR and good quality data. A simple two-layer case was used in data interpretation. The results from line 9014 have been discussed above (Section 3.4.4., Fig 3.5.). The Chalk subcrop was seen to dip gently in a southerly direction from approximately 2.00m BS to 9.00m BS, and probably delimited the northerly edge of the infilled-valley. Line 9016 was only 100m in length and is offset from line 9014 by 195m (Fig.4.24.). The depth determinations of this profile are illustrated in Fig 4.26c and show the Chalk subcrop at between 15.00m BS and 12.50m BS. Determining the southerly edge of the infilled-valley was not possible due to lack of access to the land south of line 9016.

In an attempt to define the location of the infilled-valley at the coast, seismic lines 9012, 9013, and 9019 were completed around Deal and Kennels Farm (Fig.4.24.). Line 9012 was only 35m long, as the intercept times and two cores revealed that the chalk surface was only 3.5 to 4.00m BS, and therefore that the infilled-valley did not exist in this location. Line 9019 was completed to the south of Kennels Farm (Fig.4.24.), and was 160m in length. The compact inorganic surface sediments again ensured a low SNR and high quality data. A simple two layer case was used for data interpretation, and the depth profile calculated illustrated in Fig.4.26d. From this the Chalk surface can be seen to dip in a southerly manner from approximately 9.00m BS to 17.00m BS.

A final attempt to delimit the location of the infilled-valley at the coast was made with a profile across the Sandwich golf course (Line 9013, Fig.4.25.), where surface windblown sand of unknown depth exists. The length of the line was restricted due to the presence of the coastal sand dunes, and only one geophone spread of 60m was possible. Only two depth determinations were possible, and these suggest a depth to Chalk of 17.00m BS and 21.00m BS. However, these depths should be interpreted with caution, because the refracted wave was only recorded by three or four geophones in both directions of shooting. In addition, it is probable that lower velocity sediments underlay the dune sand (Dowker 1897), and thus the V_0 determinations are probably higher than in reality. This would have resulted in an over-estimation of the depth to Chalk. Despite these reservations, it is probable that the infilled-valley does indeed pass under this short line.

Data points from selected hand-coring, seismic and spot height sources have been combined in Fig.4.27. to provide a first approximation of the form of the pre-Holocene surface in the Hacklinge/Deal area. This is a prerequisite for the interpretation of the lithostratigraphic data, and provides the context for the subsequent analysis and interpretation of palaeobotanical data collected from this area.

Chapter Five: Palaeobotanical and Elemental Data Presentation.

5.1. Introduction.

This chapter presents the palaeobotanical data collected from the East Kent Fens. The results of the pollen and diatom analyses are described in Sections 5.2. and 5.3., with the results of the elemental analyses in Section 5.4.

5.2. Pollen analysis.

5.2.1 Introduction.

Within the infilled-valley described in Chapter Four, three sites were selected for palaeobotanical analysis. The sites were selected in order to compare the biostratigraphic and sea-level record from different positions in the infilled-valley. It was hoped that through studying a number of sites it would be possible to reconstruct the environmental response of the valley vegetation to changes in the altitude and composition of the watertable, as well as to changes in sea-level.

At each of these sites two sampling locations were identified, from which material was collected. At one sampling location pollen analysis was completed for one deep piston-core. At the second sampling location pollen analysis was completed for just the upper organic sediments (in general < c.-5.00m OD).

Analysis of the deep piston-cores was designed to establish a long record of vegetation changes at three locations along the length of the valley. Analysis of the upper organic sediments from the second sampling locations was designed to enable a more detailed comparison of the vegetation changes during the later period of valley sedimentation.

Nine pollen diagrams are presented. Division of the diagrams into Local Pollen Assemblage Zones (LPAZs) has been made on the basis of a combination of objective and subjective techniques. Diagrams were zoned by CONISS (Section 3.5.3.) and checked by eye. The dendrograms produced by CONISS enable distinct groups of levels to be identified. In all cases the exact location of the zone boundary has been placed midway between adjacent levels.

5.2.2. Sandfield Farm.

The general lithostratigraphy of the Sandfield Farm area has been described in Section 4.2.7. Two piston-cores were collected from the position of hand-core 10 (SF-10) and hand-core 6 (SF-4).

5.2.2.1. Pollen analysis - lithostratigraphy of piston-core SF-10.

The lithostratigraphy of hand-core 10 is described in full in Appendix 1, and the detailed lithostratigraphy of SF-10 is described below:

Stratum	Altitude O.D. metres	Depth cm	Description
38	+1.34 to +0.49	000 to 085	Sc4 Topsoil
37	+0.49 to +0.45	085 to 089	nig. 2, strf. 0, sicc. 2, elas. 0, lim. sup. 0 Ga4, part test moll + Yellow/brown sand with occasional unidentified shell remains.

36	+0.45 to +0.09	089 to 125	nig. 2, strf. 0, sicc. 2, elas. 0, lim. sup. 0 As2, Ag2, Ga+, Lf+ Brown/grey silty-clay with some sand and iron-staining.
35	+0.09 to +0.04	125 to 130	nig. 2, strf. 0, sicc. 2, elas. 0, lim. sup. 0 As2, Ag2, Ga+ Grey silty-clay with some sand.
	+0.04 to -0.06	130 to 141	Unsampled
34	-0.06 to -0.21	141 to 156	nig. 2, strf. 0, sicc. 2, elas. 0, lim. sup. 0 As3, Ag1, Lf+ Grey silty-clay with some iron-staining. Becoming browner towards top of stratum.
33	-0.21 to -0.57	156 to 192	nig. 2, strf. 1, sicc. 2, elas. 0, lim. sup. 0 As2, Ag2 Slightly laminated grey silty-clay.
32	-0.57 to -0.61	192 to 196	nig. 2, strf. 0, sicc. 2, elas. 0, lim. sup. 0 Ga4, part test moll + Grey sand with occasional broken unidentified shells.
31	-0.61 to -0.79	196 to 214	nig. 2, strf. 0, sicc. 2, elas. 0, lim. sup. 0 Ag3, As1, Ga+, part test moll+ Dark grey clayey-silt with some sand

			and rare <u>Hydrobia</u> sp. Coarse sand in infilled worm burrow.
30	-0.79 to -0.88	214 to 223	nig. 2+, strf. 0+, sicc. 2, elas. 0, lim. sup. 0 Ag3, As1, Lf+ Blue-grey blocky clayey-silt with some iron-staining. Quite dry.
	-0.88 to -1.07	223 to 242	Unsampled
29	-1.07 to -1.33	242 to 268	nig. 2, strf. 0, sicc. 2, elas. 0, lim. sup. 0 As2, Ag2 Battleship-grey silty-clay.
28	-1.33 to -1.43	268 to 278	nig. 2, strf. 0, sicc. 2, elas. 0, lim. sup. 0 As2, Ag2, Th^2(<u>Phra</u>)+ Battleship-grey silty-clay with some <u>Phragmites</u>.
27	-1.43 to -1.77	278 to 312	nig. 3, strf. 0, sicc. 2, elas. 0, lim. sup. 0 As2, Ag2, part test moll+ Grey silty-clay with rare <u>Hydrobia</u> spp. at 294 cm.
26	-1.77 to -1.91	312 to 326	nig. 3, strf. 0, sicc. 2, elas. 0, lim. sup. 0 As3, Ag1, Th^2+ Soft dark grey silty-clay with some <u>turfa</u>.

25	-1.91 to -1.97	326 to 332	nig. 3, strf. 0, sicc. 2, elas. 0, lim. sup. 0 Sh3, $Th^3 1$, Th^3(<u>Phra</u>)+ Well-humified brown peat with some <u>Phragmites</u>.
24	-1.97 to -2.03	332 to 338	nig. 3, strf. 0, sicc. 2, elas. 0, lim. sup. 0 Sh3, $Th^3 1$, Th^3(<u>Phra</u>)+, Th^2+ Well-humified brown peat with some <u>Phragmites</u> and rare <u>turfa</u>.
	-2.03 to -2.13	338 to 348	Unsampled
23	-2.13 to -2.34	348 to 369	nig., 3, strf. 0, sicc. 2, elas. 0, lim. sup. 0 Sh3, $Th^2 1$, Th^3(<u>Phra</u>)+ Well-humified brown peat with some <u>Phragmites</u> and <u>turfa</u>.
22	-2.34 to -2.38	369 to 373	nig. 3, strf. 0, sicc. 2, elas. 0, lim. sup. 0 Sh3, As1, Th^3(<u>Phra</u>)+ Soft brown/grey well-humified peat with some clay and <u>Phragmites</u>.
21	-2.38 to -2.40	373 to 375	nig. 3, strf. 0, sicc. 2, elas. 0, lim. sup. 0 As2, Ag2, Sh+ Soft dark grey silty-clay with some organic staining.
20	-2.40 to -2.59	375 to 394	nig. 2, strf. 0, sicc. 2, elas. 0, lim. sup. 0 Ag3, As1, Dh+, Ga+

			Battleship-grey clayey-silt with
			some organic detritus and rare sand.
19	-2.59	394	nig. 2, strf. 1, sicc. 2, elas. 0,
	to	to	lim. sup. 0
	-2.68	403	Ag3, Ga1
			Battleship-grey laminated sandy-silt.
18	-2.68	403	nig. 2, strf. 1, sicc. 2, elas. 0,
	to	to	lim. sup. 0
	-3.00	435	As2, Ag2, Ga+
			Battleship-grey silty-clay with
			occasional laminations.
	-3.00	435	Unsampled
	to	to	
	-3.30	465	
17	-3.30	465	nig. 2, strf. 1, sicc. 2, elas. 0,
	to	to	lim. sup. 0
	-3.60	495	As2, Ag2
			Soft battleship-grey silty-clay with
			occasional very fine laminations.
16	-3.60	495	nig. 2, strf. 1, sicc. 2, elas. 0,
	to	to	lim. sup. 0
	-3.69	504	As3, Ga1
			Slightly laminated battleship-grey
			sandy-silt.
15	-3.69	504	nig. 2, strf. 0, sicc. 2, elas. 0,
	to	to	lim. sup. 0
	-3.93	528	As2, Ag2
			Soft battleship-grey silty-clay.

14	-3.93 to -3.97	528 to 532	nig. 2, strf. 1, sicc. 2, elas. 0, lim. sup. 0 Ag3, Ga1 Battleship-grey sandy-silt, slightly laminated.
13	-3.97 to -4.14	532 to 549	nig. 2, strf. 0, sicc. 2, elas. 0, lim. sup. 0 Ag3, As1 Soft battleship-grey clayey-silt.
	-4.14 to -4.26	549 to 561	Unsampled
12	-4.26 to -4.47	561 to 582	nig. 2, strf. 1, sicc. 2, elas. 0, lim. sup. 0 As2, Ag2, Ga+, Dh+ Slightly laminated battleship-grey silty-clay with rare detrital organic material and occasional sand.
11	-4.47 to -5.08	582 to 643	nig. 2, strf. 0, sicc. 2, elas. 0, lim. sup. 0 As2, Ag2, Dh+ Battleship-grey silty-clay with some organic detritus.
	-5.08 to -5.35	643 to 670	Unsampled
10	-5.35 to -5.53	670 to 688	nig. 2, strf. 0, sicc. 2, elas. 0, lim. sup. 0 As3, Ag1, Dh+ Battleship-grey silty-clay with some

			organic detritus.
9	-5.53 to -5.57	688 to 692	nig. 3+, strf. 1, sicc. 3, elas. 0, lim. sup. 0 Sh3, $Th^2$1, Dl+ Very compact dark brown/black well humified peat with some turfa and occasional woody detrital material.
8	-5.57 to -5.67	692 to 702	nig. 4, strf. 0, sicc. 2, elas. 0, lim. sup. 0 Sh3, Th^3(Phra)1 Well-humified black compact peat with some Phragmites rhizomes and leaves.
7	-5.67 to -5.71	702 to 706	nig. 3, strf. 0, sicc. 2, elas. 0, lim. sup. 0 Sh3, Th^3+, Th^3(Phra)1 Well-humified compact dark brown/black well-humified peat with some Phragmites.
6	-5.71 to -5.76	706 to 711	nig. 4, strf. 0, sicc. 2, elas. 0, lim. sup. 0 Sh3, $Th^3$1 Well-humified compact black peat with some well-humified turfa.
5	-5.76 to -5.80	711 to 715	nig. 3+, strf. 1, sicc. 3, elas. 0, lim. sup. 0 Sh3, $Th^2$1, part test moll+ Very compact dark brown/black well humified peat - slightly laminated with some small unidentified shells.

4	-5.80 to -5.81	715 to 716	nig. 3+, strf. 0, sicc. 2, elas. 0, lim. sup. 0 Sh2, $Th^3$1, As1 Dark brown/grey clay with some <u>turfa</u>.
3	-5.81 to -5.96	716 to 731	nig. 2, strf. 0, sicc. 2, elas. 0, lim. sup. 0 Ag3, As1, Dh+ Soft battleship-grey clayey-silt with some organic detritus.
2	-5.96 to -5.99	731 to 734	nig. 2+, strf. 0, sicc. 2, elas. 0, lim. sup. 0 As2, Ag2, Lf+, Dh+ Orange/brown silty-clay with some detrital organic material and iron-staining.
1	-5.99 to -6.18	734 to 753	nig. 2, strf. 2, sicc. 2, elas. 0, lim. sup. 0 Ag3, Ga1, Dh+ Finely laminated brown/grey sandy-silt with rare detrital organic material.

Two pollen diagrams have been completed from this core, one for each of the main organic deposits, and each is described in turn below.

5.2.2.2. SF-10 Pollen analysis: Lower organic deposit -5.81m to -5.53m OD.

Of fifteen samples prepared for pollen analysis nine samples had sufficient pollen for counting. The resulting diagram (Fig.5.1.) has been divided into five LPAZs, and the characteristics of each are described in turn below. Each LPAZ coincides with the zonation suggested by the highest four splits of CONISS.

<u>LPAZ</u>	<u>Altitude m OD</u>	<u>Zone Characteristics</u>

SF-10a -5.76 to -5.75m OD

This zone is characterised by a pollen assemblage dominated by high Gramineae frequencies which account for 91% TLP. Frequencies of trees, shrubs, aquatics and ferns and spores are very low.

SF-10b -5.75 to -5.70m OD

The lower zone boundary is defined by a rise in the frequency of aquatic taxa to 38% TLP at -5.72m OD. The zone is characterised by an assemblage dominated by obligate and non-obligate aquatic taxa, including <u>Typha angustifolia</u> and <u>Typha latifolia</u>, as well as <u>Potamogeton</u>, <u>Nymphaea</u>, <u>Myriophyllum</u>-type, and <u>Lemna</u>. Rare occurrences of other wet-habitat herbs such as Malvaceae, <u>Mentha</u> and <u>Parnassia</u>-type are also recorded. There are no significant changes in tree pollen frequencies, nor in those of shrubs, ferns and spores.

SF-10c -5.70 to -5.59m OD

The lower zone boundary is defined by a sharp fall in the frequencies of Gramineae to 27% TLP at -5.68m OD, and by a concurrent rise in the frequencies of Cyperaceae to a high of 65% TLP at -5.68m OD. In addition, frequencies of aquatic taxa fall from >30% TLP to <7% TLP over this zone boundary. The zone is characterised by an assemblage dominated by Cyperaceae and Gramineae pollen. Frequencies of Filicales rise progressively to a high of 41% TLP at -5.60m OD, whilst those of trees and shrubs remain low in this zone.

SF-10d -5.59 to -5.55m OD

The lower zone boundary is defined by an increase in the frequencies of Cyperaceae to >80% TLP at -5.58m OD, and by a decline in frequencies of Filicales and Gramineae to <10 and <15% TLP respectively. The zone is characterised by an assemblage dominated by frequencies of Cyperaceae pollen, whilst those of trees and shrubs remain low.

SF-10e -5.55 to -5.51m OD

The lower zone boundary is defined by a sharp increase in frequencies of Gramineae from <15% TLP in LPAZ SF-10d to 80% TLP. In addition, Cyperaceae frequencies fall to 6% TLP over the lower zone boundary. The zone is characterised by an assemblage dominated by high frequencies of Gramineae pollen, whilst those of Typha angustifolia rise slightly to 4% TLP, and those of trees, shrubs, ferns and spores remain low.

5.2.2.3. SF-10 Pollen analysis: Upper organic deposit -2.38m to -1.91m OD.

Of twenty-five samples prepared for pollen analysis, twelve samples had sufficient pollen for counting. The resulting diagram (Fig.5.2.), has been divided into five LPAZs, and the characteristics of each are described below. Each LPAZ coincides with the zonation suggested by the highest four splits of CONISS. A break in the sedimentary record occurs between -2.13m to -2.03m OD and was caused by the lower and upper part of the organic deposit being sampled in separate sampling tubes.

LPAZ	Altitude m OD	Zone Characteristics

SF-10f -2.38 to -2.30m OD

The zone is characterised by an assemblage dominated by high frequencies of herb pollen, with Gramineae decreasing from 78% TLP to 41% TLP between -2.38m OD and -2.32m OD, whilst frequencies of Cyperaceae increase from 13% TLP to 30% TLP. Tree pollen frequencies are dominated by Quercus, which accounts for a high of 22% TLP at -2.32m OD. Aquatic taxa are rare, and frequencies of shrubs, ferns and spores are low.

SF-10g -2.30m to -2.21m OD

The lower zone boundary is defined by an increase in the frequencies of Filicales, which rise to 77% TLP at -2.22m OD. The zone is characterised by an assemblage dominated by high frequencies of Filicales and Gramineae, and by an increase in tree pollen frequencies to 42% TLP at -2.22m OD. Of the shrub taxa, Corylus frequencies also increase towards the top of this zone. Aquatic pollen frequencies remain low, although a small peak in Typha latifolia is recorded at -2.22m OD.

SF-10h -2.21m to -2.01m OD

The lower zone boundary is defined by a sharp fall in frequencies of Filicales. The zone is characterised by an assemblage dominated by Gramineae pollen, the frequencies of which increase to 79% TLP by the top of the zone. Frequencies of trees, shrubs and herbs remain approximately constant.

SF-10i -2.01m to -1.99m OD

The lower zone boundary is defined by a sharp increase in frequencies of aquatic and tree taxa, and in particular by an increase in frequencies of Lemna to 223% TLP. The zone is characterised by an assemblage dominated by Lemna, Gramineae and Quercus. Frequencies of other non-obligate aquatics such as Myriophyllum-type, Nymphaea, and Typha latifolia also increase, as do those of the obligate aquatics such as Typha angustifolia. Frequencies of herb taxa fall, largely because of the fall in Gramineae frequencies to 28% TLP at -2.00m OD.

Of the shrub pollen, Corylus increases to 16% TLP. Tree pollen frequencies increase to c. 50% TLP, with Quercus rising to 27% TLP.

SF-10j -1.99m to -1.94m OD

The lower zone boundary is defined by a sharp fall in frequencies of Lemna. The zone is characterised by an assemblage dominated by Gramineae pollen, which rise in frequency and average c. 58% TLP, whilst tree pollen account for c. 24% TLP. Most tree taxa exhibit a decline, and frequencies of aquatic taxa and ferns and spores are low.

5.2.2.4. Pollen analysis - lithostratigraphy of piston-core SF-4.

The lithostratigraphy of hand-core 6 is described in full in Appendix 1, and the detailed lithostratigraphy of the piston-core (SF-4) is described below. The altitude of the organic deposit differs from that determined in hand-core 6, with the piston-core depths being approximately 60 cm deeper than those derived from the hand-core. This may be due to real altitudinal variations in the organic deposit, or as a result of compaction of the sediments during sampling and extrusion.

Stratum	Altitude O.D. metres	Depth cm	Description
6	-2.50 to -2.52	391 to 393	nig. 2, strf. 0, sicc. 2, elas. 0, lim. sup. 0 As4, Th^2+ Soft dark grey clay with some turfa.
5	-2.52 to -2.87	393 to 428	nig. 3, strf. 0, sicc. 2, elas. 0, lim. sup. 0 Sh3, Th^3(Phra)+, $Th^3$1

			Black well-humified peat with some <u>Phragmites</u> remains and occasional <u>turfa</u>.
4	-2.87 to -2.92	428 to 433	nig. 3, strf. 0, sicc. 2, elas. 0, lim. sup. 0 Sh2, As1, part test moll 1 Soft brown peat with some clay, and very finely broken white shells.
3	-2.92 to -3.03	433 to 444	nig. 3+, strf. 0, sicc. 2, elas. 0, lim. sup. 0 Sh3, $Th^2$1, As+ Dark brown/grey well-humified peat with some <u>turfa</u> and clay.
2	-3.03 to -3.09	437 to 444	nig. 2, strf. 0, sicc. 2, elas. 0, lim. sup. 0 As4, Ag+, Th^2+ Very soft battleship-grey clay with some silt and <u>turfa</u>.
1	-3.09 to -3.49	450 to 490	nig. 2, strf. 0, sicc. 2, elas. 0, lim. sup. 0 As3, Ag1, part test moll+ Soft battleship-grey silty-clay with some shells (unidentified).

<u>5.2.2.5. SF-4 Pollen analysis: Upper organic deposit -3.03m to -2.52m OD.</u>

One pollen diagram has been completed from the organic deposit recorded between -3.03m to -2.52m OD (Fig.5.3.). Of twenty-five samples prepared for pollen analysis twelve had sufficient pollen for counting. Poor pollen preservation, particularly towards the base of the deposit has resulted in a large gap between the first and second sample (11 cm). The diagram has been divided into five LPAZs, and the characteristics of each are described below. Each LPAZ coincides with the zonation suggested by the highest four splits of CONISS.

LPAZ	Altitude (m OD)	Zone Characteristics

SF-4a -3.02m to -2.83m OD

This zone is characterised by high frequencies of herb taxa, and in particular those of Gramineae, which fall from 74% to 48% TLP between -3.02m and -2.87m OD. Arboreal pollen account for c. 24% TLP, with Quercus and Betula being the most commonly recorded taxa. Frequencies of shrubs, aquatics and ferns and spores are low throughout this zone.

SF-4b -2.83 to -2.73m OD

The lower zone boundary is defined by a sharp increase in the frequencies of Filicales to 238% TLP at -2.79m OD. The zone is characterised by an assemblage dominated by Filicales, Potamogeton, and Gramineae. Frequencies of Filicales fall to 117% TLP at -2.75m OD. This fall is mirrored by a sharp increase in the frequencies of Potamogeton, which reach 47% TLP at -2.75m OD. Also at this level is an increase in the frequencies of Alnus to 22% TLP. Other tree and shrub taxa remain approximately constant, although herb frequencies are seen to fall to c. 45% TLP as frequencies of Gramineae decrease.

SF-4c -2.73m to -2.61m OD

The lower zone boundary is defined by a decline in the frequencies of Potamogeton and Filicales. The zone is characterised by an assemblage dominated by Gramineae, Corylus, Quercus and Alnus. Frequencies of trees, shrubs and herb taxa remain approximately constant throughout this zone.

SF-4d -2.61 to -2.56m OD

The lower zone boundary is defined by an increase in the frequencies of aquatic taxa, notably Lemna which increases to 138% TLP. The zone is characterised by an assemblage dominated by Lemna, Gramineae, Corylus and Quercus. In addition to the rise in Lemna, frequencies of other aquatic taxa including Potamogeton and Typha angustifolia increase in this zone.

SF-4e -2.56 to -2.53m OD

The lower zone boundary is defined by a decline in frequencies of Lemna and other aquatic taxa, and by an increase in shrub pollen frequencies to 45% TLP at -2.55m OD. The zone is characterised by an assemblage dominated by Corylus. Alnus and Tilia frequencies both increase throughout this zone, whilst Gramineae frequencies fall to c. 15% TLP towards the top of the zone. There is a slight increase in aquatic taxa towards the top of this zone, whilst occasional pollen of Chenopodiaceae are also recorded.

5.2.3. Marsh Lane

The general lithostratigraphy of the Marsh Lane area has been described in Section 4.2.6. One piston-core was collected from the position of hand-core 9 (ML-9). In addition, during excavations of a number of fish-ponds, face-exposures of the upper organic deposit were sampled using two overlapping monolith tins. The position of ML-9 and the monolith samples (MMON) are illustrated in Fig.4.21.

5.2.3.1. Pollen analysis - lithostratigraphy of piston-core ML-9.

The lithostratigraphy of hand-core 9 is described in Appendix 1, and the detailed stratigraphic description of ML-9 is given below. The lithostratigraphy of ML-9 is similar in altitude and composition to that recorded in hand-core 9, with the exception of a thin organic-rich clay between 163 and 169 cm.

Stratum	Altitude O.D. metres	Depth cm	Description
31	+0.68 to -0.10	000 to 078	Sc4 Topsoil
30	-0.10 to -0.60	078 to 128	nig. 2, strf. 0, sicc. 2, elas. 0, lim. sup. 0 As2, Ag2, Lf+ Brown iron-stained silty-clay with iron-staining above 104 cm.
29	-0.60 to -0.95	128 to 163	nig. 2, strf. 0, sicc. 2, elas. 0, lim. sup. 0 As4, Ag+ Soft grey clay with a trace of silt.
28	-0.95 to -1.01	163 to 169	nig. 3, strf. 0, sicc. 2, elas. 0, lim. sup. 0 As3, $Th^2$1 Brown-grey clay with some turfa.
27	-1.01 to -1.25	169 to 193	nig. 2, strf. 1, sicc. 2, elas. 0, lim. sup. 0 As2, Ag2, part test moll+ Slightly laminated grey silty-clay with occasional shells.
	-1.25 to -1.28	193 to 196	Unsampled

26	-1.28 to -1.38	196 to 206	nig. 2, strf. 0, sicc. 2, elas. 0, lim. sup. 0 As2, Ag2, Ga+ Grey clayey-silt with some sand.
25	-1.38 to -1.73	206 to 241	nig. 2, strf. 0, sicc. 2, elas. 0, lim. sup. 0 As3, Ag1 Soft grey clay with some silt.
24	-1.73 to -1.77	241 to 245	nig. 3, strf. 1, sicc. 2, elas. 0, lim. sup. 0 As3, $Th^2$1, Th^2(<u>Phra</u>)+ Slightly laminated clay with some <u>turfa</u> and <u>Phragmites</u>.
23	-1.77 to -2.08	245 to 276	nig. 2, strf. 0, sicc. 2, elas. 0, lim. sup. 0 As3, Ag1, Th^2(<u>Phra</u>)+ Grey clay with some silt and occasional <u>Phragmites</u> remains.
22	-2.08 to -2.23	276 to 291	nig. 2, strf. 1, sicc. 2, elas. 0, lim. sup. 0 As2, Ag2, Ga+ Grey, slightly laminated silty-clay with some sand.
	-2.23 to -2.39	291 to 307	Unsampled
21	-2.39 to -2.56	307 to 324	nig. 2, strf. 0, sicc. 2, elas. 0, lim. sup. 0 As4, Ag+ Very soft battleship-grey silty-clay.

20	-2.56 to -2.65	324 to 333	nig. 3, strf. 0, sicc. 2, elas. 0, lim. sup. 1 Sh3, $Th^3$1, As+ Well-humified, very soft brown peat with a slightly eroded contact and some inclusions of clay.
19	-2.65 to -2.91	333 to 359	nig. 4, strf. 0, sicc. 2, elas. 1, lim. sup. 0 $Th^2$3, Th^2(Phra)+, Sh1, Dl+ Turfa with occasional detrital wood and Phragmites. Less humified than stratum 18.
18	-2.91 to -2.98	359 to 366	nig. 4, strf. 0, sicc. 3, elas. 0, lim. sup. 0 Sh3, $Th^3$1, Th^3(Phra)+ Well-humified, compact and quite dry black peat, with some turfa and well humified Phragmites.
17	-2.98 to -3.02	366 to 370	nig. 3, strf. 0, sicc. 2, elas. 0, lim. sup. 0 Sh3, $Th^3$1, Dl+ Soft, well-humified brown peat with some turfa and a piece of detrital wood (Alnus?) 3 cm in length.
16	-3.02 to -3.12	370 to 380	nig. 2, strf. 0, sicc. 2, elas. 0, lim. sup. 0 As3, Ag1, Dh+ Very soft, dark grey silty-clay with some detrital organic material.
15	-3.12 to -3.36	380 to 404	nig. 2, strf. 0+ sicc. 2, elas. 0, lim. sup. 0 As2, Ag2, Dh+

			Grey silty-clay occasionally finely laminated.
	-3.36 to -3.56	404 to 424	Unsampled
14	-3.56 to -4.26	424 to 494	nig. 2, strf. 1, sicc. 2, elas. 0, lim. sup. 0 As2, Ag2, Dh+ Grey silty-clay with some detrital organic material and finely laminated throughout.
13	-4.26 to -4.55	494 to 523	nig. 2, strf. 2, sicc. 2, elas. 0, lim. sup. 0 Ag2, As1, Ga1, Dh+ Well laminated clayey-silt with some sand and detrital organic material.
	-4.55 to -4.81	523 to 549	Unsampled
12	-4.81 to -4.88	549 to 556	nig. 2, strf. 2, sicc. 2, elas. 0, lim. sup. 0 Ag2, As1, Ga1, Dh+ Well laminated clayey-silt with some sand and detrital organic material.
11	-4.88 to -5.80	556 to 648	nig. 2, strf. 1, sicc. 2, elas. 0, lim. sup. 0 As2, Ag2, Dh+ Battleship-grey silty-clay with some detrital organic material. Slightly laminated throughout.

	-5.80 to -6.00	648 to 668	Unsampled
10	-6.00 to -6.03	668 to 671	nig. 2, strf. 0, sicc. 2, elas. 0, lim. sup. 0 As4, Ag+, Dh+ Very soft clay with some silt and occasional detrital material.
9	-6.03 to -6.05	671 to 673	nig. 3, strf. 0, sicc. 2, elas. 0, lim. sup. 0 As4, Dh+ Very soft dark grey clay with some detrital organic material.
8	-6.05 to -6.09	673 to 677	nig. 3, strf. 1, sicc. 3, elas. 1, lim. sup. 0 Th^3(*Phra*)1, Th^3+, Sh3, Dl+, As+ Dark brown well-humified peat with some *Phragmites* and occasional woody remains. Some inclusions of clay present in root channels, and finely laminated.
7	-6.09 to -6.33	677 to 701	nig. 3+, strf. 1, sicc. 2, elas. 0, lim. sup. 0 Sh3, Th^3+, Th^3(*Phra*)1 Well-humified, slightly laminated peat with some *Phragmites*.
6	-6.33 to -6.36	701 to 704	nig. 3+, strf. 0, sicc. 2, elas. 0, lim. sup. 0 Sh3, As1, part test moll+ Light brown well-humified peat with some clay and fine white powdered shells.

5	-6.36 to -6.41	704 to 709	nig. 3+, strf. 0, sicc. 3, elas. 1, lim. sup. 0 Sh3, $Th^3 1$, Th^3(Phra)+, As+, Dl+ Compact dark brown/black well humified peat with some turfa and Phragmites. Occasional small woody pieces, and some clay.
4	-6.41 to -6.48	709 to 716	nig. 2, strf. 0, sicc. 2, elas. 0, lim. sup. 0 As3, Ag1, Th^3+ Dark grey silty-clay with some turfa.
3	-6.48 to -6.60	716 to 728	nig. 2, strf. 0, sicc. 2, elas. 0, lim. sup. 0 As3, Ag1, Dh+ Battleship-grey silty-clay with some detrital organic material.
2	-6.60 to -6.62	728 to 730	nig. 2, strf. 2, sicc. 2, elas. 0, lim. sup. 0 Ag2, As1, Ga1, Dh+ Laminated battleship-grey clayey-silt with some sand and detrital organic material.
1	-6.62 to -6.75	730 to 743	nig. 2, strf. 1, sicc. 2, elas. 0, lim. sup. 0 As3, Ag1, Ga+, Dh+, part test moll+ Laminated battleship-grey silty-clay with some detrital organic material, sand and rare unidentified shells. Occasional coarser laminations recorded.

5.2.3.2. Marsh Lane Bore 9 Pollen analysis: Lower organic deposit -6.41m to -6.05m OD.

Of fifteen samples prepared for pollen analysis eleven samples had sufficient pollen for counting. The resulting diagram (Fig.5.4.) has been divided into five LPAZs, and the characteristics of each are described in turn below. Each LPAZ split coincides with the zonation suggested by the highest four splits of CONISS.

LPAZ	Altitude (m OD)	Zone Characteristics

ML-9a -6.38m to -6.35m OD

This zone is characterised by high frequencies of herb taxa, with low frequencies of trees, shrubs, aquatics and ferns and spores. In the lower sample of the zone Gramineae pollen account for 47% TLP. Also recorded in this level are Chenopodiaceae (13% TLP), and low frequencies of *Aster*-type and *Atriplex*-type pollen. The other principle herb recorded in this zone is Cyperaceae.

ML-9b -6.35m to -6.30m OD

The lower zone boundary is defined by an increase in frequencies of aquatic taxa and Gramineae. The zone is characterised by an assemblage dominated by *Lemna*, which rises to 37% TLP at -6.34m OD, and then falls slightly to 29% TLP at -6.32m OD. Frequencies of *Typha latifolia* also fall from 25% to 13% between these levels. Other aquatic taxa recorded include *Potamogeton* and *Typha angustifolia*, whilst damp-loving herbs such as *Malvaceae*, *Parnassia*-type, *Radiola linoides* and *Sanguisorba officialis* are also recorded. Gramineae frequencies rise to *c*. 56% TLP, and frequencies of trees, shrubs, ferns and spores are low throughout this zone.

ML-9c -6.30m to -6.22m OD

The lower zone boundary is defined by a decrease in frequencies of _Lemna_ and _Typha latifolia_, and by an increase in frequencies of Cyperaceae. The zone is characterised by an assemblage dominated by Gramineae and Cyperaceae, whilst frequencies of trees, shrubs, ferns and spores are low throughout this zone.

ML-9d -6.22m to -6.18m OD

The lower zone boundary is defined by a sharp increase in the frequencies of Filicales and _Thelypteris palustris_, which together total _c_. 150% TLP. Gramineae frequencies fall slightly, whilst tree, shrubs and aquatic frequencies are low (<12% TLP).

ML-9e -6.18m to -6.06m OD

The lower zone boundary is defined by a fall in frequencies of Filicales from 133% TLP to 16% TLP. The zone is characterised by an assemblage dominated by Gramineae and Cyperaceae, although in the uppermost sample there is a slight increase in the frequencies of shrub and tree pollen, notably _Corylus_ and _Tilia_.

5.2.3.3. ML-9 Pollen analysis: Upper organic deposit -3.02m to -2.56m OD.

Of fifteen samples prepared for pollen analysis, eleven samples contained sufficient pollen for counting. The resulting pollen diagram (Fig.5.5.) has been divided into five LPAZs, and the characteristics of each are described in turn below. Each LPAZ coincides with the zonation suggested by the four highest splits of CONISS.

LPAZ	Altitude (m OD)	Zone Characteristics

ML-9f -2.98m to -2.92m OD

The zone is characterised by an assemblage dominated by high Gramineae frequencies which account for c. 60% TLP. Frequencies of trees, shrubs, ferns and spores remain low throughout this zone. At -2.94m OD, Cyperaceae and aquatic taxa increase in frequency.

ML-9g -2.92m to -2.80m OD

The lower zone boundary is defined by an increase in frequencies of Filicales. The zone is characterised by an assemblage dominated by Gramineae, Cyperaceae, Corylus and Filicales. Tree pollen accounts for <15% TLP, whilst aquatic taxa decrease in this zone to <5% TLP.

ML-9h -2.80m to -2.64m OD

The lower zone boundary is defined by an increase in frequencies of Gramineae, and a decline in frequencies of Cyperaceae. The zone is characterised by an assemblage dominated by Gramineae, which increases to a high of 60% TLP. Frequencies of trees and shrubs remain low. At -2.66m OD there is an increase in the frequency of aquatic taxa recorded, notably Typha latifolia which increases to 9% TLP.

ML-9i -2.64m to -2.58m OD

The lower zone boundary is defined by an increase in the frequency of both aquatic taxa and those of ferns and spores. Frequencies of trees, shrubs and herbs remain similar to those in LPAZ ML9-h. Lemna frequencies increase to 14% TLP, and aquatic taxa together total 21% TLP. Frequencies of Filicales increase to 28% TLP, and ferns and spores together total 44% TLP.

ML-9j -2.58m to -2.56m OD

The lower zone boundary is defined by a decrease in frequencies of herbs, aquatics, and ferns and spores. The zone is characterised by an assemblage dominated by Gramineae, Cyperaceae, Corylus and Alnus. Of the trees, Alnus and Tilia increase, whilst frequencies of Corylus total 26% TLP.

5.2.3.4. Pollen analysis - lithostratigraphy of Marsh Lane Monolith. (MMON)

The lithostratigraphy of the organic deposit recorded in these monolith samples is described below:

Stratum	Altitude O.D. Metres	Description
14	-1.51 to -1.57	nig. 2, strf. 0, sicc. 2, elas. 0, lim. sup. 0 As4, Ag+ Battleship-grey clay with some silt.
13	-1.57 to -1.64	nig. 3, strf. 0, sicc. 2, elas. 0, lim. sup. 0 As4, Th^2(Phra)+, Sh+ Soft grey/brown clay with some Phragmites.
12	-1.64 to -1.66	nig. 3, strf. 0, sicc. 2, elas. 1, lim. sup. 0 Sh3, $Th^2$1, Dl+, Th^2(Phra)+ Brown well-humified peat with some turfa, Phragmites and occasional woody remains.

11	-1.66 to -1.73	nig. 4, strf. 0, sicc. 2, elas. 1, lim. sup. 0 $Th^2$2, Dl+, Th^2(Phra)2 Dark brown/black turfa with some Phragmites.
10	-1.73 to -1.75	nig. 3, strf. 0, sicc. 2, elas. 0, lim. sup. 0 $Th^2$2, Th^2(Phra)2, Sh+, Dl+ Turfa with some Phragmites and occasional woody remains.
9	-1.75 to -1.82	nig. 4, strf. 0, sicc. 2, elas. 1, lim. sup. 0 $Th^3$2, Th^2(Phra)1, Sh1, Dl+ Dark brown/black turfa with some Phragmites.
8	-1.82 to -1.86	nig. 4, strf. 0, sicc. 2, elas. 1, lim. sup. 0 Sh4, Th^3+, Th^2(Phra)+ Black well-humified peat with some Phragmites and turfa.
3	-1.86 to -2.03	nig. 4, strf. 0, sicc. 2, elas. 1, lim. sup. 0 $Th^2$1, Th^2(Phra)1, Sh1, Dl1 Dark brown/black turfa with some Phragmites and detrital wood.
6	-2.03 to -2.10	nig. 4, strf. 0, sicc. 2, elas. 1, lim. sup. 0 Dl2, $Th^2$1, Sh1 Dark brown/black woody (Quercus?) peat with some turfa.

5	-2.10 to -2.25	nig. 4, strf. 0, sicc. 2, elas. 1, lim. sup. 0 Sh3, $Th^2$1, Th^2(Phra)+ Dark brown/black well-humified peat with some turfa and Phragmites.
4	-2.25 to -2.30	nig. 4, strf. 0, sicc. 2, elas. 1, lim. sup. 0 $Th^2$3, Dl+, Sh1, part test moll+ Dark brown/black turfa with some large pieces of wood (Alnus?), and a Corylus nut at -2.30m OD. Some Planorbis spp. shells recorded to base of stratum.
3	-2.30 to -2.32	nig. 3, strf. 0, sicc. 2, elas. 1, lim. sup. 0 Sh3, $Th^2$1, Dl+, Th^2(Phra)+ Well-humified brown peat with some turfa, Phragmites and occasional woody remains.
2	-2.32 to -2.40	nig. 3, strf. 0, sicc. 2, elas. 0, lim. sup. 0 As2, Sh2, Th^2+ Soft brown clay with some turfa.
1	-2.40 to -2.42	nig. 2, strf. 0, sicc. 2, elas. 0, lim. sup. 0 Ag4, Ga+, Lf+ Compact white/grey sandy-silt with some iron-staining.

5.2.3.4. Marsh Lane Monolith Pollen analysis -2.32m to -1.64m OD.

Of seventeen samples prepared for pollen analysis, all samples contained sufficient pollen for counting. The resulting diagram (Fig.5.6.) has been divided into five LPAZ's, and the characteristics of each are described in turn below. Each LPAZ coincides with the zonation suggested by the four highest splits of CONISS.

LPAZ **Altitude (m OD)** **Zone Characteristics**

MMON-a -2.29m to -2.15m OD

The zone is characterised by an assemblage dominated by high frequencies of herbs, shrubs, and ferns and spores. Gramineae frequencies are high at the base of the zone (41% TLP), but fall to 13% by -2.17m OD. This decline is contrasted by an increase in frequencies of Cyperaceae from 18% to 38% TLP. Of the shrub taxa Corylus frequencies increase from 28% TLP to an average of c. 35% TLP. Aquatic taxa account for >40% TLP at the base of the zone, but decline sharply to c. 17% TLP above -2.29m OD. This is principally due to the reduction in frequencies of Lemna and Typha latifolia. Frequencies of ferns and spores are dominated by Filicales and Thelypteris palustris, of which the latter accounts for c. 55% TLP.

MMON-b -2.15m to -2.07m OD

The lower zone boundary is defined by a decline in the frequencies of Corylus and Thelypteris palustris, and by the rise in frequencies of Cyperaceae and Filicales. The zone is characterised by an assemblage dominated by Cyperaceae, which accounts for 66% TLP at -2.09m OD, and Filicales which increase to 128% TLP at -2.13m OD, before falling to 36% TLP by -2.09m OD. Aquatic pollen frequencies decrease to c. 6% TLP in this zone.

MMON-c -2.07 to -1.95m OD

The lower zone boundary is defined by a rise in the frequencies of Gramineae and a decline in those of Cyperaceae and Filicales. The zone is characterised by an assemblage dominated by Gramineae and Cyperaceae. Frequencies of Corylus continue to fall in this zone, whilst those of tree pollen begin a gradual rise in zone, largely due to an increase in the frequencies of Alnus to >10% TLP at -1.97m OD. Gramineae frequencies increase to a high of 49% TLP at -1.97m OD, and Filicales frequencies fall to c. 10% TLP. Frequencies of aquatic taxa remain low.

MMON-d -1.95m to -1.75m OD

The lower zone boundary is defined by a rise in the frquencies of tree pollen, as those of herb pollen decline. The zone is characterised by an assemblage dominated by Alnus, Tilia, Cyperaceae and Gramineae. Frequencies of Alnus pollen increase to a high of 45% TLP at -1.81m OD, and Tilia frequencies also increase to c. 10-20% TLP. Gramineae frequencies fall over the lower zone boundary, and then remain at c. 20% TLP for the rest of the zone. Frequencies of Filicales increase and fluctuate between c. 7% and 30% TLP. Aquatic taxa frequencies remain low.

MMON-e -1.75m to -1.65m OD

The lower zone boundary is defined by a decline in tree pollen frequencies, and by an increase in the frequencies of herbs, ferns and spores. The zone is characterised by an assemblage dominated by Gramineae, Cyperaceae, Chenopodiaceae and Filicales. Alnus pollen frequencies fall to 5% TLP by -1.65m OD, whilst Tilia frequencies also fall to >10% TLP. At the top of the zone, tree pollen collectively account for only 15-20% TLP. In contrast, frequencies of herb pollen increase throughout the zone to a maximum of 77% TLP at -1.65m OD. In particular, frequencies of Gramineae increase to c. 40% TLP. Frequencies of Chenopodiaceae increase throughout this zone from 2% to 18% TLP, and at -1.73m OD there is a slight increase in frequencies of Lemna, which exceed 10% TLP. Filicales frequencies increase to >50% TLP at -1.69m OD.

5.2.4. Hacklinge.

The general lithostratigraphy of the Hacklinge area has been described in Sections 4.2.5.1. to 4.2.5.5.. Four piston cores were collected from the area, one from the position of hand-core H7 of Transect 1, and three from the position of hand-core GR2. Piston-core 7 (H-7) was collected and analysed as part of an undergraduate dissertation (Long 1988), in which a pollen diagram from the upper four metres of sediments was constructed. Piston cores H-2a and b were collected from the same location towards the edge of the infilled-valley, where a deeper suite of organic and inorganic sediments was sampled.

Of the two piston-cores collected from Hacklinge, elemental and pollen analyses were completed on the first piston-core (H-2a). As the elemental analysis involved the destruction of this core, a second piston-core (H-2b) was collected for diatom analysis and ^{14}C dating.

5.2.4.1. Pollen analysis - lithostratigraphy of piston-core H7.

The detailed lithostratigraphic description of H-7 is given below.

Stratum	Altitude O.D. metres	Depth cm	Description
	-0.79 to -1.33	000 to 054	Unsampled

20	-1.33 to -1.49	054 to 070	nig. 3, strf. 0, sicc. 2, elas. 2, lim. sup. 0 $Th^2$2, As1, Th^2(<u>Phra</u>)1, part test moll + <u>Turfa</u> with some <u>Phragmites</u>. Humification increases to base of stratum. Very thin shell marl (0.8 cm) recorded at 057 cm. Rare shells (unidentified) found to base of stratum.
19	-1.49 to -1.57	070 to 078	nig. 2, strf. 1, sicc. 2, elas. 0, lim. sup. 0 As3, Ag1, Sh+, Th^2(<u>Phra</u>)+, part test moll + Soft and buttery slightly laminated silty-clay with some <u>turfa</u>, unidentified shells and <u>Phragmites</u>.
18	-1.57 to -1.66	078 to 087	nig. 2, strf. 0, sicc. 2, elas. 0, lim. sup. 1 As2, Ag2, part test moll+, Th^2(<u>Phra</u>)+ Same as stratum above, but becoming coarser with more silt and yellow/ grey in colour.
17	-1.66 to -1.67	087 to 088	nig. 2, strf. 1, sicc. 1, elas. 0, lim. sup. 1 As2, Ag2, Th^2+, part test moll+ Slightly laminated silty-clay with Some <u>turfa</u> and shell remains (unidentified). Occasional black (mica?) particles found. Yellow in colour.

16	-1.67 to -1.72	088 to 093	nig. 3, strf. 0, sicc. 2, elas. 0, lim. sup. 0 As2, Th^{2}1, Th^2(*Phra*)1, part test moll + Clay-rich *turfa* with some *Phragmites* and few (unidentified) shells. Dark brown in colour.
15	-1.72 to -1.87	093 to 108	nig. 3, strf. 0, sicc. 2, elas. 0, lim. sup. 0 Th^{2}2, Th^2(*Phra*)1, As1 Dark brown *turfa* with some *Phragmites* and some clay. *Turfa* content increase with depth.
14	-1.87 to -1.89	108 to 110	nig. 2, strf. 0, sicc. 2, elas. 0, lim. sup. 0 As2, Ag1, part test moll1+ Yellow/white shell marl with some clay and silt.
13	-1.89 to -2.04	110 to 125	nig. 3, strf. 0, sicc. 2, elas. 1, lim. sup. 2 Th^{2}3, Th^2(*Phra*)1 Dark brown *turfa* with some *Phragmites*, becoming red/brown with depth.
12	-2.04 to -2.13	125 to 134	nig. 3, strf. 0, sicc. 2, elas. 0, lim. sup. 0 As2, Th^{2}1, Ag1 Grey/brown silty-clay, with some *turfa* transitional to lower stratum.
11	-2.13 to -2.44	134 to 165	nig. 2, strf. 0, sicc. 2, elas. 0, lim. sup. 0 As3, Ag1, Th^2+

			Soft silty-clay with some *turfa*. Turfa content decrease with depth.
10	-2.44 to -2.62	165 to 183	nig. 3, strf. 0, sícc. 2, elas. 0, lim. sup. 0 Th^2(*Phra*)2, $Th^2$2, Brown *Phragmites* peat with some *turfa*.
9	-2.62 to -2.99	183 to 220	nig. 2, strf. 0, sicc. 2, elas. 0, lim. sup. 0 As3, Ag1, Th^2(*Phra*)+ Grey silty-clay with some *Phragmites*.
8	-2.99 to -3.31	220 to 252	nig. 2, strf. 0, sicc. 2, elas. 0, lim. sup. 0 As3, Ag1, Th^2(*Phra*)+, part test moll + Silty-clay with some *Phragmites*, and occasional unidentified shells recorded.
	-3.31 to -3.45	252 to 266	Unsampled
7	-3.45 to -3.71	266 to 292	nig. 3, strf. 0, sicc. 2, elas. 1, lim. sup. 0 $Th^2$2, Th^2(*Phra*)2, Ag+, As+ Dark brown *turfa* with some *Phragmites*, silt and clay present.
6	-3.71 to -3.86	292 to 307	nig. 4, strf. 0, sicc. 2, elas. 2, lim. sup. 0 $Th^2$3, Dl1 *Turfa* with some woody detrital

			material (*Alnus*?). Small flint at 300 cm.
5	-3.86 to -3.99	307 to 320	nig. 4, strf. 0, sicc. 2, elas. 2, lim. sup. 0 $Th^2 2$, Dl2 Black *turfa* with woody detrital material.
4	-3.99 to -4.49	320 to 370	nig. 4, strf. 0, sicc. 2, elas. 2, lim. sup. 0 $Th^2 3$, Dl1 Black *turfa* with some detrital wood.
3	-4.49 to -4.64	370 to 385	nig. 3, strf. 0, sicc. 2, elas. 0, lim. sup. 0 As3, Sh1, Th^2+, Anth+ Orange/brown clay with some *turfa* and small charcoal flecks.
2	-4.64 to -4.76	385 to 397	nig. 3, strf. 0, sicc. 2, elas. 0, lim. sup. 0 Th^2(*Phra*)1, As1, Dl1, Sh1 Brown *turfa* with some clay and woody detrital material (*Alnus*?).
1	-4.76 to -6.99	397 to 620	nig. 2, strf. 0, sicc. 2, elas. 0, lim. sup. 0 As3, Ag1, Th^2(*Phra*)+ Battleship-grey silty-clay with some silt and *Phragmites*.

5.2.4.2. H-7 Pollen analysis: Upper organic deposit -4.76m to -1.33m OD.

Of seventy samples prepared for pollen analysis, twenty-six samples contained sufficient pollen for counting. The resulting pollen diagram (Fig.5.7.) has been divided into seven LPAZs, and the characteristics of each zone are described below. Each LPAZ coincides with the zonation suggested by each of the six highest splits of CONISS.

LPAZ	Altitude (m OD)	Zone Characteristics
H-7a	**-4.76m to -4.64m OD**	

The zone is characterised by an assemblage consisting of high frequencies of herb taxa (c. 80% TLP), with Gramineae and Cyperaceae dominating. Cyperaceae frequencies are high at the base of the zone, but are replaced by Gramineae above -4.76m OD as the main herb type. Tree pollen accounts for c. 14% TLP, with Quercus dominating. Frequencies of shrubs, aquatics, ferns and spores are low.

H-7b **-4.64m to -4.40m OD**

The lower zone boundary is defined by a fall in frequencies of Gramineae to <16% TLP, a rise in the frequencies of Cyperaceae to >35% TLP, and by an increase in frequencies of tree pollen and aquatic pollen types. The zone is characterised by an assemblage dominated by Cyperaceae, tree pollen and Myriophyllum-type and Typha angustifolia. Of the tree pollen, Alnus, Betula, and Quercus fluctuate to reach a combined high of 63% TLP at the base of the zone, and then decrease to c. 26% TLP at the top of the zone. Shrub frequencies fluctuate as Corylus varies between 7-27% TLP. Of the aquatic taxa, Myriophyllum-type rises sharply at the base of the zone to 32% TLP. As frequencies of Myriophyllum-type decrease, so frequencies of Typha angustifolia increase to c. 20% TLP.

H-7c -4.40m to -4.05m OD

The lower zone boundary is defined by a sharp increase in the frequencies of Gramineae which increases to c. 90% TLP. In addition, frequencies of trees and shrubs fall over the lower zone boundary. The zone is characterised by an assemblage dominated by Gramineae, but at -4.11m OD there is an isolated peak in Typha angustifolia which accounts for 64% TLP at this level. Frequencies of ferns and spores are low throughout this zone.

H-7d -4.05m to -3.73m OD

The lower zone boundary is defined by a decline in the frequencies of Typha angustifolia. The zone is characterised by an assemblage dominated by Gramineae and Cyperaceae, although the former decline to c. 24% TLP. Frequencies of tree pollen increase to 10-15% TLP, whilst those of aquatic taxa fall sharply to <15% TLP, largely due to the decline in frequencies of Typha angustifolia. Filicales frequencies increase to a high of 13% TLP at -3.89m OD.

H-7e -3.73m to -2.27m OD

The lower zone boundary is defined by a fall in frequencies of Cyperaceae to c. 20% TLP. The zone is characterised by an assemblage dominated by high frequencies of herb pollen, which continually exceed 75% TLP. Frequencies of Chenopodiaceae are high throughout this zone, and fluctuate between 5-10% TLP. Tree pollen (mainly Quercus) generally account for <20% TLP, with a high at -3.47m OD, where they account for >35% TLP. Frequencies of ferns, spores and aquatics are consistently low in this zone.

H-7f -2.27m to -1.59m OD

The lower zone boundary is defined by an increase in the frequencies of Typha latifolia, by a decline in those of Chenopodiaceae. The zone is characterised by an assemblage dominated by Gramineae and Cyperaceae. There is an increase in the frequencies of other herb types such as Plantaginaceae, Taraxacum vulgare, and Umbelliferae. Frequencies of Typha angustifolia and Typha latifolia also increase and are recorded throughout this zone. Frequencies of Filicales fluctuate, and reach a high of 14% TLP at -1.90m OD. In general, tree pollen frequencies account for <10% TLP.

H-7g -1.59m to -1.35m OD

The lower zone boundary is defined by an increase in frequencies of Gramineae and by a decline in frequencies of Cyperaceae to <6% TLP. In addition, frequencies of tree pollen fall to <3% TLP, as do those of ferns and spores. Aquatic taxa increase sharply, notably Typha angustifolia, which accounts for 47% TLP at -1.48m OD. The zone is characterised by an assemblage dominated by Gramineae and Typha angustifolia.

5.2.4.3. Pollen analysis - lithostratigraphy of piston-core H-2(a).

The lithostratigraphy of hand-core GR is described in full in Appendix 1, and the detailed lithostratigraphy of H-2(a) is given below.

Stratum	Altitude O.D. metres	Depth cm	Description
40	-0.86 to -1.41	000 to 055	Sc4 Topsoil

39	-1.41 to -1.62	055 to 076	nig. 3, strf. 0, sicc. 2, elas. 0, lim. sup. 0 $Th^2 4$ Dark brown turfa with occasional chalk clasts, becoming lighter in colour with depth.
38	-1.62 to -1.71	076 to 085	nig. 3, strf. 0, sicc. 2, elas. 0, lim. sup. 0 As1, part test moll 1, Sh1, $Th^2 1$ Yellow-brown clay-rich shell marl with some turfa.
37	-1.71 to -2.16	085 to 130	nig. 3, strf. 0, sicc. 2, elas. 0, lim. sup. 0 Th^2(Phra)3, $Th^2 1$ Soft brown Phragmites-rich peat with some turfa.
36	-2.16 to -2.21	130 to 134	nig. 2, strf. 0, sicc. 2, elas. 0 lim. sup. 0 As4, Dh+ Soft grey clay with some turfa.
	-2.21 to -2.28	134 to 141	Unsampled
35	-2.28 to -2.58	141 to 172	nig. 3, strf. 1, sicc. 2, elas. 2, lim. sup. 0 $Th^2 2$, Th^2(Phra)1, As1 Dark brown/black turfa with common Phragmites, and in situ rhizomes. At 146 cm strong vertical orientation of Phragmites roots, and layered Phragmites leaves at 156 cm. Occasional slightly

			clayey layers @ 1-2 cm thick recorded at 166-168 cm.
34	-2.58 to -2.80	172 to 194	nig. 2/3, strf. 0, sicc. 2, elas. 1, lim. sup. 0 Th^2(Phra)2, As1, $Th^2$1 Yellow turfa with some Phragmites and some clay. Slight decrease in turfa content compared with stratum above. Between 180-185 cm strong vertical orientation of Phragmites roots, and at 193 cm there is a slight increase in the clay component.
33	-2.80 to -2.96	194 to 210	nig. 2, strf. 0, sicc. 2, elas. 0, lim. sup. 0 As3, Th^2(Phra)1 Grey/brown Phragmites-rich clay.
32	-2.96 to -3.14	210 to 228	nig. 2, strf. 0, sicc. 2, elas. 0, lim. sup. 0 As2, Ag1, Th^2(Phra)1 Grey silty-clay with some Phragmites.
31	-3.14 to -3.29	228 to 243	nig. 3/4, strf. 0, sicc. 2, elas. 1, lim. sup. 0 $Th^3$2, Sh1, As1 Black peat with some well-humified turfa, Substantia humosa and clay.
	-3.29 to -3.68	243 to 282	Unsampled

30	-3.68 to -3.81	282 to 295	nig. 3+, strf. 0, sicc. 2, elas. 1, lim. sup. 0 Dl2, Sh1, Tl1, Th^2(_Phra_)+ Woody detrital peat with some twigs (_Alnus_?) up to 1cm long. At 284 cm a salmon-pink piece of wood, a piece of bark (_Alnus_?) and _Menyanthes_ seed recorded. At 285 cm the _Phragmites_ content increases, with vertical roots recorded. At 286 cm a 2.5 cm piece of wood (_Alnus_?) recorded.
29	-3.81 to -3.82	295 to 296	nig. 3, strf. 0, sicc. 2, elas. 0, lim. sup. 0 Dl4 Section of wood fill chamber, grey/brown in colour with a high water content. A few roots penetrate stringey wood (_Quercus_?).
28	-3.82 to -4.00	296 to 314	nig. 3+, strf. 0, sicc. 2, elas. 1, lim. sup. 0 Tl2, Sh1, $Th^2$1, Dl+ Woody detrital peat with some twigs (_Alnus_?) up to 1 cm long. At 297 cm a 4 cm long piece of wood (_Alnus_?), possibly struck at one end recorded. At 306 cm a piece of wood (_Alnus_) 2-3 cm recorded.
27	-4.00 to -4.31	314 to 345	nig. 4, strf. 0, sicc. 2, elas. 1, lim. sup. 0 $Th^2$3, Dl1, Sh+, Tl+ Black _turfa_ peat with some woody detrital material. At 320 cm a twig (_Alnus_?) recorded.

	-4.31 to -4.43	345 to 357	Unsampled
26	-4.43 to -4.49	357 to 363	nig. 4, strf. 0, sicc. 2, elas. 1, lim. sup. 0 $Th^2 3$, Dl1, part test moll+, Sh+ Th^2(<u>Phra</u>)+ Black <u>turfa</u> with some detrital woody material and rare shells (unidentified). At 360 cm there is a slight increase in <u>Phragmites</u>.
25	-4.49 to -4.54	363 to 368	nig. 4, strf. 0, sicc. 2, elas. 0, lim. sup. 0 Th^2(<u>Phra</u>)2, $Th^2 2$, part test moll+ Dl+ <u>Turfa</u> with some <u>Phragmites</u> and rare shells (unidentified). At 367-368 cm <u>Phragmites</u> content increase.
24	-4.54 to -4.66	368 to 380	nig. 4, strf. 0, sicc. 2, elas. 0, lim. sup. 0 Dh1, $Th^2 1$, Dl1, As1, part test moll+ Slightly clayey, soft detrital yellow/brown peat with some <u>turfa</u> and occasional unidentified shells.
23	-4.66 to -4.71	380 to 385	nig. 2, strf. 0, sicc. 2, elas. 0, lim. sup. 0 As2, Th^2(<u>Phra</u>)2 Yellow/brown <u>Phragmites</u>-peat with occasional white flecks - possibly shells, and some clay.

22	-4.71 to -4.87	385 to 401	nig. 2, strf. 0, sicc. 2, elas. 0, lim. sup. 0 Th^2(<u>Phra</u>)2, Sh1, Dh1 Black <u>Phragmites</u>-peat with some detrital herbaceous material.
21	-4.87 to -4.91	401 to 405	nig. 2, strf. 0, sicc. 2, elas. 0, lim. sup. 0 Ag3, Dl1 Dark grey silt with some detrital woody material.
20	-4.91 to -4.96	405 to 410	nig. 2, strf. 0, sicc. 2, elas. 0, lim. sup. 0 As2, Ag2, Dh+ Battleship-grey silty-clay becoming more clay-rich with depth, and an eroded peat ball at 406 cm.
19	-4.96 to -5.01	410 to 415	nig. 2, strf. 0, sicc. 2, elas. 0, lim. sup. 0 As3, $Th^2$1 Soft dark grey clay with some <u>turfa</u>.
18	-5.01 to -5.26	415 to 440	nig. 2, strf. 0, sicc. 2, elas. 0, lim. sup. 0 As4, Dh+ Battleship-grey clay with some dertital herbaceous material.
17	-5.26 to -5.48	440 to 462	nig. 2, strf. 0, sicc. 2, elas. 0, lim. sup. 0 As3, Ag1, Dh+ Soft battleship-grey silty-clay with some detrital herbaceous material.

	-5.48 to -5.76	462 to 490	Unsampled
16	-5.76 to -6.88	490 to 602	nig. 2, strf. 0, sicc. 2, elas. 0, lim. sup. 0 As3, Ag1, Dh+ Soft battleship-grey silty-clay with rare detrital herbaceous material.
	-6.88 to -7.15	602 to 629	Unsampled
15	-7.15 to -7.48	629 to 662	nig. 2, strf. 0, sicc. 2, elas. 0, lim. sup. 0 As3, Ag1, Dh+ Soft battleship-grey silty-clay with some detrital herbaceous material.
14	-7.48 to -7.50	662 to 664	nig. 2, strf. 0, sicc. 2, elas. 0, lim. sup. 0 As2, Ag2, Th^2(Phra)+, Dl+ Soft dark grey silty-clay with some detrital wood and Phragmites roots, vertical and compressed at 664 cm.
13	-7.50 to -7.81	664 to 695	nig. 2, strf. 0, sicc. 2, elas. 0, lim. sup. 0 Sh2, Dl1, Th^3(Phra)1 Quite compact, well oxidised and well-humified peat with some Phragmites and woody material. At 680, 688 and 694 cm brittle and compressed red wood recorded.

12	-7.81 to -7.86	695 to 700	nig. 3+, strf. 2, sicc. 3+, elas. 1, lim. sup. 0 $Th^3 1$, Dl2, Sh1 Dark brown laminated detrital peat with some large woody pieces. Very compact and dry.
11	-7.86 to -8.01	700 to 715	nig. 3+, strf. 2, sicc. 2+, elas. 1, lim. sup. 0 Dl3, Sh+, Th^3(Phra)1 Well laminated detrital peat with some *Phragmites* and woody material. *Phragmites* leaves horizontally bedded.
10	-8.01 to -8.16	715 to 730	nig. 3+, strf. 2, sicc. 2+, elas. 1, lim. sup. 0 Dl2, Sh1, Th^3(Phra)1 Well-humified and laminated woody detrital peat with some *Phragmites*.
9	-8.16 to -8.27	730 to 741	nig. 4, strf. 2, sicc. 3, elas. 1, lim. sup. 0 Sh1, As1, $Th^3 1$, Dl1 Black, laminated and well-humified, very compact peat with some clay and detrital woody material.
	-8.27 to -8.41	741 to 755	Unsampled
8	-8.41 to -8.48	755 to 762	nig. 3+, strf. 2, sicc. 2, elas. 1, lim. sup. 0 Dl3, Dh1 Dark red/black woody detrital peat, well stratified and very compact. At

			756 cm a thin yellow piece of wood 2 cm in length recorded.
7	-8.48 to -8.60	762 to 774	nig. 3, strf. 2, sicc. 2, elas. 1, lim. sup. 0 $Th^3$2, Sh2 Laminated black detrital peat, with some well-humified _turfa_. At 767 cm _Phragmites_ rhizome recorded.
6	-8.60 to -8.83	774 to 797	nig. 2, strf. 0, sicc. 2, elas. 0, lim. sup. 0 As3, Dl1, Ag+ Soft buttery clay with some detrital woody material. Occasional pink wood in clay.
5	-8.83 to -8.84	797 to 798	nig. 3+, strf. 3, sicc. 2, elas. 1, lim. sup. 1 Dh2, Sh1, Th^2(_Phra_)1 Dark brown/black laminated detrital peat with some _Phragmites_.
4	-8.84 to -8.87	798 to 801	nig. 2, strf. 2, sicc. 2, elas. 0, lim. sup. 1 As2, Sh2, Dh+, part test moll+, Th^2(_Phra_)+ Yellow laminated clay with some _Phragmites_ and rare unidentified shells.
3	-8.87 to -8.93	801 to 807	nig. 3, strf. 2, sicc. 3, elas. 0, lim. sup. 3 As2, Sh2, Th^2(_Phra_)+, part test moll+ Well-humified clayey-peat with some unidentified shells and _Phragmites_.

			At 803 cm shells quite common, and 806 cm no shells recorded.
2	-8.93 to -9.09	807 to 823	nig. 3, strf. 0, sicc. 2, elas. 0, lim. sup. 1 Ag1, As3, Dh+, Th^2(<u>Phra</u>)+, Dl+, part test moll+ Dark grey clay with some silt with herbaceous detritus and occasional remains of <u>Phragmites</u>. At 810 cm a very thin twig 3.5 cm long recorded, light brown in colour (<u>Quercus</u>?). Occasional remains of <u>Scrobicularia</u> sp. recorded. Clay content increases slightly at 820 cm.
1	-9.09 to -9.27	823 to 841	nig. 2, strf. 2, sicc. 2, elas. 0, lim. sup. 0 As4, Th^2(<u>Phra</u>)+, Dh+ Slate-grey laminated clay with occasional remains of <u>Phragmites</u>. Very small flint recorded at 834 cm and an eroded peat ball at 835 cm.

Three pollen diagrams have been constructed from this piston-core, one for the lower two organic deposit between -8.93 to -7.50m OD, and two for the upper organic sediments between -4.87 to -0.86m OD. Each diagram is described below.

<u>5.2.4.4. H-2(a) Pollen analysis: Lower organic deposit -8.93 to -7.50m OD.</u>

Of thirty samples prepared for pollen analysis, nineteen samples contained sufficient pollen for counting. The resulting diagram (Fig.5.8.) has been divided into seven LPAZs, and the characteristics of each are described in turn below. Each LPAZ coincides with the zonation suggested by each of the highest six splits of CONISS.

LPAZ	Depth cm	Zone Characteristics

H-2(a)a -8.94m to -8.85m OD

This zone is characterised by high tree pollen frequencies, notably those of Quercus and Tilia. Tree pollen accounts for c. 70% TLP in this zone, with Quercus frequencies rising from 46% to 63% TLP by the top of the zone. Corylus frequencies dominate the shrub pollen sum, accounting for c. 15% TLP by the top of the zone. Herb pollen frequencies are low, falling from c. 26% TLP in the base of the zone to c. 11% TLP at the top of the zone, and are dominated by Gramineae and Cyperaceae. Aquatic taxa total <5% TLP throughout this zone, whilst ferns and spores total c. 10% TLP.

H-2(a)b -8.85m to -8.68m OD

The lower zone boundary is defined by a sharp drop in frequencies of tree pollen to 35% TLP. In particular frequencies of Quercus fall to 11% TLP, whilst of the shrub taxa Corylus frequencies increase to 33% TLP. The zone is characterised by an assemblage dominated by shrubs and herbs. Of the latter Gramineae and Cyperaceae are recorded in low frequencies in conjunction with rare grains of Aster-type and Atriplex-type. Frequencies of aquatic pollen and ferns and spores remain low.

H-2(a)c -8.68m to -8.20m OD

The lower zone boundary is defined by a rise in the frequencies of Gramineae to 74% TLP, and by an increase in the frequencies of Quercus. The zone is characterised by an assemblage dominated by Gramineae and Quercus, although the former declines to 39% TLP by the top of this zone, as frequencies of trees, aquatics and ferns and spores increase. Tree pollen frequencies increase to 35% TLP, largely because of an increase in frequencies of Quercus. Of the shrub taxa, Corylus frequencies fall to c. 7% TLP. Aquatic taxa generally increase throughout the zone, and by the top of the zone have risen to 33% TLP and are dominated by frequencies of Typha angustifolia.

H-2(a)d -8.20m to -8.14m OD

The lower zone boundary is defined by a decline in frequencies of Filicales, Thelypteris palustris, and Nymphaea. The zone is characterised by an assemblage dominated by Cyperaceae and Gramineae.

H-2(a)e -8.14m to -8.04m OD

The lower zone boundary is defined by an increase in frequencies of Cyperaceae, and by a decline in those of trees, shrubs, aquatics and ferns and spores. The zone is characterised by an assemblage dominated by herb pollen, which accounts for c. 97% TLP in this zone, with Cyperaceae accounting for 96% TLP by the top of the zone.

H-2(a)f -8.04m to -7.87m OD

The lower zone boundary is defined by an increase in the frequencies of Filicales and Thelypteris palustris and by a decline in the frequencies of Cyperaceae. The zone is characterised by an assemblage dominated by ferns and spores which account for c.75% TLP, and by Cyperaceae and Gramineae. Gramineae frequencies rise to c. 30% TLP, whilst those of trees, shrubs, and aquatic taxa remain very low.

H-2(a)g -7.87m to -7.72m OD

The lower zone boundary is defined by a decline in Cyperaceae frequencies to <20% TLP, and an increase in frequencies of Gramineae to c. 80% TLP. Frequencies of ferns and spores fall sharply to <11% TLP, whilst frequencies of trees, shrubs and aquatic taxa all remain low. The zone is characterised by an assemblage dominated by Gramineae and Cyperaceae.

5.2.4.5. H-2(a) Pollen analysis: Upper organic deposit -4.87m to -0.86m OD.

Of sixty samples prepared for pollen analysis, fourty-two samples contained sufficient pollen for counting, and the results of the pollen analysis are presented graphically in Fig.5.9. The diagram has been divided into seven LPAZs, and the characteristics of each zone are described in turn below. Each LPAZ coincides with the zonation suggested by each of the six highest splits of CONISS.

LPAZ Altitude (m OD) Zone Characteristics

H-2(a)h -4.85m to -4.80m OD

High frequencies of herb and tree pollen characterise this zone, notably those of Gramineae (c. 43% TLP) and Betula (c. 24% TLP). Shrub pollen frequencies are dominated by Corylus (c. 9% TLP), whilst frequencies of aquatics and ferns and spores are low.

H-2(a)i -4.80m to -4.55m OD

The lower zone boundary is defined by an increase in the frequencies of aquatic taxa. The zone is characterised by an assemblage dominated by Gramineae, Betula, and various aquatic taxa. Aquatic taxa fluctuate between c. 20-70% TLP, and also in this zone there is a progressive decline in frequencies of

Gramineae from 54% to 29% TLP. The lowest sample of this zone, at -4.77m OD, sees a sharp increase in frequencies of Potamogeton and Typha angustifolia, so that the combined aquatic taxa total 69% TLP. At this level frequencies of Betula fall to 7% TLP. At -4.71m OD aquatic taxa fall, but in the two succeeding levels increase again to high frequencies, with Lemna, Potamogeton, Typha angustifolia and Typha latifolia being recorded. Towards the top of this zone Cyperaceae frequencies increase to c. 15% TLP. Frequencies of ferns and spores remain low throughout this zone.

H-2(a)j -4.55m to -4.37m OD

The lower zone boundary is defined by an increase in the frequencies of Gramineae, and by a decline in aquatic taxa. The zone is characterised by an assemblage dominated by Gramineae and Cyperaceae. Frequencies of Cyperaceae rise to >50% TLP, and those of Gramineae continue to fall to <10% TLP at the top of the zone. Frequencies of shrubs, ferns and spores remain low.

H-2(a)k -4.37m to -4.00m OD

The lower zone boundary is defined by a rise in the frequencies of Alnus and Filicales. The zone is characterised by an assemblage dominated by frequencies of Cyperaceae and Filicales. Frequencies of Alnus increase in this zone from 15% TLP at -4.31m OD to 34% TLP at -4.19m OD before falling to c. 10% TLP for the rest of the zone. Filicales frequencies increase and fluctuate between 13% and 51% TLP in this zone. Frequencies of Gramineae account for c. 60% TLP in this zone.

H-2(a)l -4.00m to -3.52m OD

The lower zone boundary is defined by a decrease in the frequencies of Filicales and Cyperaceae, and by an increase in those of Gramineae. The zone is characterised by an assemblage dominated by Gramineae. Frequencies of Cyperaceae fall to c. 15% TLP as do those of Filicales (to c. 10% TLP). In contrast there is an increase in the frequencies of Gramineae to 66% TLP at -3.69m OD. Above -3.81m OD, there is an increase in the frequencies of aquatic taxa recorded, notably those of Lemna, Potamogeton, and Typha angustifolia. At -3.81m OD aquatic taxa total 43% TLP, but decline towards the top of the zone.

H-2(a)m -3.52 to -2.24m OD

The lower zone boundary is defined by a decline in the frequencies of aquatic taxa and by an increase in those of Chenopodiaceae. The zone is characterised by an assemblage dominated by herb pollen types and in particular by Gramineae and Cyperaceae. In general Gramineae frequencies dominate, accounting for c. 50-60% TLP, whilst Cyperaceae frequencies fluctuate between c. 10-20% TLP. Frequencies of Chenopodiaceae increase in this zone, and in general exceed 5% TLP, whilst other saltmarsh indicators such as Aster-type and Atriplex-type are recorded in low frequencies throughout.

H-2(a)n -2.24m to -1.67m OD

The lower zone boundary is defined by a decrease in the frequencies of Chenopodiaceae, a decline in frequencies of tree pollen, and a slight increase in the frequencies of aquatic taxa. The zone is characterised by an assemblage dominated by frequencies of Gramineae and Cyperaceae. There is also an increase in frequencies of Plantago lanceolata and Taraxacum vulgare in this zone. Towards the top of the zone frequencies of herb pollen account for >98% TLP, and in the upper two levels of the zone there is an increase in the frequencies of Typha angustifolia to c. 10% TLP.

5.3. Diatom analysis.

5.3.1. Introduction.

Within the infilled-valley described in Chapter Five, two sites at Sandfield Farm and Hacklinge were selected for diatom analysis. The sites were selected in order to compare the diatom record from two sites in different positions in the infilled-valley. Two piston-cores were analysed for their diatom content, H-2(b) and SF-10. In general diatom preservation was good, with the exception of the upper inorganic sediments recorded in SF-10. For each of the piston cores sampling was completed at either 0.02m or 0.04m intervals for all inorganic sediments recorded. In the case of Sandfield Farm a total of eighty-five levels were counted, and at Hacklinge ninety-five. Seven diatom diagrams are presented.

5.3.2. Sandfield Farm.

The lithostratigraphy of SF-10 has been described above (5.2.2.1). Three diatom diagrams are presented from SF-10 from the lower, middle and upper inorganic deposits.

5.3.2.1. SF-10 Diatom analysis: Lower inorganic deposit -6.18m to -5.80m OD

Of thirteen samples prepared for diatom analysis, ten samples had sufficient diatoms for counting. The resulting diagram (Fig.5.10.) has been divided into five LDAZs, and the characteristics of each are described in turn below. Each LDAZ coincides with the zonation suggested by the four highest splits of CONISS.

<u>LPAZ</u> <u>Altitude (m OD)</u> <u>Zone Characteristics</u>

SF-10a -6.12m to -6.05m OD

The zone is characterised by an assemblage dominated by high frequencies of <u>Nitzschia navicularis</u>, which at -6.12m OD accounts for 58% TV, and which declines to 31% TV by -6.10m OD. This decrease in B frequencies is matched by an increase in the frequencies of MB taxa, notably <u>Diploneis didyma</u>, which increases to 52% TV at -6.10m OD.

SF-10b -6.05m to -5.89m OD

The lower zone boundary is defined by a an increase in frequencies of <u>Nitzschia navicularis</u> and by a decrease in frequencies of <u>Diploneis didyma</u>. The zone is characterised by an assemblage dominated by high B frequencies which decline from 80% to <u>c</u>. 50% TV. B frequencies are dominated by <u>Nitzschia navicularis</u>, which accounts for between <u>c</u>. 75-45% TV. An increase in first <u>Nitzschia punctata</u> (from 4-20% TV between -6.00m to -5.92m OD) and then <u>Paralia sulcata</u> occurs towards the top of the zone as B frequencies decline.

SF-10c -5.89m to -5.87m OD

The lower zone boundary is defined by a sharp increase in frequencies of <u>Diploneis didyma</u> to 67% TV. The zone is characterised by an assemblage dominated by <u>Diploneis didyma</u> and <u>Nitzschia navicularis</u>. The latter continues to decline, and there is a sharp fall in M frequencies, and in particular in those of <u>Paralia sulcata</u>.

SF-10d -5.87m to -5.84m OD

The lower zone boundary is defined by an increase in frequencies of <u>Diploneis interrupta</u> to 61% TV. <u>Diploneis interrupta</u> dominates the zone, whilst there is a decline in frequencies of Nitzschia navicularis and an abrupt fall in frequencies of Diploneis didyma to 8% TV.

SF-10e -5.84m to -5.80m OD

The lower zone boundary is defined by an increase in frequencies of Diploneis didyma and Nitzschia navicularis, and by a decrease in the frequencies of Diploneis interrupta. Frequencies of the former increase from 35% to 70% TV, whilst those of Nitzschia navicularis fall from 51% to 23% TV.

5.3.2.2. SF-10 Diatom analysis: Middle inorganic deposit -5.53m to -2.38m OD.

Of sixty-two samples prepared for diatom analysis, all samples had sufficient diatoms for counting. The resulting diagram (Fig.5.11.) has been divided into eight LDAZs, and the characteristics of each are described in turn below. Each LDAZ coincides with the zonation suggested by the seven highest splits of CONISS.

LPAZ Altitude (m OD) Zone Characteristics

SF-10f -5.52m to -5.25m OD

The zone is characterised by an assemblage dominated by initial high frequencies of BM and MB taxa, which are replaced towards the top of the zone by M and (to a lesser extent) B taxa. Frequencies of Nitzschia granulata increase from 15-55% TV, whilst those of Diploneis didyma and Nitzschia punctata decrease from >30% to <5% TV. Frequencies of Nitzschia navicularis fluctuate between 14% and 29% TV.

SF-10g -5.25m to -4.76m OD

The lower zone boundary is defined by a decline in frequencies of Nitzschia granulata to >5% TV, and by a rise in those of

Scoliopleura turmidia. The zone is characterised by an assemblage dominated by frequencies of Paralia sulcata, Scoliopleura turmida, and Nitzschia navicularis. Frequencies of Paralia sulcata rise to c. 20% TV, and those of Scoliopleura turmida fluctuate between 8% and 50% TV.

SF-10h -4.76m to -4.30m OD

The lower zone boundary is defined by a decline in frequencies of Scoliopleura turmida. The zone is characterised by an assemblage dominated by frequencies of Paralia sulcata and Nitzschia navicularis. Within this zone frequencies of Nitzschia navicularis increase to c. 45% TV, whilst those of Scoliopleura turmida fall to <10% TV (with an isolated peak of 50% TV at -4.56m OD). Frequencies of Paralia sulcata decrease progressively in this zone to <10% TV, whilst those of Nitzschia socialis fluctuate between 0-28% TV. Trachyneis aspera is recorded in low frequencies throughout this zone.

SF-10i -4.30m to -3.88m OD

The lower zone boundary is defined by a decline in frequencies of **B** taxa, notably those of Nitzschia navicularis which falls to <15% TV, and by an increase in frequencies of **M** and **MB** taxa. The zone is characterised by an assemblage dominated by Paralia sulcata, which increases to a high of 43% TV at -4.02m OD, and which then falls slightly towards the top of the zone. Frequencies of Aulacodiscus argus and Podosira stelliga also increase in this zone. Of the **MB** taxa there is a rise in the frequencies of Actinoptychus undulatus, and a sharp increase in the frequencies of Rhaphoneis nitida to a high of 26% TV at -4.06m OD. Frequencies of Rhaphoneis amphiceros increase sharply to 20% TV at the base of the zone, and then decrease to <15% TV for the rest of the zone.

SF-10j -3.88m to -3.60m OD

The lower zone boundary is defined by a sharp increase in the frequencies of Nitzschia granulata and by a decrease in those of Paralia sulcata. The zone is characterised by an assemblage dominated by M and MB taxa. Frequencies of Paralia sulcata fall to c. 15-20% TV (with an isolated high of 32% TV at -3.74m OD), whilst those of Nitzschia granulata increase sharply to c. 30% TV before falling towards the top of the zone. Frequencies of Coscinodiscus centralis increase towards the top of this zone. Of the MB taxa Rhaponeis spp. continue to dominate, with an isolated peak in Raphoneis nitida at -3.70m OD of 40% TV, whist frequencies of Podosira stelliga and Actinoptychus undulatus fall slightly.

SF-10k -3.60m to -2.87m OD

The lower zone boundary is defined by a sharp increase in frequencies of Paralia sulcata (to c. 40% TV) and a decrease in the frequencies of Nitzschia granulata to <10% TV. The zone is characterised by an assemblage dominated by M and MB taxa, although there is a slight increase in the frequencies of Epithemia turgida in the lower half of this zone.

SF-10l -2.87m to -2.56m OD

The lower zone boundary is defined by an increase in the frequencies of Scoliopleura turmida. The zone is characterised by an assemblage dominated by frequencies of Nitzschia navicularis, Scoliopleura turmida and Paralia sulcata. Within the zone frequencies of Paralia sulcata and Nitzschia granulata fall to <20% and <3% TV respectively, whilst there is an increase in the frequencies of both Podosira stelliga and Trachyneis aspera. Of the BM and B taxa, Scoliopleura turmida and Nitzschia navicularis both increase to >30% TV by the top of the zone.

SF-10m -2.56m to -2.44m OD

The lower zone boundary is defined by a decline in frequencies of Scoliopleura turmida, and by an increase in frequencies of Nitzschia navicularis. The zone is characterised by an assemblage dominated by Nitzschia navicularis. Frequencies of **M**, **MB** and **BM** taxa decline as **B** frequencies rise to >90% TV by the top of this zone. Frequencies of Scoliopleura turmida fall to <5% TV, and the increase in **B** taxa is largely due to Nitzschia navicularis which accounts for 91% TV by the top of the zone.

5.3.2.3. SF-10 Diatom analysis: Upper inorganic deposit -1.91m to +1.34m OD.

Of fourty-two samples prepared for diatom analysis, only twenty samples had sufficient diatoms for counting. Diatom preservation was good except for between -1.50m to -0.52m OD, and -0.22m to +0.53m OD where no diatoms were recorded. Fig.5.12. has been divided into six LDAZs, and the characteristics of each are described in turn below. Each LDAZ coincides with the zonation suggested by the five highest splits of CONISS.

LPAZ	Altitude (m OD)	Zone Characteristics

SF-10n -1.90m to -1.84m OD

The zone is characterised by an assemblage dominated by high frequencies of **Z** taxa, notably those of Nitzschia linearis which increase from c. 20% to 45% TV. Other taxa recorded include a mixed assemblage of **B** taxa (Rhopalodia gibberula), **BM** taxa (Navicula crucicula), **MB** taxa (Actinoptychus undulatus, Rhaphoneis spp.), and **M** taxa (Paralia sulcata and Navicula peregrina).

SF-10o -1.84m to -1.72m OD

The lower zone boundary is defined by a decline in frequencies of Nitzschia linearis, and by a rise in those of Gyrosigma acuminatum. The zone is characterised by an assemblage dominated by frequencies of Gyrosigma acuminatum and Paralia sulcata. There is a decline in frequencies of **Z** taxa, and an increase in those of **BZ** taxa, notably Gyrosigma acuminatum which rises to a high of 64% TV at -1.78m OD. No major changes in other taxa occur, except for an increase in the frequencies of Nitzschia navicularis to 16% TV by the top of the zone, and the disappearance of Navicula crucicula.

SF-10p -1.72m to -1.60m OD

The lower zone boundary is defined by a decrease in frequencies of Gyrosigma acuminatum, and by an increase in those of Nitzschia navicularis. The zone is characterised by an assemblage dominated by frequencies of Nitzschia navicularis, Scoliopleura turmida, and Paralia sulcata. Within this zone frequencies of **ZB** taxa decline, followed by an increase in the frequencies of firstly **B**, **BM** and then **MB** taxa. Frequencies of Gyrosigma acuminatum collapse over the lower zone boundary, whilst those of Nitzschia navicularis rise to a high of 35% TV at -1.70m OD before falling. As frequencies of Nitzschia navicularis decline, so those of **BM** taxa increase largely due to a rise in Scoliopleura turmida to >15% TV. Of the **MB** taxa, there is a slight increase in frequencies of Rhaphoneis amphiceros.

SF-10q -1.60m to -1.01m OD

The lower zone boundary is defined by an increase in frequencies of Scoliopleura turmida. The zone is characterised by an assemblage dominated by initially Scoliopleura turmida and Paralia sulcata, and then as frequencies of Scoliopleura turmida decrease, by frequencies of Nitzschia linearis and

Paralia sulcata. In the uppermost sample of this zone, at -1.50m OD frequencies of Z taxa increase as those of Nitzschia linearis and Stauroneis anceps increase to 32% and 7% TV respectively.

SF-10r -1.01m to -0.36m OD

The lower zone boundary is defined by an increase in the frequencies of Paralia sulcata. This zone is characterised by high frequencies of Paralia sulcata (c. 65% TV). There is almost a complete absence of fresh and brackish diatoms in this zone.

SF-10s -0.36m to -0.24m OD

The lower zone boundary is defined by a decline in frequencies of Paralia sulcata, and by an increase in those of Nitzschia navicularis. The zone is characterised by an assemblage dominated by frequencies of Nitschia navicularis and Paralia sulcata. Within this zone the latter taxon falls and then increases in frequency (from 15% to 46% TV), whilst the latter rises and then falls (from 60% to 21% TV). No significant changes in other taxa are recorded.

5.3.3. Hacklinge Diatom analysis.

Piston-core H-2(b) was analysed for its diatom content and to provide material for ^{14}C dating. As the depths and lithostratigraphy vary slightly from that of H-2(a) the composition of the inorganic sediments from which samples for diatom analysis were collected is described at the beginning of each of the appropriate sections.

5.3.3.1. Diatom analysis - lithostratigraphy of H-2(b) lower inorganic deposit.

The lithostratigraphy of the lower inorganic sediments from which diatom samples were collected for analysis is described below.

Stratum	Altitude O.D. metres	Depth cm	Description
6	-8.62 to -8.66	772 to 776	nig. 3+, strf. 0, sicc. 3, elas. 1, lim sup. 0 Sh4, part test moll+ Dark brown well-humified peat with some broken (unidentified) shells.
5	-8.66 to -8.875	776 to 797.5	nig. 2, strf. 0, sicc. 2, elas. 0, lim sup. 0 As4, Dh+ Dark grey clay with some detrital herbaceous material.
4	-8.875 to -8.91	797.5 to 801	nig. 3+, strf. 0, sicc. 2, elas. 1, lim sup. 0 Sh4, Th^2(<u>Phra</u>)+ Dark brown well-humified peat with some <u>Phragmites</u>.
3	-8.91 to -8.925	801 to 802.5	nig. 3, strf. 2, sicc. 2, elas. 1, lim sup. 0 Sh1, Th^2(<u>Phra</u>)+, $Th^2$3, part test moll +, As+, Dl+ Brown <u>turfa</u> with some <u>Phragmites</u> and detrital wood. Also some shells (unidentified) and clay, finely laminated.

2	-8.925 to -8.96	802.5 to 806	nig. 3+, strf. 1, sicc. 2, elas. 1, lim sup. 0 Sh3, Dl+, Th^2(Phra)+, part test moll+ Dark brown or black well-humified peat with some Phragmites and some Hydrobia ulvae and Hydrobia ventrosa. Slightly laminated with occasional detrital wood remains.
1	-8.96 to -9.01	806 to 811	nig. 2+, strf. 0, sicc. 2, elas. 0, lim sup. 0 As4, Dh+ Dark grey clay with some detrital organic material.

5.3.3.2. H-2(b) Diatom analysis: Lower inorganic deposit -9.01m to -8.66m OD.

Of fifteen samples prepared for diatom analysis, thirteen samples had sufficient diatoms for counting. The resulting diagram (Fig.5.13.) has been divided into four LDAZs, and the characteristics of each are described in turn below. Each LDAZ coincides with the zonation suggested by the three highest splits of CONISS.

LPAZ	Altitude (m OD)	Zone Characteristics
H-2(b)a	**-9.00m to -8.89m OD**	

This zone is characterised by high **M** and **B** frequencies, with Nitzschia granulata and Paralia sulcata accounting for c. 34% TV and 17% TV respectively, and Nitzschia navicularis for c. 24% TV.

H-2(b)b -8.89m to -8.81m OD

The lower zone boundary is defined by a decrease in the frequencies of Nitzschia navicularis, and by an increase in those of Paralia sulcata. The zone is characterised by an assemblage dominated by frequencies of Nitzschia punctata, and Paralia sulcata. Frequencies of the former increase to 23% TV at -8.82m OD, and those of Paralia sulcata increase to >35% TV.

H-2(b)c -8.81m to -8.67m OD

The lower zone boundary is defined by a sharp increase in the frequencies of Nitzschia granulata, and by a decrease in those of Paralia sulcata and Nitzschia punctata. The zone is characterised by an assemblage dominated by frequencies of Nitzschia granulata, Paralia sulcata, and Nitzschia navicularis. Within this zone frequencies of Nitzschia granulata increase to c. 55-65% TV. Frequencies of Nitzschia punctata fall and remain low throughout this zone, whilst those of Nitzschia navicularis fluctuate to reach a high of 40% TV by the top of the zone.

H-2(b)d -8.67m to -8.66m OD

The lower zone boundary is defined by a decrease in frequencies of Nitzschia granulata, and by an increase in the frequencies of Nitzschia punctata. The zone is characterised by an assemblage dominated by frequencies of Nitzschia navicularis, and Nitzschia punctata. Frequencies of Nitzschia granulata fall to 7% TV, whilst those of Nitzschia punctata increase to 26% TV. Of the MB taxa there are small increases in the frequencies of Diploneis didyma and Diploneis smithii.

5.3.3.3. Diatom analysis - lithostratigraphy of H-2(b) middle inorganic deposit.

The lithostratigraphy of the middle inorganic sediments from which diatom samples were collected for analysis is described below.

Stratum	Altitude O.D. metres	Depth cm	Description
7	-4.55 to -4.59	365 to 369	nig. 3, strf. 0, sicc. 2, elas. 0, lim sup. 0 $Th^2 3$, As1, Th^2(Phra)+ Grey-brown *turfa* with some clay and *Phragmites*. Soft and fibrous.
6	-4.59 to -4.75	369 to 385	nig. 3, strf. 0, sicc. 2, elas. 0, lim sup. 0 As3, $Th^2 1$ Very soft dark grey clay with some *turfa*.
5	-4.75 to -4.95	385 to 405	nig. 2, strf. 0, sicc. 2, elas. 0, lim sup. 0 As4, Dh+ Very soft battleship-grey clay with some organic material.
4	-4.95 to -5.30	405 to 440	nig. 2, strf. 0, sicc. 2, elas. 0, lim sup. 0 As3, Ag1, Dh+ Very soft battleship-grey silty-clay with some detrital herbaceous material.

	-5.30 to -5.59	440 to 469	Unsampled
3	-5.59 to -6.20	469 to 530	nig. 2, strf. 0, sicc. 2, elas. 0, lim sup. 0 As4, Ag+, Dh+, part test moll+ Battleship-grey clay with some rare unidentified shells.
2	-6.20 to -6.47	530 to 557	nig. 2, strf. 0, sicc. 2, elas. 0, lim sup. 0 As3, Ag1, Dh+ Battleship-grey silty-clay with some organic material.
	-6.47 to -6.68	557 to 578	Unsampled
1	-6.68 to -7.56	578 to 666	nig. 2, strf. 0, sicc. 2, elas. 0, lim sup. 0 As3, Ag1, Dh+ Battleship-grey silty-clay with some organic material.
	-7.56 to -7.60	666 to 670	Unsampled

5.3.3.4. H-2(b) Diatom analysis: Middle inorganic deposit -7.56m to -4.75m OD.

Of sixty-two samples prepared for diatom analysis, all had sufficient diatoms for counting. The resulting diagram (Fig. 5.14.) has been divided into eight LDAZs, and the characteristics of each are described in turn below. Each LDAZ coincides with the zonation suggested by the seven highest splits of CONISS.

LPAZ	Altitude (m OD)	Zone Characteristics

H-2(b)e -7.54m to -7.00m OD

This zone is characterised by high frequencies of **M** taxa, notably Paralia sulcata and Nitzschia granulata which account for c. 40-50% and c. 5-20% TV respectively. **M** taxa together account for c. 60% TV. The remaining taxa recorded consist of a mixed assemblage of **MB**, **BM**, **B**, **ZB** and **Z** taxa, and in particular by Rhaphoneis spp. and Nitzschia navicularis.

H-2(b)f -7.00m to -6.58m OD

The lower zone boundary is defined by an increase in frequencies of Nitzschia navicularis and Nitzschia parvula. The zone is characterised by an assemblage dominated by frequencies of Nitzschia parvula, Nitzschia navicularis, and Paralia sulcata. Frequencies of Paralia sulcata fall to c. 10-30% TV, as frequencies of Rhaphoneis spp. also decline. Frequencies of both Nitzschia navicularis and Nitzschia parvula increase sharply with the latter reaching a high of 37% TV.

H-2(b)g -6.58m to -6.27m OD

The lower zone boundary is defined by a decline in frequencies of Nitzschia parvula fall to <5% TV. The zone is characterised by an assemblage dominated by frequencies of Nitzschia navicularis and Paralia sulcata. The lower two samples of this zone are dominated by high frequencies of Nitzschia navicularis, but these fall to a low of 18% TV at -6.38m OD, and then rise once more towards the top of the zone. Fluctuations in the frequencies of Nitzschia navicularis are the reverse of fluctuations in frequencies of Paralia sulcata, which increases to a high of 54% TV at -6.38m OD, and then fall to 33% TV by the top of the zone.

H-2(b)h -6.27m to -6.04m OD

The lower zone boundary is defined by an increase in the frequencies of Nitzschia navicularis. The zone is characterised by an assemblage dominated by Nitzschia navicularis, Paralia sulcata, and Nitzschia granulata. Frequencies of Nitzschia navicularis rise to a high of 64% TV at -6.18m OD. Frequencies of Paralia sulcata remain low, whilst those of Nitzschia granulata increase to a high of 22% TV at the top of the zone.

H-2(b)i -6.04m to -5.26m OD

The lower zone boundary is defined by an increase in the frequencies of Paralia sulcata and by a decrease in frequencies of Nitzschia navicularis. The zone is characterised by an assemblage dominated by frequencies of Nitzschia granulata, Paralia sulcata, and Nitzschia navicularis. Frequencies of Nitzschia granulata remain between c. 10-25% TV in this zone, whilst those of Z taxa, which had been recorded in low frequencies throughout the lower part of the diagram, almost disappear. Frequencies of Paralia sulcata and Nitzschia navicularis co-vary in opposite directions.

H-2(b)j -5.26m to -4.94m OD

The lower zone boundary is defined by a decrease in the frequencies of Nitzschia navicularis, and Nitzschia punctata, and by an increase in the frequencies of Paralia sulcata. The zone is characterised by an assemblage dominated by **M** taxa, which rise to 86% TV at -5.08m OD, notably due to Paralia sulcata which rise in frequency to c. 50-60% TV, and by the decline in the frequencies of Nitzschia navicularis.

H-2(b)k -4.94m to -4.67m OD

The lower zone boundary is defined by an increase in the frequencies of Diploneis didyma, Diploneis smithii, and Caloneis fasciata. The zone is characterised by an assemblage dominated by frequencies of Nitzschia navicularis. Within the zone frequencies of **M** taxa decline, most notably those of Paralia sulcata which fall to c. 20% TV. The frequency of **MB** taxa increase, with Diploneis didyma rising to a high of 20% TV at -4.72m OD. Diploneis smithii is recorded throughout this zone at c. 7% TV. B taxa also increase, with frequencies of Nitzschia navicularis falling, but those of Caloneis faciata rising to 21% TV at -4.68m OD. In the uppermost sample of this zone there is an increase in the frequency of **M** taxa to >50%.

H-2(b)l -4.67m to -4.64m OD

The lower zone boundary is defined by an increase in the frequency of Nitzschia navicularis. The zone is characterised by an assemblage dominated by frequencies of Nitzschia navicularis, which rises to 67% TV by the top of the zone. Frequencies of Caloneis fasciata fall sharply to >5% TV in this zone.

5.3.3.5. Diatom analysis - lithostratigraphy of H-2(b) upper inorganic deposit.

The lithotratigraphy of the upper inorganic sediments from which diatom samples were collected is described below.

Stratum	Altitude O.D. metres	Depth cm	Description
7	-2.33 to -2.38	143 to 148	nig. 3, strf. 0, sicc. 2, elas. 0, lim sup. 0 Th^2(Phra)2, $Th^2$1, As1

			Phragmites-rich *turfa* with some clay, - soft and fibrous.
6	-2.38 to -2.43	148 to 153	nig. 3, strf. 0, sicc. 2, elas. 0, lim sup. 0 As3, Th^2(*Phra*)+, $Th^2$1 *Turfa*-rich clay with some *Phragmites*.
5	-2.43 to -2.74	153 to 184	nig. 2, strf. 0, sicc. 2, elas. 0, lim sup. 0 As4, Dh+ Battleship-grey clay, very soft.

Two sample tubes were collected from this depth in order to ensure a continuous sedimentary record. However, due to differential compaction during either collection or extrusion, the depths of the deposit recorded in each sample tube differ. Here there is an apparent sample gap between 184 cm and 197 cm, but this does not indicate a real break in the sedimentary record.

4	-2.87 to -2.91	197 to 201	nig. 3, strf. 0, sicc. 2, elas. 0, lim sup. 0 $Th^2$3, As1 Brown clay-rich *turfa*.
3	-2.91 to -3.28	201 to 238	nig. 2, strf. 0, sicc. 2, elas. 0, lim sup. 0 As4, Th^2(*Phra*)+, Dh+, part test moll+ Very soft grey clay with some *Phragmites* and rare unidentified shells.

2	-3.28 to -3.42	238 to 252	nig. 3, strf. 0, sicc. 2, elas. 0, lim sup. 2 $Th^2$2, Dh+, As2 Turfa-rich clay with eroded inclusions of peat and clay.
1	-3.42 to -3.46	252 to 256	nig. 3, strf. 0, sicc. 2, elas. 1, lim sup. 0 $Th^2$3, Th^2(Phra)+, Sh1 Dark brown soft fibrous turfa with some Phragmites.

5.3.3.6. H-2(b) Diatom analysis: Upper inorganic deposit -3.42m to -2.38m OD.

Of eighteen samples prepared for diatom analysis, all had sufficient diatoms for counting. The resulting diagram (Fig. 5.15.) has been divided into five LDAZs, and the characteristics of each are described in turn below. Each LDAZ coincides with the zonation suggested by the four highest splits of CONISS.

LPAZ	Altitude (m OD)	Zone Characteristics

H-2(b)m -3.39m to -2.89m OD

This zone is characterised by high frequencies of **MB** and **B** taxa, and by a sharp increase in **Z** taxa at the top of the zone. **MB** taxa are dominated by Diploneis didyma which fluctuate between 13% and 28% TV. **B** taxa are dominated by high frequencies of Nitzschia navicularis, which remain at c. 35-40% TV throughout this zone. There is a progressive increase in frequencies of **ZB** taxa above -3.00m OD, to a high at -2.91m OD of 24% TV. This reflects the increase in frequencies of Synedra capita.

H-2(b)n -2.89m to -2.67m OD

The lower zone boundary is defined by an increase in the frequencies of Nitzschia granulata and Nitzschia navicularis. The zone is characterised by an assemblage dominated by high frequencies of **B** taxa, notably those of Nitzschia navicularis which account for c. 60% TV. Frequencies of Syndedra capita fall sharply over the lower zone boundary.

H-2(b)o -2.67m to -2.56m OD

The lower zone boundary is defined by an increase in frequencies of Paralia sulcata. The zone is characterised by an assemblage dominated by frequencies of Paralia sulcata and Nitzschia navicularis. Within this zone there is an increase in frequencies of **M** taxa, notably those of Paralia sulcata to a high of 63% TV at -2.58m OD, and by a decrease in frequencies of **B** taxa, notably those of Nitzschia navicularis to 15% TV. Frequencies of Diploneis didyma also decrease in this zone.

H-2(b)p -2.56m to -2.44m OD

The lower zone boundary is defined by a decrease in frequencies of Paralia sulcata, which fall to <10% TV. The zone is characterised by a mixed salinity assemblage of **MB**, **BM**, **B** and **ZB** taxa, with high frequencies of Diploneis didyma, Scoliopleura turmida, Nitzschia navicularis and Diploneis ovalis.

H-2(b)q -2.44m to -2.42m OD

The lower zone boundary is defined by an increase in frequencies of **ZB** taxa, notably those of Synedra capita which rise to 35% TV. The zone is characterised by an assemblage dominated by Synedra capita, Nitzschia navicularis, and Diploneis didyma. Frequencies of **MB** taxa remain approximately constant, but those of **M**, **BM**, and **B** taxa fall slightly.

5.4. Elemental analysis.

5.4.1. Introduction

Elemental analyses of piston-core H-2(a) were made in an experimental attempt to identify whether changes in elemental composition might act as proxy data for changes in the elemental composition and height of the watertable at the time of sediment deposition. Piston-core H-2(a) was selected for analysis because the organic deposits sampled were thick, and because pollen analyses had already been completed for the core. As this work was experimental, the first stage of analysis was to compare the elemental data with that of established techniques.

Four elemental diagrams are presented (Figs.5.16-19.), two for the elemental analysis of bulk samples, and two for the analysis of *Phragmites* macrofossils.

5.4.2. A comparison of the elemental composition of bulk samples with the pollen and diatom record from H-2(a) and H-2(b).

Ninety samples were collected from H-2(a) and analysed for their elemental composition of Ca, Mg, Na, and Fe. For each sample a wash ($_w$) and a digest ($_d$) value was determined.

5.4.2.1. Elemental analysis H-2(a) -9.27m to -7.46m OD. Fig. 5.16.

No pollen data are available for the lower predominantly inorganic sediments between -9.27m to -8.93m OD, although diatom analyses have indicated that they accumulated under a predominantly **M** or **B** environment with little or no major changes in salinity towards the regressive contact (Section 5.3.3.2.). The elemental analyses of these sediments are presented in Fig 5.16. All $_w$ and $_d$ values remain approximately constant, with no major changes in elemental composition of the inorganic sediments occur towards the regressive contact at -8.93m OD.

Immediately above the regressive contact there is a major change in elemental composition associated with a change in material analysed from inorganic to organic. Pollen analysis from this deposit has identified high frequencies of *Quercus* and *Corylus* pollen. The uppermost pollen sample from this organic deposit indicates a change in sedimentary conditions, with a fall in tree pollen frequencies and an increase in those of *Corylus*, associated with a sharp decline in pollen preservation. The elemental composition of this deposit is characterised by an increase in Ca_d and a decrease in Ca_w. Mg_d values fall sharply over the regressive contact, and increase again towards the transgressive contact. Mg_w values increase slightly, as do those of Na_w, Na_{wd} and Fe_w. The pollen data suggest a pronounced change in depositional environment from a *Quercus*/*Corylus* environment to more open conditions. Changes in the elemental composition of the peat also occur at similar altitudes.

Above the transgressive contact at -8.83m OD, diatom data indicate a strong M environment became established but with a freshening of the assemblage above -8.63m OD. With the changes in material analysed from organic to inorganic there is a change in elemental composition, and a return to values similar to those found between -9.27m to -8.93m OD. All $_w$ and $_d$ values remain approximately constant between -8.83m OD and -8.60m OD.

The regressive contact and gross change in lithology at -8.60m OD is associated with a sharp change in the elemental composition of the samples analysed. Within the overlying peat, there are three main changes in the elemental record:

i. The first is a dramatic fall in values for Ca_d at -8.58m OD, which remain low until -7.59m OD, where they begin to rise below the transgressive contact.

ii Secondly there is the decline in values of Mg_d which persists until -8.27m OD and then rises and fluctuates between -8.12m to -7.70m OD, before falling sharply and begining a final rise towards the transgressive contact above -7.63m OD.

iii Finally, approaching the transgressive contact there are also increases in Ca_d, Mg_d, Na_d and Fe_d. This contrasts the $_w$ values which all tend to decrease apart from Fe_w.

Marine conditions were probably approaching during the latter period of organic sedimentation, as diatom analysis immediately above the transgressive contact indicates a strong **M** environment above -7.48m OD. However, in the absence of pollen data (due to poor pollen preservation), any interpretation of these changes is difficult.

5.4.2.2. Elemental analysis H-2(a) -5.02m to -2.31m OD. Fig. 5.17.

Diatom data from H-2(b) indicates that during the period of inorganic sedimentation prior to the regressive contact recorded in H-2(a) at -4.87m OD, there was a freshening of depositional conditions indicated by a change from an **M** to a **B** diatom assemblage. The elemental assemblage is very similar to that recorded in the uppermost samples of Fig.5.16.

Over the regressive contact, Mg_d values fall, and there are no other major changes recorded. As the aquatic pollen taxa increase in frequency above -4.77m OD, so there is a dramatic rise in the values for Ca_d which persists until -4.44m OD, and which is matched by a decline in values for Mg_{dw} and Na_w.

Above -4.46m OD Ca_d remains very low for the rest of core, and between -4.28m to -3.68m OD the elemental assemblage remains largely unchanged. However, during this period of peat accumulation, pollen analysis suggests several significant changes in the altitude of the watertable. Fluctuating frequencies of Alnus, Gramineae, Cyperaceae, various aquatic taxa and Filicales, which probably reflect real changes in the altitude of the watertable, occur independent to the elemental composition of the peat.

The inorganic deposit recorded in H-2(a) between -3.14m and -2.80m OD is thinner than that recorded in H-2(b), but diatom analyses of this deposit in H-2(b) indicate that it accumulated under a mixed but predominantly B sedimentary environment. There are a number of changes in the elemental content of the core immediately below the transgressive contact, most notably with an increase in the values for Mg_d and Fe_d. The pollen data suggests an increase in the marine influence immediately below this contact, with a rise in frequencies of Chenopodiaceae and Aster-type.

Mg_d values remain high throughout the inorganic deposit between -3.14m to -2.80m OD and continue to remain high within the organic samples overlying the regressive contact. Mg_d values only begin to decline above c. -2.51m OD. Fe_d fluctuate but in general remain high towards the top of the core, whilst other elements remain approximately constant.

5.4.3. A comparison of the elemental composition of Phragmites with the pollen and diatom record from H-2(a).

5.4.3.1. Elemental analysis H-2(a) -7.97m to -7.46m OD. Fig. 5.18.

Ten samples of Phragmites were collected from this organic deposit for comparison with the pollen and elemental content of bulk samples. Samples of the latter were always collected from points adjacent to where where samples of Phragmites were collected in order to enable a comparison of their respective elemental content.

No major changes in elemental composition of Phragmites occur between -7.97m and -7.60m OD. Above this level Ca_d values increase sharply, and in the uppermost sample (-7.50m OD taken from on the transgressive contact), all elements except Ca_d increase in value. The pollen record suggests a change between -7.92m to -7.72m OD from a Cyperaceae, Filicales and Thelypteris palustris environment, to one dominated by Gramineae. Above this level poor pollen preservation inhibits any direct palaeobotanical comparison with the elemental record.

5.4.3.2. Elemental analysis H-2(a) -5.02m to -2.31m OD. Fig. 5.19.

Between -5.02m and -4.36m OD the elemental composition of the Phragmites samples fluctuates widely. Values for Mg_d, Na_d, and Fe_d fall above the regressive contact, whilst those of Ca_d increase steadily. Values for Ca_w increase sharply (note mg/10 g) and then fall above -4.36m OD and remain low for the rest of the core. A comparison with the pollen record indicates that the increase in Ca_w values coincides with the increase in aquatic taxa recorded above the regressive contact in LPAZ H-2(a)i.

Above -4.36m OD there are only a few major changes in elemental composition, other than for an isolated high in values for all elements at c. -3.71m OD (apart from Ca_w and Fe_w). This occurs at the same part of the core where there is an increase in the frequencies of aquatic taxa, although there does not appear to be a consistent relationship between the elemental composition of Phragmites and frequencies of aquatic taxa.

The elemental composition of the upper part of the core remains similar, although there is a sharp fall in values of Fe_d above -2.86m OD. In general Fe_w is seen to increase in samples of Phragmites collected from close to or from within inorganic sediments (see -7.70m OD, and between -4.90m and -4.85m OD), and the changes observed between c. -3.71m and -2.86m OD are a further example of this.

5.4.4. Discussion.

An exploratory analysis of the elemental composition of piston-core H-2(a) was made in order to identify whether changes in the elemental composition of the core could be used as proxy data for changes in the altitude and composition of the watertable through time. Detailed pollen and diatom data have enabled an asessment of the technique. Significant changes in the elemental composition with bulk samples as well as in samples of Phragmites do occur, especially where there is a change in gross lithology or sample material analysed. Changes within deposits are also recorded, most notably the sharp increase in Ca values above the regressive contact of the upper organic deposit. However once again these changes appear to reflect the relatively high inorganic fraction at these levels.

An absence of any consistent relationship between the elemental composition of the material studied and the independent pollen and diatom record has been observed. It would appear, therefore, that the effects of differential nutrient uptake, storage and subsequent loss upon decomposition, render the application of the technique used here of little value in establishing the detailed record of changes in water depth and quality. Subsequent analyses of the evidence for watertable and sea-level changes in this thesis are based on pollen and diatom data alone.

Chapter Six: Holocene watertable movements in the East Kent Fens - The site scale.

6.1. Introduction.

This chapter combines the litho- and biostratigraphic data described in Chapters Five and Six in order to analyse the evidence for Holocene watertable changes in the East Kent Fens at the site scale. Pollen and diatoms are used to identify the nature of sedimentary changes associated with transgressive and regressive contacts, as well as to identify changes in the biostratigraphic record caused by watertable changes. This chapter begins by discussing the use of the tendency approach in the analysis of watertable and sea-level changes. This is followed by a presentation of the radiocarbon dates collected during this study, which provide the chronological basis for the interpretation of the pattern of watertable movements recorded.

6.2. The tendency approach.

In Section 1.5. it was noted that in general two approaches can be used in the analysis of Holocene watertable and sea-level movements, namely the time/altitude and the tendency approaches. The following sections assess the potential of the tendency approach in Holocene watertable and sea-level studies. It is argued that the known Holocene vegetation record from the coastal lowlands of the UK clearly indicates that the dating methodology currently employed in the tendency analysis of sea-level movements provides only an approximate chronology of watertable or sea-level tendencies. An alternative approach based on the analysis of within-deposit changes in the watertable is proposed, and this forms the methodological context for interpreting the data presented in Chapters Five and Six.

6.2.1. Watertable movements and vegetation changes.

In order to assess the tendency approach it is necessary to establish the basic processes involved in vegetation and sedimentary changes in coastal environments. The pioneering work of Dr. Godwin in the Fenland Research Committee and the Botany sub-department at the University of Cambridge, established the link between changes in the contemporary vegetation communities of the East Anglian Fenlands, and the biostratigraphic changes observed in the analysis of past vegetation changes in the UK.

The contemporary vegetation succession (or "seral" succession) which Godwin observed characteristically saw the replacement of open water by aquatic taxa, open reed swamp, closed reedswamp, sedge fen, fen carr, fen wood, and finally transitional fen woodland and then raised bog. These changes in vegetation were autogenic, - they occurred

> "without outside influence, by the gradual accumulation of the plant remains that it generates,"
>
> (Godwin (1978 :12)

largely due to the progressive decline in the relative height of the watertable.

Godwin and Godwin (1933) identified a similar palaeo-succession in the pollen analysis of stratified Holocene sediments recorded at St. German's. Here a succession from saltmarsh plant communities to a freshwater fen, with an early dominance of alder and willow, and then to a fen oak woodland was recorded. The complete succession to raised bog was not observed, although this transition was recorded elsewhere in the Fenlands, such as at Wood Fen (Godwin and Mittre 1975).

The seral vegetation changes observed occurred in an environment where the dominant control on plant succession was the relative rate of peat accumulation and watertable movement. However, a difficulty inherent in the analysis of plant community changes in a coastal context is that the relative height of the watertable is unlikely to have continued to fall for long periods of time (Walker 1970), except in an area of rapid isostatic uplift. Identifying the full seral succession in coastal locations in southern England is therefore rare.

Indeed, for this full succession to occur, one must envisage a situation in which no allogenic processes alter the progressive decline in the relative altitude of the watertable during the period of succession. Such a situation could arise in a coastal context in one of three situations:

i. If the absolute watertable remained static.

ii. If the absolute watertable fell due to the operation of an allogenic process (for example, the watertable falling faster than the rate of crustal subsidence).

iii. If the rate of absolute watertable rise was less than the rate of peat accumulation.

An ideal autogenic seral succession is unidirectional, and therefore one would only ever expect to observe evidence for the progressive drying of the peat surface. However, it is rare to find such a succession in coastal areas. For example, at St German's Godwin and Godwin (1933) recorded a reversal of this drying succession, with oak fen woodland being replaced by saltmarsh conditions prior to the change in sedimentation from organic to predominantly inorganic associated with the transgressive contact. The clear reversal of the succession observed here may only be explained by the operation of an allogenic process, and thus the separation of autogenic from allogenic successional changes is crucial in any analysis of watertable movements and sea-level changes in coastal contexts.

6.2.2. The tendency approach, watertable movements and vegetation changes.

If one accepts that the reversal of an autogenic vegetation succession can be identified from within an organic (and in a similar sense from within an inorganic) sedimentary profile, then one must also accept that the transgressive or regressive contacts merely reflect a point in time when either the rate of organic or inorganic accumulation exceeds the rate of watertable fall or rise. As such, transgressive and regressive contacts provide information on only one point in a time-transgressive process of watertable movements. They do not necessarily provide information concerning the detailed chronology of watertable movements, as they will nearly always date a tendency of watertable change which began some time before a change in gross lithology is recorded.

However, it is recognised that exceptions to this pattern may be expected to have occurred if, for example, the rate of change in relative sea-level was exceptionally fast, in which case there may no biostratigraphic evidence for a progressive rise in the watertable prior to a change in lithology (eg under conditions of barrier breaching).

With its concentration on age and not altitude, the tendency approach has the potential (in conjunction with palaeobotanical data) to identify the earliest indicator of a change in sea-level. Levels such as these (which are identified within organic deposits) may be dated using ^{14}C dating techniques, although for similar levels identified in the analyses of inorganic sediments (by diatom analysis, for example) a suitable dating technique is yet to be developed.

This methodology may also be extended beyond a single litho-, bio-, and chronostratigraphic sequence to the analysis of these variables in a three-dimensional context. This requires an appreciation of the complex nature of sedimentary palaeoenvironments, as well as the relationship between the freshwater and saline water in coastal aquifers. A simple working hypothesis can be proposed to illustrate this point.

If a transgressive contact is believed to result from an increase in marine influence, the earliest registration of this change would be expected in a location close to the marine influence. In contrast, a regressive overlap would be expected to be recorded at an earlier date in locations distal to the marine source. Therefore, there exist two hypothetical age gradients which, under ideal conditions, see a younging gradient for a regressive contact in a seaward direction, and a younging gradient for the transgressive contact in a landward direction. The methodology employed in data acquisition should, therefore, recognise both the spatial location of a single core in a dynamic sedimentary palaeoenvironment, and the specific point within that core where the onset of a time transgressive change in the altitude of the watertable is recorded.

6.2.3. Sedimentary palaeoenvironments.

The working hypothesis proposed above assumes a simple onshore/offshore movement of the coastline and the saltwater/freshwater interface. However, a consideration of the palaeodrainage network of coastal areas indicate that this simple model is unlikely to have occurred. The presence of palaeochannels in Holocene sedimentary sequences have been widely recognised in the Fenlands (Seale 1975, Shennan 1986b, Adam 1990). These channels form part of a complex drainage system which characterises most contemporary saltmarsh environments such as those of the Fenlands of East Anglia, and which will complicate any simple lateral onshore/offshore movement in saline conditions.

In the current study the palaeogeography of the study area will have changed throughout the Holocene. During the early-Holocene the infilled valley would have been comparatively narrow, and the marine influence localised to the valley floor. As relative sea-level rose, however, so the valley width would have increased, reaching a maximum of about 400m. During the recent Holocene the valley would have been infilled and a larger, more open sedimentary environment incorporating the Lydden Valley become established (see Section 7.6.). Therefore, the relative proximity of any core to the marine influence will have changed through time, both as relative sea-level fluctuated, as well as changes in the form of the palaeoenvironment occurred.

6.2.4. The saltwater/freshwater interface.

Fig.6.1. illustrates the changing altitude of the groundwater table recorded at the Victoria Park, Deal. No data are available on the lithology of the water-bearing strata, nor on any change in salinity of the watertable associated with these fluctuations, but a clear tidal control on the altitude of the watertable is apparent. Any longer term change in the altitude of relative sea-level would be expected to increase or decrease these changes, and also change the position of the saltwater/freshwater interface.

The fundamental mechanism which controls the movement of the saltwater/freshwater interface is the density of water. Pure water has a density of 0.9982 kg l^{-1} at 20° C, whilst saltwater has a density of between 1.022 and 1.028 kg l^{-1} at 20° C (Chow 1964). In a relatively homogenous porous media in the coastal zone, Cooper et al (1964, in Reilly and Goodman 1985) found that the denser saltwater was overlain by less dense freshwater (Fig.6.2.).

Cooper et al (1964) identified a zone of mixing, known as the zone of diffusion or dispersion, between the fresh and saltwater. At this zone, some saltwater mixes with freshwater and moves seawards, causing more saltwater to move towards this zone of mixing. The mechanisms which can cause a movement in this zone are complex, and may be controlled by changes in both the freshwater and saltwater aquifers. For example, Eissaid (1990) has noted that

> "Any change in the flow regimen within the freshwater region, caused by changes in discharge or recharge inland, induces movement of the freshwater-saltwater interface. Reduction in freshwater flow towards the sea causes intrusion of saltwater aquifers as the interface moves inland...The nature and time frame of aquifer response during the transient period will depend on the flow conditions, boundary conditions, and aquifer properties. The ease with which saltwater can move into, or out of, an aquifer system affects the rate of interface movement in response to changes in freshwater discharge. To fully understand the behaviour of coastal systems it is necessary to examine the dynamics of both the freshwater and saltwater flow domains."

The altitude and salinity of the groundwater at any point in time and space may be affected by a number of factors. For example, sediments of differing porosity and permeability will support different groundwater regimes, responding to different levels in temperature, precipitation, evaporation, and evapotranspiration in a spatially and temporally specific manner. These factors combine to determine the altitude at which, for example, peat growth will occur. Jelgersma (1961) has noted that

> "The level of groundwater at which the peat moor is formed, is related to sea-level in a complicated way: it

> depends on the distance to the shore-line, the height of the tides and the permeability of the sandy subsoil. The relation of groundwater to sea-level is likely to be different from place to place along the coast".

Thus, Jelgersma (1961) illustrated that the relationship between the groundwater table, organic accumulation and sea-level within a tidal estuary can vary along the length of that estuary in response to changes in the availibility of flood depressions. Jelgersma (1961) also argued that it was possible that the altitude of the groundwater upstream in an estuary may be notably higher than the altitude of the groundwater table in the lower estuary area.

In a discussion of the pattern of water movements within a saltmarsh, Chapman (1939) divided the saltmarsh into seven separate divisions on the basis of a number of criteria, including the elemental composition of the groundwater, nature of plant communities, and daily tidal submergence duration. Chapman (1960) noted that the great differences of water movement in sands, silts and clays indicated that a full understanding of watertable movement within a saltmarsh was not possible without a detailed study of marsh geological structure.

More recently, Hemond and Fifield (1982) have modelled the subsurface flow in a Spartina saltmarsh peat, and concluded that there was considerable variability in the pattern of water movements within a saltmarsh. Hemond and Fifield (1982) noted that

> "Because of its mode of formation, there is every reason to believe peat is generally anisotropic, having unequal horizontal and vertical permeabilities",

and observed that within the interior regions of a saltmarsh the pattern of subsurface flow may often be dominated by evapotranspiration and not simply by tidal oscillations or changes in the groundwater throughput, supporting the conclusions made by Valiela et al (1978). Indeed, Dacey and Howes (1984) noted that

> "The role of plants in determining the movement of sediment water has not been defined",

and observed that on a diurnal basis in certain areas of a saltmarsh virtually all the drop in the watertable was due to evaporation, and not drainage. Dacey and Howes (1984) also suggested that an increase in plant production could lead to an increase in the amount of watertable fluctuation as the effect of evapotranspiration increased.

Furthermore, the simple relationship between tidal range and saltmarsh zonation proposed by Johnson and York (1915) is not always the case. Salinity inversions in saltmarsh profiles between fully marine and brackish parts of an estuary are common (Gillham 1957, Ranwell 1974, Eleutrius and Eleutrius 1979), whilst within individual estuaries there often cases where individual species of a saltmarsh are found at notably higher or lower elevations than elsewhere in the estuary (Adam 1990).

Therefore, it is apparent that the relationship between the height of sea-level and the altitude and salinity of the groundwater table is far from clear. At one scale, changes are controlled by long-term movements in the position of the saltwater/freshwater interface, whilst at another local scale movements of the groundwater table may be affected by differing topographic controls, the nature of the pre-Holocene and Holocene sediments, as well as ecological factors such as variable patterns in rates of evapotranspiration.

The following Chapters seek to determine whether detailed litho-, bio-, and chronostratigraphic analyses can be used to identify the most suitable site for the determination of positive and negative tendencies of sea-level movement. This approach requires the accurate definition of the pre-Holocene sedimentary basin and a three-dimensional understanding of the litho-, bio- and chronostratigraphic data. In addition, it requires the analysis of within-deposit changes in vegetation communities as proxy data for changes in the altitude of the watertable through time. Finally, it needs the ^{14}C dating of the earliest levels identified within a biostratigraphic profile indicative of a clear movement of the watertable.

6.3. Radiocarbon dates from the East Kent Fens.

Twenty radiocarbon assays had been completed on samples collected from the area under study. The aims of the dating programme have been discussed in detail in Section 3.8.1., but to recapitulate, the two main aims of the dating programme were to determine the age of transgressive and regressive contacts, and to date within-peat levels indicative of a change in the altitude of the watertable. These dates have been grouped according to the scheme proposed in Section 2.2., and are listed in full in Table 6.1. below.

Table 6.1. Radiocarbon dates from the East Kent Fens.

Group 2

Site / Material	Lab code	^{14}C Age	Depth (m OD)
Hacklinge H-2(b)	Hv. 17496	6450±170	-8.91 to -8.875
Dark brown well-humified peat with some Phragmites.			
Hacklinge H-2(b)	Hv. 17498	3905±205	-3.42 to -3.38
Dark brown fibrous turfa, soft with some Phragmites.			

Marsh Lane ML-9 Hv. 17332 5290±75 -6.09 to -6.05
Dark brown well-humified peat with some woody detritus and occasional Phragmites. Rare clay inclusions.

Marsh Lane ML-9 Hv. 17330 4105±130 -2.60 to -2.56
Well-humified brown peat with some clay. Slightly eroded contact (lim. sup. 1).

Marsh Lane MMON Hv. 17337 3550±140 -1.66 to -1.64
Brown well-humified peat with some turfa, Phragmites and occasional woody detritus.

Sandfield Farm SF-10 Hv. 17341 5550±110 -5.56 to -5.52
Very compact dark brown or black well-humified peat with occasional woody detritus.

Sandfield Farm SF-10 Hv. 17338 4020±70 -1.95 to -1.91
Well-humified brown peat with some Phragmites.

Group 3

Site **Sample** **^{14}C Age** **Depth (m OD)**
Material

Hacklinge H-2(b) Hv. 17497 6250±175 -8.96 to -8.925
Dark brown or black well-humified brown peat with some Phragmites and occasional shells. Slightly laminated with occasional detrital wood.

Hacklinge H-2(b) Hv. 17494 6445±105 -8.66 to -8.62
Dark brown well-humified peat with some broken shells.

Hacklinge H-2(b) Hv. 17495 4890±130 -4.59 to -4.55
Grey or brown turfa with some clay, soft and fibrous.

Hacklinge H-2(b) Hv. 17499 2400±230 -2.38 to -2.33
Phragmites-rich turfa with some clay. Very soft and fibrous.

Marsh Lane ML-9 Hv. 17334 5765±150 -6.41 to -6.37
Compact dark brown or black well-humified peat with some turfa and Phragmites. Occasional woody detritus and some clay.

Marsh Lane ML-9 Hv. 17331 3900±200 -3.02 to -2.98
Soft brown well-humified turfa.

Marsh Lane MMON Hv. 17335 4570±140 -2.32 to -2.30
Well-humified brown peat with some turfa, Phragmites and occasional woody remains.
Sandfield Farm SF-10 Hv. 17343 5975±75 -5.81 to -5.77
Very compact dark brown or black well-humified peat, slightly laminated with some small shells.
Sandfield Farm SF-10 Hv. 17340 4640±110 -2.38 to -2.34
Soft brown well-humified peat with some clay and Phragmites.

Group 5a

Site Sample ^{14}C Age Depth (m OD)
Material

Marsh Lane MMON Hv. 17336 3980±140 -1.75 to -1.73
Turfa with some Phragmites and some woody detritus.
Sandfield Farm SF-10 Hv. 17339 4135±110 -2.02 to -1.98
Soft well-humified peat with some Phragmites and rare turfa.

Group 5b

Site Sample ^{14}C Age Depth (m OD)
Material

Marsh Lane ML-9 Hv. 17333 5825±80 -6.28 to -6.24
Well-humified, slightly laminated brown peat with some Phragmites.
Sandfield Farm SF-10 Hv. 17342 5655±150 -5.72 to -5.68
Compact dark brown or black well-humified peat with some Phragmites.

When considering these data two points require further discussion. Firstly, the standard errors for all the dates are large, with three dates having a one standard error of 200 ^{14}C years or more, twelve dates having a one standard error of 100 to 199 ^{14}C years, and only five dates with a one standard error of less than 100 ^{14}C years. This has two important implications.

i. The first is that the fine resolution analysis of watertable movements is made difficult, for the large standard errors mean that many of the dates are overlapping when these errors are taken into account.

ii. The second is that when these dates are calibrated to sidereal years, the size of the one standard error has an important effect on the sidereal age range calculated. This has been discussed above in Section 3.8.2.1., and restricts the feasibility of the fine resolution analysis attempted here.

In addition to the large standard errors, there are two significant age reversals in the sequence of dates listed in Table 6.1., and both of these are discussed below. Their screening requires a re-assessment of the litho- and biostratigraphic data in conjunction with the other chronostratigraphic data collected.

The lower three dates collected from Hacklinge (H-2(b)) provide a confusing sequence, although it is only the lower of the three dates (Hv. 17496, 6250±175 BP) which is clearly anomalous. This age anomaly may be due to a number of factors.

i. The first is that the lower organic deposit is not _in situ_. Were this to be the case one might expect a sharp transgressive and regressive contact, and no clear biostratigraphic transition over the respective contacts. The lithostratigraphic data show the regressive and transgressive contacts both have a diffuse transition to the stratum above. However, this deposit was sampled three times, once by core GR2 and once by piston-core H-2(a) and H-2(b). Whilst in core GR2 both these contacts were also diffuse, in piston-core H-2(a) the regressive and transgressive contacts have a lim. sup. of 3 and 1 respectively. All cores were located immediately adjacent to each other, and although the nature of the regressive and transgressive contacts suggest that differential erosion of the peat surface may have occurred, the lithostratigraphic evidence to indicate that the deposit is not in situ remains equivocal.

The biostratigraphic data are difficult to assess, for the pollen analysis was completed from H-2(a) where the contacts are abrupt, and the diatom analysis from H-2(b), where they are diffuse. The diatom data presented in Section 6.7.3. indicate that the sediments immediately below the regressive contact accumulated under **M** or **B** conditions, with no clear freshening (or any significant change for that matter) of the assemblage below the contact. Nor is there a clear saltmarsh transition in the pollen data immediately above the regressive contact.

The pollen data associated with the transgressive contact indicate the proximity of saltmarsh conditions during the final phase of organic sedimentation. However, diatom data show that the overlying inorganic sediments accumulated under a strong **M** environment, with no indication of supra- or intertidal diatom flora being recorded immediately above the contact. In conclusion, it would appear that this deposit may not be in situ, although other explanations for the age anomaly are discussed below.

ii. Another possible explanation for the age anomalies is that the regressive contact has been contaminated by younger carbon. This type of error is discussed in detail in Section 3.8.3.4.. Although the sample from the regressive contact contained some Phragmites and some detrital wood, these were carefully removed prior to the samples submission to the dating laboratory. However, this does not preclude the possibility that the sample has been contaminated by younger humic acids.

The second date which appears anomalous is from ML-9 (Hv. 17331, 3900±200 BP). This date is clearly anomalous when compared with other dates from the area, as samples collected from MMON, SF-10 and H-2(b) indicate that this regressive contact formed between c. 5000 and 4500 BP. The lithostratigraphy indicates that the regressive contact is diffuse, with a clear fining-upwards sequence towards the regressive contact. The pollen data indicates that a Gramineae-dominated environment became established immediately above the regressive contact, with occasional saltmarsh indicators being recorded. Therefore, on the basis of litho- and biostratigraphic data the deposit is clearly in situ.

The sample submitted for dating was a well-humified turfa with one piece of detrital wood, although all allochthonous material was removed prior to dating. Therefore, the age anomaly would appear to reflect either post-depositional contamination caused by the penetration of younger humic acids, or by a laboratory error. The possibility of the former being the case is remote; as the transgressive contact in ML-9 is dated to 4105±130 BP, and therefore the opportunity for humic acids of a younger age forming above and subsequently penetrating to this level is doubtful.

In conclusion, therefore, there are two age anomalies in the chronological data presented, and no clear explanation is forthcoming for either of these two anomalies. Neither of these dates is used in any subsequent analysis.

6.4. The use of Local Assemblage Zones in the analysis of watertable movements.

A sedimentary system will respond to a change in the elevation of the watertable in a complex and often time transgressive manner. For example, if one assumes a simple onshore/offshore movement of the coast parallel to the marine influence, for a site proximal to the marine influence an elevation in the watertable may result in the replacement of freshwater aquatic plant communities by saltmarsh communities, whilst at a more distal location this change may be registered by the replacement of alder carr by freshwater aquatic communities. Although this is likely to be a simplification of reality (see Section 6.2.3. and 6.2.4.), at an intra- or inter-site scale, although changes in the vegetation communities may differ, they may still reflect the same initial change in the watertable.

In order to aid in the interpretation of the biostratigraphic data presented in Chapter Five each LAZ has been classified as being indicative of an increase or a decrease in the height of the watertable. If the evidence is inconclusive, no directional movement is assigned to the zone. By combining litho- and biostratigraphic data it is thus possible to establish a continuous record of watertable movements at a site-scale.

Comparison of data at a variety of spatial scales may subsequently be used to establish whether the changes observed represent an intra- or inter-site change in the watertable, or whether they represent the operation of local processes.

6.5. Watertable movements identified at Sandfield Farm.

6.5.1. SF-10 Lower inorganic deposit.

The deepest inorganic sediments recorded in SF-10 illustrate a fining-upwards sequence towards a regressive contact at -5.81m OD (Section 5.2.2.1.). This sequence sees the gradual replacement of a finely laminated sandy-silt (stratum 1) by a clay with some turfa (statum 4). The diatom assemblage from these strata is mixed, with fluctuating frequencies of **M**, **MB**, **BM** and **B** taxa, and very low frequencies of **BZ**, **ZB**, or **Z** taxa (Fig.5.10.). The presence of fluctuating frequencies of Diploneis didyma, Nitzschia navicularis and rare occurrences of Diploneis interrupta (LDAZ SF-10d), combined with the low frequencies of truly marine forms such as Paralia sulcata and

Nitzschia granulata, suggest that the sediments accumulated in the intertidal or shallow subtidal zone (Vos and de Wolf 1988). Round (1960) has noted that both _Diploneis didyma_ and _Nitzschia navicularis_ are more commonly recorded on the middle to upper saltmarsh, whilst Vos and de Wolf (1988) observed that high frequencies of _Diploneis interrupta_ can also be recorded in the supratidal zone.

Assigning a directional movement to each LDAZ is difficult due to the small number of levels counted, and because most of the main taxa identified have similar ecological tolerances. Most notably, however, there appears to be a freshening above LDAZ SF-10b.

Each LDAZ has been assigned a directional movement with respect to the altitude and salinity of the watertable based on biostratigraphic data in Table 6.2. below.

Table 6.2. Relative watertable movements and salininty for each LDAZ identified in the lower inorganic deposit - SF-10.

LDAZ	Depth (m OD)	Relative watertable movement
SF-10e	-5.84 to -5.80	?/-ve
SF-10d	-5.87 to -5.84	-ve
SF-10c	-5.89 to -5.87	-ve
SF-10b	-6.05 to -5.89	+ve
SF-10a	-6.12 to -6.05	?/-ve

6.5.2. SF-10 Lower organic deposit.

Organic sedimentation replaces inorganic sedimentation at -5.81m OD, and this regressive contact has been ^{14}C dated to 5975±75 BP. No pollen was recorded immediately above the regressive contact, and the first countable level was at -5.76m

OD, indicating a Gramineae-dominated environment (91% TLP), but with no taxa indicative of saltmarsh conditions (Fig. 5.1.). The lithostratigraphy is a well-humified compact black peat with some turfa (stratum 6), which extends from -5.76 to -5.71m OD.

LPAZ SF-10b sees a rise in the frequencies of aquatic taxa to a high of 38% TLP at -5.72m OD, and in particular an increase in *Typha angustifolia*, *Typha latifolia*, as well as *Potamogeton* and *Lemna*. Rare occurrences of other wet-loving herbs such as Malvaceae-type and *Parnassia*-type are also recorded. The presence of saltmarsh indicators within this zone (Chenopodiaceae, *Aster*-type, *Atriplex*-type, and *Plantago coronopus*) indicate the proximity of saltmarsh conditions, and it is suggested that these vegetation changes reflect part of the progressive lowering of the watertable associated with the regressive contact.

Within LPAZ SF-10c there is a sharp decline in the frequencies of aquatic taxa, Gramineae, as well as a deterioration in pollen preservation (a sample at -5.70m OD contained insufficient pollen for counting). The end of the aquatic phase defined by the opening of LPAZ SF-10c has been dated to 5655±150 BP. The decline in aquatic taxa, followed by a rise in the frequencies of first Cyperaceae and then Filicales suggest that a fall in the watertable occurred during this LPAZ. Towards the top of LPAZ SF-10c frequencies of Filicales rise to a high of 41% TLP at -5.60m OD

Godwin and Godwin (1933) and Godwin (1978) have noted that high frequencies of Filicales are commonly caused by a lowering of the watertable and the resulting drying of the peat surface. This conclusion was also reached by Dimbleby (1957) who noted that

> "It has been observed that when anaerobic fen peats become aerated, the pollen is for the most part

> destroyed, leaving only the extremely resistant grains, notably fern spores; in fact, high frequencies of fern spores have been used as an indication of a period of aeration in a fen peat profile".

Smith et al (1989) have also interpreted increases in the frequency of Filicales in the Gwent Levels as a reflection of a reduction in the height of the watertable. Here Smith et al (1989) noted that in sub-zone GC1-1b the increase in Filicales frequencies indicated that

> "The reedswamp appears to have become drier, leading to conditions in which ferns had a competitive advantage".

In this situation, the increase in Filicales frequencies do not appear to be a function of differential pollen preservation, but specifically of a change in hydrological conditions.

Therefore, there is general agreement that the presence of high frequencies of Filicales, in association with poor pollen preservation and an increase in humification indicates a lowering of the watertable and a drying of the peat surface.

In LPAZ SF-10d and SF-10e Gramineae frequencies first fall slightly, and then rise towards the transgressive contact at -5.53m OD. No saltmarsh indicators were recorded immediately below the transgressive contact. Diatom data however, confirm the nature of sedimentary changes associated with the transgressive contact, with high frequencies of BM and MB taxa which are progressively replaced by M taxa (see below). This transgressive contact has been eroded in all cores except 5 and 10, suggesting a rapid change in sedimentation occurred. The transgressive contact has been dated to 5550±110 BP.

Each LPAZ has been assigned a directional movement with respect to the altitude of the watertable in Table 6.3. below.

Table 6.3. Relative watertable movements for each LPAZ identified in the lower organic deposit - SF-10.

LPAZ	Depth (m OD)	Directional watertable movement
SF-10e	-5.55 to -5.51	+ve
SF-10d	-5.59 to -5.55	-ve
SF-10c	-5.70 to -5.59	-ve
SF-10b	-5.75 to -5.70	-ve
SF-10a	-5.76 to -5.75	-ve

6.5.3. SF-10 Middle inorganic deposit.

Immediately above the transgressive contact high frequencies of *Diploneis didyma*, *Nitzschia granulata*, *Nitzschia punctata* and *Nitzschia navicularis* are recorded (Fig.5.11.). Vos and de Wolf (1988) have suggested that *Diploneis didyma* and *Nitzschia navicularis* prefer clayey sediments in the intertidal or shallow subtidal zone, whilst Carter (1933) suggested that *Nitzschia punctata* prefers the lower zones of the saltmarsh. The assemblage identified in LDAZ SF-10f indicates a rapid change to a lower intertidal or shallow subtidal depositional environment.

An increase in the frequencies of *Scoliopleura turmida* occurs in LDAZ SF-10g, with a decline in those of *Nitzschia granulata*. Round (1960) has noted that *Scoliopleura* spp favours bare estuarine sands, a conclusion supported by Carter (1933), who observed that the species prefers the lower zones of the saltmarsh. Compared with LDAZ SF-10f this LDAZ suggests a slight freshening of depositional conditions, a conclusion supported by the slight increase in frequencies of ZB taxa, notably those of *Epithemia turgida*.

Frequencies of Scoliopleura turmida decline sharply towards the top of LDAZ SF-10g, and a further slight reduction in salinity is inferred by a gradual decline in the frequencies of Paralia sulcata and an increase in those of Nitzschia navicularis.

The lithostratigraphy at this point indicates the replacement of a silty-clay (stratum 11) by a finely laminated silty-clay (stratum 12) towards the top of LDAZ SF-10h. Thus, the apparent increase in depositional energy environment is not reflected by changes in the diatom content of this deposit.

The junction between LDAZ SF-10h and LDAZ SF-10i indicates a significant increase in salinity, with frequencies of Nitzschia navicularis falling sharply, and a more fully **M** or **MB** environment becoming established. Frequencies of Paralia sulcata increase to a high of 43% TV at -4.02m OD, and those of Aulacodiscus argus and Podosira stelliga also increase. Of the **MB** taxa, Actinoptycus undulatus and Rhaphoneis nitida increase. This strong **M** or **MB** environment persists through LDAZs SF-10i, SF-10j and SF-10k.

The opening of LDAZ SF-10l reflects the onset of a reduction in salinity prior to the regressive contact at -2.38m OD, where a soft dark grey silty-clay (stratum 21) is replaced by a soft brown or grey, well-humified peat with some clay and Phragmites (stratum 22). Once again there is a fining-upwards sequence from stratum 19 to stratum 21, with a change from a slightly laminated sandy-silt to an unlaminated silty-clay. The diatom assemblage indicates a decrease in **M** and **MB** taxa in LDAZ SF-10l, with their replacement by **BM** and **B** taxa. In LDAZ SF-10l frequencies of Scolipleura turmida and Nitzschia navicularis replace those of Paralia sulcata, indicating a reversal back to a lower intertidal or shallow subtidal environment. In LDAZ SF-10m frequencies of **B** taxa rise to >90% TV immediately below the regressive contact, and these changes suggest a reduction in salinity and a vertical movement up the saltmarsh sequence.

The regressive contact at -2.38m OD has been dated to 4640±110 BP.

Each LDAZ has been assigned a directional movement with respect to the altitude and salinity of the watertable in Table 6.4. below.

Table 6.4. Relative watertable movements and salinity for each LDAZ identified in the middle inorganic deposit - SF-10.

LDAZ	Depth (m OD)	Directional watertable movement
SF-10m	-2.56 to -2.44	-ve
SF-10l	-2.87 to -2.56	-ve
SF-10k	-3.60 to -2.87	+ve
SF-10j	-3.88 to -3.60	+ve
SF-10i	-4.30 to -3.88	+ve
SF-10h	-4.76 to -4.30	-ve
SF-10g	-5.25 to -4.76	-ve
SF-10f	-5.52 to -5.25	+ve

6.5.4. SF-10 Upper organic deposit.

Immediately above the regressive contact pollen analysis (Fig.5.2.) indicates high frequencies of Gramineae, Cyperaceae and Quercus pollen (LPAZ SF-10f). High frequencies of Quercus are commonly recorded above or below a transgressive or regressive contact. In the East Anglian Fenlands, for example, Shennan (1980) has noted that such an increase in Quercus frequencies can reflect an increase in the regional pollen rain caused by the relatively open conditions associated with a regressive or transgressive contact.

Occasional grains of Chenopodiaceae and Aster-type, combined with the macroscopic remains of Phragmites suggest the close proximity of saltmarsh conditions. LPAZ SF-10g sees a sharp increase in the frequencies of Filicales to 77% TLP at -2.22m OD, associated with an increase in pollen deterioration (no pollen was countable at -2.26 and -2.24m OD). This increase in the frequencies of Filicales is interpreted as a drying of the peat surface. There follows a decline in the frequencies of Filicales, and a return to a Gramineae-dominated environment in LPAZ SF-10h.

The opening of LPAZ SF-10h is associated with a small increase in frequencies of aquatic taxa, notably Typha latifolia and Typha angustifolia. It is possible that this slight increase in the height of the watertable was responsible for the decline in Filicales frequencies described above. It is notable that Alnus frequencies increase towards the top of LPAZ SF-10g, and it is possible that this also reflects an increase in the height of the watertable. A Gramineae-dominated environment persists throughout LPAZ SF-10h, and no clear directional movment of the watertable is apparent. The opening of LPAZ SF-10i, however, sees a sharp elevation of the watertable with an rise in the frequencies of aquatic and tree taxa. In particular, Lemna frequencies increase to 223% TLP, whilst those of Myriophyllum-type, Nymphaea, Ranunculus-type, Typha latifolia and Typha angustifolia also increase. Lemna is a small aquatic herb, which commonly forms a green carpet on the surface of stagnant water. Potamogeton favours freshwater <1m deep, preferring a highly organic substratum, whilst Typha latifolia is commonly recorded in lakes and ponds where there is silting and rapid decay of organic material (Clapham et al 1962). There is no significant change in the stratigraphy associated with this increase in aquatic taxa.

The presence of Chenopodiaceae and Aster-type in LPAZ SF-10i and SF-10j would suggest that the changes reflect the onset of a rise in the watertable consequential to an increase in the marine influence prior to the transgressive contact. Once again the transgressive overlap reflects a change in sedimentation which is part of a progressive elevation in the watertable, first identifiable within the organic deposit (in LPAZ SF-10d). This rise in aquatic taxa has been dated to 4135±90 BP. High frequencies of Gramineae (c. 58% TLP) and the presence of Chenopodiaceae and Aster-type, in LPAZ SF-10j indicate the proximity of saltmarsh conditions. The lithostratigraphy illustrates a gradual change from a well-humified brown peat with some Phragmites (stratum 25), to a soft dark grey silty-clay with some turfa (stratum 26).

The presence of macroscopic remains of Phragmites immediately below the transgressive contact has been used by Godwin and Godwin (1933) as an indicator of approaching marine conditions. Thus, Godwin and Godwin (1933) noted that an increase in the macroscopic remains of Phragmites below the transgressive contact at St. German's was

> "indicative of the wet freshwater or brackish water conditions preceding the actual saltmarsh formation".

The transgressive contact at -1.91m OD has been dated to 4020± 70 BP.

Each LPAZ has been assigned a directional movement with respect to the altitude of the watertable in Table 6.5. below.

Table 6.5. Relative watertable movements for each LPAZ identified in the upper organic deposit - SF-10.

LPAZ	Depth (m OD)	Directional watertable movement
SF-10j	-1.99 to -1.94	+ve
SF-10i	-2.01 to -1.99	+ve
SF-10h	-2.21 to -2.01	?
SF-10g	-2.30 to -2.21	-ve
SF-10f	-2.38 to -2.30	-ve

6.5.5. SF-10 Upper inorganic deposit.

Diatom analysis immediately above the transgressive contact (Fig.5.12.) illustrate that stratum 26 began accumulating under strong **Z** sedimentary conditions (>50% TV), and then under a progressively more saline environment with the replacement of **Z** by **ZB**, **ZB** by **B**, and then **B** by **BM**, **MB**, and **M** taxa (LDAZs SF-10n-q). These changes indicate a progressive increase in salinity above the transgressive contact.

No diatoms were recorded between -1.50m and -0.52m OD. Samples were prepared from the upper inorganic deposit recorded at Marsh Lane, but only very rare broken valves of Paralia sulcata were recorded. The frequencies of these diatoms were too low and sporadic to enable adequate counting. Pollen analysis from this deposit may throw more light on its depositional environment.

The re-appearance of diatoms at -0.52m OD indicates that a strongly saline **M** depositional environment existed at this time, with high frequencies of Paralia sulcata dominating LDAZ SF-10r. The opening of LDAZ SF-10s indicates a brief freshening of the environment with a reduction in the frequencies of **M** taxa, and an increase in those of Nitzschia navicularis. Towards the top of this LDAZ these **B** and **BM** taxa decline, to be replaced once more by high frequencies of Paralia sulcata. No diatoms were recorded above -0.26m OD, and no conclusions concerning the depositional environment above this level may be made.

Each LPAZ has been assigned a directional movement with respect to the altitude and salinity of the watertable in Table 6.6. below.

Table 6.6. Relative watertable movements for each LDAZ identified in the upper inorganic deposit - SF-10.

LDAZ	Depth (m OD)	Directional watertable movement
SF-10s	-0.36 to -0.24	-ve
SF-10r	-1.01 to -0.36	+ve
SF-10q	-1.60 to -1.01	+ve
SF-10p	-1.72 to -1.60	+ve
SF-10o	-1.84 to -1.72	+ve
SF-10n	-1.90 to -1.84	+ve

6.5.6. SF-4 Upper organic deposit.

Pollen analysis has also been completed on the upper organic deposit recorded at SF-4 (Fig.5.3.), although no ^{14}C dates were collected from this piston-core. The regressive contact here is recorded at -3.03m OD, where a soft battleship-grey clay with some silt and turfa (stratum 2) is overlain by a dark brown or grey well-humified peat with some turfa and clay (stratum 3). Pollen preservation in the lower part of the peat was very poor, but a Gramineae-dominated environment with rare grains of saltmarsh taxa such as Aster-type and Chenopodiaceae (LPAZ SF-4a) indicate that the base of stratum 3 accumulated in close proximity to saltmarsh conditions.

The opening of LPAZ SF-4b sees a sharp increase in the frequencies of Filicales at -2.79m OD, suggesting that a drying of the peat surface may have occurred. This suggestion is supported by a decrease in pollen preservation (no pollen was counted between -2.86 and -2.80m OD). However, the occurrence of high frequencies of Potamogeton and Filicales at -2.75m OD suggest either a complex sedimentary environment with pools of standing water and drier hummocks supporting Filicales, or the inwashing of Filicales from a drier source area. The decline in frequencies of Filicales which marks the end of LPAZ SF-4b may be due to the elevation of the watertable suggested by the increase in frequencies of <u>Potamogeton</u> and the concurrent slight increase in frequencies of <u>Alnus</u>. These conclusions are tentative, but are given more credence by the clearer evidence for watertable movements identified in LPAZ SF-10 (Section 6.5.4.). There follows a return to a Gramineae-dominated environment which persists throughout LPAZ SF-4c. No clear directional movement of the watertable is apparent in this LPAZ.

In contrast, the vegetation changes recorded in LPAZ SF-4d indicate a clear increase in the height of the watertable, with frequencies of <u>Lemna</u> increasing to 138% TLP, as well as an increase in those of <u>Potamogeton</u> and <u>Typha angustifolia</u>. Above this level aquatic taxa decline towards the transgressive contact, whilst frequencies of <u>Corylus</u> increase. The continued presence of <u>Lemna</u> and other aquatic taxa in LPAZ SF-4e suggest that their increase in LPAZ SF-4d is a reflection of the onset of a rise in the watertable prior to the transgressive contact at -2.52m OD. Assignment of a directional movement to this LPAZ is based on the changes observed in LPAZ SF-10d and the lithological and diatom data associated with the transgressive contact and the overlying inorganic sediments recorded in SF-10. The presence of Chenopodiaceae suggest the local presence of saltmarsh conditions, although no clear saltmarsh transition is apparent, with frequencies of Gramineae remaining low.

Each LPAZ has been assigned a directional movement with respect to the altitude of the watertable in Table 6.7. below.

<u>Table 6.7. Tendency of watertable movements for each LPAZ identified in the upper organic deposit - SF-4.</u>

LPAZ	Depth (m OD)	Directional watertable movement
SF-4e	-2.56 to -2.53	+ve

SF-4d	-2.61 to -2.56	+ve
SF-4c	-2.73 to -2.61	?
SF-4b	-2.83 to -2.73	-ve
SF-4a	-3.02 to -2.83	-ve

6.6. Watertable changes identified at Marsh Lane.

No diatom data have been collected from Marsh Lane, although pollen analysis has been completed on the lower and upper organic deposit recorded in ML-9, and the upper organic deposit recorded in MMON.

6.6.1. ML-9 Lower organic deposit.

The lowest regressive contact recorded in ML-9 is at -6.41m OD, where a compact dark brown or black well-humified peat with some turfa and Phragmites (stratum 5) is recorded overlying a sequence of clays, silts and sands (strata 1-4). These inorganic sediments illustrate a fining-upwards sequence towards the regressive contact, with a laminated silty-clay with some sand (stratum 1) passing into an unlaminated silty-clay. Pollen analysis from the lowermost 0.02m. of the organic deposit failed to produce countable pollen. The lowermost levels counted (Fig.5.4., LPAZ ML-9a) indicate a Gramineae/Cyperaceae-dominated environment, with the presence of Chenopodiaceae (13% TLP), Atriplex-type and Aster-type indicating the local development of saltmarsh conditions. The regressive contact has been dated to 5765±150 BP.

LPAZ ML-9b is characterised by a sharp increase in the frequencies of aquatic taxa, notably Lemna (to c. 32% TLP), Typha latifolia, Typha angustifolia, Potamogeton, as well those of several damp-loving herbs including Malvaceae-type, Parnassia-type, and Radiola linoides. These changes suggest the waterlogging of the peat surface with standing fresh water. This change in biostratigraphy is manifest in the lithostratigraphy by a change from a compact dark brown or black well-humified peat with some _turfa_ and _Phragmites_ (stratum 5) to a light brown well-humified peat with fine white powdered shells (stratum 6). This stratum extends between -6.36 and -6.33m OD, and was recorded in most cores completed at Marsh Lane and Sandfield Farm (Sections 4.2.6., 4.2.7.). These litho- and biostratigraphic changes suggest that the increase in aquatic taxa in LPAZ ML-9b represent part of the fall in the watertable associated with the regressive contact.

Aquatic taxa decline in LPAZ ML-9c, indicating the continued lowering of the watertable and drying of the peat surface. The opening of this LPAZ has been dated to 5825±80 BP, and indicates that the lower organic sediments covered by LPAZs ML-9a and ML-9b accumulated rapidly. Evidence for the continued fall of the watertable is found in LPAZ ML-9d, where frequencies of Filicales and _Thelypteris palustris_ increase. The latter is usually associated with damp shady conditions, commonly growing in association with _Alnus_ (Clapham _et al_ 1962, Godwin 1978, Devoy 1977).

The lithostratigraphy associated with LPAZs ML-9c, -9d, and -9e consists of a slightly laminated, compact and well-humified peat with some _Phragmites_. The laminated nature of this deposit suggests a possible waterlain origin. However, the poor pollen preservation at -6.24m OD (which was responsible for the low pollen count at this level), and the absence of aquatic taxa, suggest that the changes recorded here represent a drying of the peat surface and lowering of the watertable. A mixed Gramineae/Cyperaceae-dominated environment persists until the transgressive contact at -6.05m OD, with no apparent saltmarsh transition before the onset of inorganic sedimentation. No directional watertable movement has been assigned to this LPAZ. This transgressive contact has been dated to 5290±75 BP.

Each LPAZ has been assigned a directional movement with respect to the altitude of the watertable in Table 6.8. below.

Table 6.8. Relative watertable movements for each LPAZ identified in the lower organic deposit - ML-9.

LPAZ	Depth (m OD)	Relative watertable movement
ML-9e	-6.18 to -6.06	?
ML-9d	-6.22 to -6.18	-ve
ML-9c	-6.30 to -6.22	-ve
ML-9b	-6.35 to -6.30	-ve
ML-9a	-6.38 to -6.35	-ve

6.6.2. ML-9 Upper organic deposit.

The regressive contact of the upper organic deposit is recorded at -3.02m OD, where a soft well-humified peat with some turfa (stratum 17) is recorded overlying a sequence of clays, silts and sands. These inorganic sediments illustrate a fining-upwards sequence with a grey, finely laminated silty-clay (stratum 15) being replaced by a silty-clay with some detrital organic material (stratum 16). The regressive contact has been dated to 3900±200 BP and the anomalous nature of this date has been discussed above in Section 6.3.

No pollen was recorded between -3.02 and -2.98m OD, and the lowermost sample counted was in stratum 18, - a well-humified compact and quite dry black peat with some turfa and well-humified Phragmites. This and the sample above it (Fig.5.5.) indicate a Gramineae-dominated environment, with low frequencies of saltmarsh taxa such as Chenopodiaceae (LPAZ ML-9f).

Throughout LPAZs ML-9g and ML-9h frequencies of Gramineae and Cyperaceae fluctuate. The lithostratigraphy illustrates a turfa with occasional detrital wood and Phragmites (stratum 19). The slight decline in Gramineae and the concurrent increase in frequencies of Cyperaceae in LPAZ ML-9g suggest the continued lowering of the watertable. This is supported by the increase in frequencies of Filicales in this LPAZ. However, the increase in Gramineae in LPAZ ML-9h is more difficult to interpret, with no changes in the lithostratigraphy recorded. No indicative watertable movement has been assigned to this LPAZ.

The opening of LPAZ ML-9i is associated with an increase in the frequencies of Lemna and Filicales to 14% and 28% TLP respectively. These changes are reflected by a change in the lithostratigraphy from stratum 19 to a well-humified very soft brown peat (stratum 20). Other aquatic taxa recorded at this level include Typha angustifolia and Potamogeton, although these taxa are recorded in low and sporadic frequencies throughout the preceding LPAZs. The presence of low frequencies of Chenopodiaceae in this zone indicate the close proximity of saltmarsh conditions, and suggest that the rise in aquatic taxa may have resulted from a rise in the watertable prior to the transgressive contact. The co-existence of high frequencies of Lemna and Filicales suggest either a complex environment with open pools with drier surroundings, or the inwashing of Filicales from a drier source area.

A Gramineae/Cyperaceae-dominated environment is established immediately before the transgressive contact (at -2.56m OD), with a slight increase in the frequencies of Alnus, Tilia, and Corylus. No clear saltmarsh transition is apparent, and this may reflect the slightly eroded nature of this transgressive contact (lim. sup. 1). Assigning a directional watertable movement to this LPAZ is therefore not possible. This transgressive contact has been dated to 4105±120 BP.

Each LPAZ has been assigned a directional movement with respect to the altitude of the watertable in Table 6.9. below.

Table 6.9. Relative watertable movements for each LPAZ identified in the upper organic deposit - ML-9.

LPAZ	Depth (m OD)	Relative watertable movement
ML-9j	-2.58 to -2.56	?
ML-9i	-2.64 to -2.58	+ve
ML-9h	-2.80 to -2.64	?
ML-9g	-2.92 to -2.80	-ve
ML-9f	-2.98 to -2.92	-ve

6.6.3. MMON Upper organic deposit.

The lithostratigraphy of the lowermost sediments recorded in MMON indicates a compact white or grey sandy-silt with some iron-staining (stratum 1), overlain by a soft brown clay with some turfa (stratum 2) below the regressive contact which is recorded at -2.32m OD. Immediately above this contact is a well-humified peat with some Phragmites, turfa, and occasional woody detritus (stratum 3), overlain by a dark brown or black turfa with some large pieces of wood and a Corylus nut at -2.30m OD (stratum 4). Planorbis spp. shells are recorded towards the base of this stratum, suggesting a high watertable and waterlogged conditions.

Samples of the lower inorganic deposit were analysed for their diatom content, and no diatoms were recorded. Pollen analysis, however, provides information concerning the nature of sedimentary changes associated with the onset of organic sedimentation. A herb and shrub-dominated environment characterises the early stages of organic sedimentation, with the presence of standing water suggested by high frequencies of Lemna (Fig.5.6, LPAZ MMON-a). Other aquatic taxa recorded in this LPAZ include Nymphaea, Potamogeton, and Typha angustifolia. Gramineae and Cyperaceae dominate the herb pollen, with Corylus averaging c. 35% TLP. The base of this zone contains rare saltmarsh indicators, with occasional grains of Aster-type and Chenopodiaceae suggesting that the underlying inorganic sediments may have accumulated under brackish/marine conditions. The regressive contact at -2.32m OD has been dated to 4570±140 BP.

The presence of a Corylus nut at -2.30m OD combined with the high pollen frequencies of this taxa indicate that Corylus must have formed an important component of the local vegetation cover. However, given the close proximity of the site to the valley edge, separating local valley floor from valley side pollen is difficult. The presence and co-variance of Thelypteris palustris with Corylus suggest that they grew in conjunction, although the latter is normally associated with alder-carr (see above).

A progressive reduction in the height of the watertable is suggested by the decline in frequencies of Lemna and other aquatic taxa through LPAZ MMON-a, and by a change in the lithostratigraphy above -2.25m OD to a dark brown or black well-humified peat with some Phragmites and turfa (stratum 5). LPAZ MMON-b sees a further decline in frequencies of Lemna and other aquatic taxa, the replacement of Gramineae by Cyperaceae, and a brief increase in the frequencies of Filicales. These changes are interpreted as a reflection of the continuing drying of the peat surface during this period.

Conditions change once more during LPAZ MMON-c, with a reduction in the frequencies of Filicales and the replacement of Cyperaceae by Gramineae as the dominant herb. This zone may represent the beginning of wetter conditions, with a slight increase in frequencies of Lemna, Typha angustifolia, Thalictrum, and the onset of a rise in frequencies of Alnus being recorded. Frequencies of herb pollen fall in LPAZ MMON-d, as Alnus frequencies expand to 45% TLP at -1.81m OD, and those of Tilia also increase to c. 10-20% TLP. Frequencies of Filicales fluctuate in this LPAZ zone between c. 7-30% TLP.

Piggott and Huntley (1980) have observed that in north-west England _Tilia_ will tolerate some dampness, but definitely prefers drier conditions. Waller (1987 :264) has noted that in LPAZ PB3A at Pannel Bridge, _Corylus_ was replaced by _Tilia_, and suggested that

> "the rise in _Tilia_ may (given the poor dispersal of lime pollen) be the result of a decline in the fringe of hazel dominated woodland around the site, though alder carr might subsequently be expected to have a similar effect. _Tilia_ is shade tolerant and considered (Pigott 1975) to be characteristic of undisturbed woodland, it would not be expected to colonise open areas".

In this situation alder is seen to replace _Corylus_, and given the poor dispersal characteristics of _Tilia_, the increase in _Tilia_ may represent inwashing from the adjacent slopes.

The increase in tree pollen frequencies recorded here is a rare feature in other pollen diagrams constructed from the study area. Of the tree pollen, changing frequencies of _Alnus_, _Quercus_ and _Pinus_ and _Tilia_ have been used by a number of authors to identify changes in the altitude of the watertable. Godwin and Clifford (1938) and Godwin (1940), for example, used changes in the frequencies of _Quercus_ and _Alnus_ to determine wetter and drier periods during peat growth. They proposed that under dry periods alder fens develop, whilst during wetter periods these are destroyed by the rising watertable and the regional pollen rain characterised by _Quercus_ is seen to increase. Furthermore, local alder fen can be replaced by the development of local oak fen under drier conditions, and therefore alternating frequencies of _Alnus_ and _Quercus_ can occur under both rising and falling watertable conditions (Shennan 1980 :170).

In the current study the general absence of tree pollen preclude their use in the detailed analysis of watertable movements. However, in LPAZ MMON-d the rise in Alnus frequencies does appear to reflect the beginning of a progressive increase in the altitude of the watertable, although the absence of significant frequencies of Quercus restrict the use of the Alnus-Quercus model.

Rising groundwater conditions appear to persist, eventually destroying the Alnus in LPAZ MMON-e. In contrast, frequencies of herb pollen increase in this LPAZ, with Chenopodiaceae gradually rising from 2 to 18% TLP by the transgressive contact. Lemna frequencies increase at the base of this zone (>10% TLP), as a prelude to the approaching marine conditions. Changes in the pollen record are not reflected by any lithostratigraphic changes. The opening of LPAZ MMON-e at -1.76m OD has been dated to 3980±140 BP. Immediately below the transgressive contact are recorded high frequencies of Gramineae, Cyperaceae, Chenopodiaceae, suggesting the proximity of saltmarsh conditions. The transgressive contact at -1.64m OD has been dated to 3550±140 BP.

Each LPAZ has been assigned a directional movement with respect to the altitude of the watertable in Table 6.10. below.

Table 6.10. Relative watertable movements for each LPAZ identified in MMON.

LPAZ	Depth (m OD)	Relative watertable movement
MMON-e	-1.75 to -1.65	+ve
MMON-d	-1.95 to -1.75	+ve
MMON-c	-2.07 to -1.95	?
MMON-b	-2.15 to -2.07	-ve
MMON-a	-2.29 to -2.15	-ve

6.7. Watertable changes identified at Hacklinge.

6.7.1. H-7 Upper organic deposit.

The litho and biostratigraphy of H-7 have been described above (Sections 5.2.4.1.), and three transgressive and two regressive contacts have been identified. Five samples were submitted to Professor R. Switsur at the Godwin Laboratory in the University of Cambridge in 1987, although the results of these assays are not yet available. The lower regressive contact is recorded at -4.76m OD, where a battleship-grey clay with some silt and Phragmites (stratum 1) is overlain by a brown turfa with some clay and woody detrital material (stratum 2). Detailed diatom analysis of this core was not completed, although a number of spot samples were analysed. A description of these data is included in the description of the pollen data where appropriate.

The lowermost diatom sample analysed suggests that stratum 1 accumulated under MB conditions with high frequencies of Raphoneis amphiceros, Actinophytus undulatus, and Nitzschia granulata (Long 1988). Pollen analysis immediately above the regressive contact (Fig.5.7.) indicates a Cyperaceae-, and then Gramineae-dominated environment with Aster-type and Chenopodiaceae taxa recorded, suggesting the local development of saltmarsh conditions (LPAZ H-7a). The opening of LPAZ H-7b sees an increase in the frequencies of aquatic taxa, notably Myriophyllum-type and Typha angustifolia. Gramineae frequencies fall in this LPAZ and are replaced by Cyperaceae, whilst there is an increase in tree pollen frequencies, notably Alnus, Betula, Tilia, and Corylus.

The biostratigraphic changes observed in LPAZs H-7a and H-7b are reflected by changes in the lithostratigraphy, where stratum 2 is replaced by an orange or brown clay with some turfa and small charcoal flecks (stratum 3). This stratum extends between -4.64 and -4.49m OD, which approximately coincides with the extent of LPAZ H-7b.

These litho- and biostratigraphic changes suggest a transition from a saltmarsh to wet freshwater environment, with pools of still or slowly moving water. The increase in tree pollen may reflect an increase in the regional tree pollen influx caused by a reduction in the local vegetation cover and the development of open- or semi-open water conditions. These changes appear to represent part of the fall in the watertable associated with the regressive contact.

Overlying stratum 3 is a black turfa containing some detrital wood (stratum 4). Pollen preservation in this deposit was poor (LPAZ H-7c), and frequencies of Gramineae rise to c. 90% TLP, whilst those of trees and shrubs fall sharply. At -4.18m OD, there is an isolated increase in the frequency of Typha angustifolia (to 64% TLP), which coincides with the registration of occasional saltmarsh taxa such as Aster-type, Atriplex-type and other Chenopodiaceae. These changes suggest that during LPAZ H-7c saltmarsh conditions may have developed once more, following the freshwater (and largely inorganic) sedimentation of LPAZ H-7b and stratum 3.

In the following LPAZ (H-7d) a lowering of the watertable is indicated by the replacement of Gramineae by Cyperaceae, a small expansion in tree pollen frequencies, and an increase in those of Filicales. Frequencies of aquatic taxa are low in this LPAZ. However, the proximity of saltmarsh conditions throughout this period (LPAZ H-7c and H-7d) is illustrated by the continued presence of low frequencies of Aster-type and other Chenopodiaceae.

Within LPAZ H-7e frequencies of Cyperaceae fall and are replaced by those of Gramineae and Quercus, indicating the approach of marine conditions. The transgressive contact was not sampled due to sampling error, and is recorded between -3.45 and -3.31m OD. The overlying inorganic deposit consists of a silty-clay with some Phragmites (strata 8 and 9), and two diatom samples analysed from within this deposit indicate that it accumulated under a mixed **M**, **MB**, **BM**, and **BZ** environment. Insufficient samples have been analysed to enable any detailed conclusion to be made concerning changes in salinity during the accumulation of this deposit.

Between -2.62m and -2.44m OD a thin Phragmites peat with some turfa is recorded. Pollen preservation within this deposit was extremely poor, but indicate that it accumulated under saltmarsh conditions. High frequencies of Gramineae and Cyperaceae are recorded, in addition to those of Chenopodiaceae and Aster-type. The transgressive contact of this deposit is recorded at -2.44m OD, where a soft silty-clay with some turfa is recorded (stratum 11).

Above stratum 11 a grey or brown silty-clay with some turfa (stratum 12) is recorded, which is in turn overlain by a dark brown turfa with some Phragmites (stratum 13). Diatom data from the base of stratum 12 indicates that it initially accumulated under a **M** environment, with high frequencies of Raphoneis nitida, and that later accumulated under a less saline **MB**, **BM**, and **B** environment. High frequencies of Diploneis didyma, Actinoptychus undulatus, Nitzschia punctata and Diploneis didyma are recorded towards the top of this zone, although the limited number of levels counted restrict any definite conclusions concerning within-strata changes in salinity.

The regressive contact is recorded at -2.04m OD, and pollen analysis from the base of stratum 13 indicates the establishment of a Gramineae/Cyperaceae-dominated environment, with some saltmarsh indicators such as Chenopodiaceae and Aster-type being recorded (LPAZ H-7f). A wet environment is suggested by the continued presence of Typha angustifolia and Typha latifolia in this LPAZ.

Predominantly organic sedimentation persists until -1.67m OD, where a slightly laminated silty-clay with some turfa and unidentified shells is recorded. This deposit has been divided into three strata (stratum 17, 18, and 19), which illustrate a fining-upwards sequence from a yellow silty-clay with shells (strata 17 and 18), to a soft and buttery slightly laminated silty-clay with some turfa and Phragmites (stratum 19). No pollen were recorded from within these strata, although two diatom samples indicate that the deposit accumulated under **BZ** or **Z** conditions. Frequencies of Synedra capita and Nitzschia amphibia, as well as rare occurrences of Paralia sulcata are recorded, indicating that the strata accumulated under an elevated fresh/brackish watertable.

Two pollen samples immediately above this lithostratigraphic unit taken from within a turfa with some Phragmites and rare unidentified shells (stratum 20), indicate sedimentation under a high (but falling) freshwater table. High frequencies of Gramineae, Typha angustifolia and Typha latifolia are recorded in this stratum (LPAZ H-7g). These data support the diatom and lithostratigraphic evidence for an elevation and subsequent fall in the watertable during this period.

Each LPAZ has been assigned a directional movement with respect to the altitude of the watertable in Table 6.11. below.

Table 6.11. Relative watertable movements for each LPAZ identified in H-7.

LPAZ	**Depth (m OD)**	**Relative watertable movement**
H-7g	-1.59 to -1.35	-ve/+ve
H-7f	-2.27 to -1.59	-ve
H-7e	-3.73 to -2.27	+ve/-ve
H-7d	-4.05 to -3.73	-ve
H-7c	-4.40 to -4.05	+ve

H-7b	-4.64 to -4.40	-ve
H-7a	-4.76 to -4.64	-ve

6.7.2. Hacklinge H-2(a, b).

Five regressive and four transgressive contacts have been identified at H-2(a,b). Pollen and diatom analysis have been completed on H-2(a) and H-2(b) respectively, providing a continuous record of sedimentation and watertable changes between c. -9.00m and OD.

6.7.3. H-2(b) Lower inorganic and organic deposit.

The deepest inorganic sediments recorded in H-2(b) consist of a dark grey clay with some detrital organic material between -9.01 and -8.96m OD. Diatom analysis of this deposit (Fig.5.13.) indicate that the deposit accumulated under a **M** or **B** depositional environment, with Nitzschia granulata and Paralia sulcata accounting for c. 34% and 17% TV respectively (LDAZ H-2(b)a). Of the **B** taxa, Nitzschia navicularis accounts for c. 24% TV, and this assemblage suggests a lower tidal mudflat or shallow subtidal depositional environment (Vos and de Wolf 1988), with only rare **BZ**, **ZB**, or **Z** taxa recorded. No significant changes in the diatom assemblage are apparent prior to the regressive contact, which is recorded in H-2(b) at -8.96m OD, and in H-2(a) at -8.97m OD.

Pollen analysis immediately above the regressive contact in H-2(a) (Fig.5.8.) indicates that a Quercus-dominated environment became established, with relatively high frequencies of Corylus and Gramineae recorded (LPAZ H-2(a)a). No clear saltmarsh transition is apparent immediately above the regressive contact. LPAZ H-2(a)a extends between -8.94 and -8.85m OD, above which a dramatic decrease in tree pollen occurs. Frequencies of Quercus fall from 63% to 11% TLP, whilst those of Corylus increase to 33% TLP. Of the herbs, Gramineae and Cyperaceae are recorded in low frequencies, in conjunction with rare grains of Aster-type, Atriplex-type, and Suaeda maritima (LPAZ H-2(a)b). These changes are paralleled by a change in the lithostratigraphy, with a well-humified clayey-peat (stratum 3), being replaced by a thin yellow laminated clay with some Phragmites at -8.87m OD (stratum 4). Pollen preservation in strata 4 and 5 (a thin dark brown or black laminated detrital peat with some Phragmites) was very poor, and the pollen sum for the uppermost sample counted in this LPAZ H-2(a)b is low.

No pollen was recorded in stratum 5, and the absence of aquatic taxa at this level suggest that the decline in frequencies of Quercus were not caused by changing hydrological conditions. However, the presence of saltmarsh taxa such as Aster-type and Atriplex-type indicate the proximity of saltmarsh conditions, and an alternative explanation for the changes in taxa recorded must be sought. The sharp boundary between stratum 3 and 4 (lim. sup. 3) suggest that either a period of erosion, or a sedimentary hiatus may have occurred prior to the deposition of stratum 4.

This transgressive contact is recorded in H-2(b) at -8.875m OD, where a dark grey clay with some detrital herbaceous material is recorded extending towards a regressive contact at -8.66m OD (stratum 5). The transgressive and regressive contacts have been dated to 6450±105 and 6445±170 BP respectively. Following the onset of inorganic deposition, diatom analysis (Fig.5.13.) illustrates that the inorganic sediments accumulated under a strong M environment, with high frequencies of Paralia sulcata and Nitzschia granulata being recorded (LDAZ H-2(b)b). Above -8.80m OD a strong M depositional environment persists (LDAZ H-2(b)c), with frequencies of Nitzschia granulata increasing to c. 55-65% TV. However, a freshening is apparent towards the top of this zone, with frequencies of Paralia sulcata falling, and those of Nitzschia navicularis gradually increasing to c. 40% TV. This reduction in salinity continues towards the regressive contact at -8.66m OD, with an increase in the frequency of Nitzschia punctata to 26% TV, and a further decline in frequencies of **M** taxa (LDAZ H-2(b)d). Only rare occurrences of **BZ**, **ZB**, or **Z** taxa are recorded immediately below the regressive contact.

In H-2(a) this regressive contact is recorded at -8.60m OD, where a soft buttery clay with some woody detrital material (stratum 6) is replaced by a laminated black detrital peat with some well-humified turfa (stratum 7). Pollen preservation in the lower part of this deposit was too poor to enable counting, and the lowermost sample counted at -8.51m OD (Fig.5.8.) indicate that a Gramineae-dominated environment with some saltmarsh indicators such as Chenopodiaceae and Aster-type became established. Frequencies of Gramineae decline in LPAZ H-2(a)c from 74% to 39% TLP, whilst those of Quercus increase to >20% TLP, and aquatic taxa (dominated by Typha angustifolia) increase to 33% TLP. The changes of the latter group reflect the progressive reduction in altitude of the watertable associated with the regressive contact.

Lithostratigraphic data indicate the replacement of a laminated woody detrital peat between -8.41 and -8.48m OD (stratum 8) by a black laminated and well-humified peat with some clay (stratum 9). This increase in humification, combined with an expansion in frequencies of Cyperaceae and a rise in those of Thelypteris palustris and Filicales may suggest a reduction in the altitude of the watertable (LPAZ H-2(a)c). An alternative possibility is that wetter conditions persisted, and that the increase in frequencies of ferns reflect inwashing associated with the elevated watertable. This is supported by the presence of some clay, as well as the increase in frequencies of Nympheae and Typha latifolia in this LPAZ, - both of which prefer standing water (unlike Typha angustifolia which prefers shallower water). Accordingly no clear directional movement has been assigned to this LPAZ.

In LPAZ H-2(a)e frequencies of both aquatic taxa and ferns fall sharply, and the dominance of Cyperaceae suggests the local development of a dense sedge environment. Because there is no clear evidence for the direction of watertable movements in the preceding LPAZ, assigning an directional movement to LPAZ H-2(a)e is difficult. However, the increase in ferns in the succeeding LPAZ, and the absence of aquatic taxa suggest that LPAZ H-2(a)e may represent a transitional stage between the wet environment of LPAZ H-2(a)d and H-2(a)c and the drier environment of LPAZ H-2(a)f. Frequencies of Cyperaceae continue to dominate in LPAZ H-2(a)f, although there is a sharp increase in the frequencies of Filicales and Thelypteris palustris to c. 75% TLP. These changes, combined with the absence of aquatic taxa in this LPAZ, suggest that a drying of the peat surface occurred during the accumulation of this LPAZ.

Pollen preservation between -7.93 and -7.81m OD was too poor to enable counting, suggesting that aerobic conditions associated with a lowering of the watertable persisted. At -7.80m OD pollen preservation improved, and a Gramineae-dominated environment with some Cyperaceae and low frequencies of aquatic taxa and those of ferns and spores being recorded. Above -7.71m OD pollen preservation was again poor, and pollen analysis could not be used to establish the sedimentary changes associated with the transgressive contact at -7.50m OD. The lithostratigraphy indicates a well oxidised and humified peat with some Phragmites (stratum 13). This transgressive contact is recorded in H-2(b) at -7.56m OD, although sampling error has meant that this contact had not been dated at the time of writing.

Each LAZ has been assigned a directional movement with respect to the altitude and salininty of the watertable in Table 6.12. below.

Table 6.12. Relative watertable movements for each LAZ identified in the lower inorganic and organic deposits recorded in H-2(a) and H-2(b).

LDAZ	LPAZ	Depth (m OD)	Relative watertable movement
	H-2(a)g	-7.87 to -7.72	+ve
	H-2(a)f	-8.04 to -7.87	-ve
	H-2(a)e	-8.14 to -8.04	?
	H-2(a)d	-8.20 to -8.14	?
	H-2(a)c	-8.68 to -8.20	-ve
H-2(b)d		-8.67 to -8.66	-ve
H-2(b)c		-8.81 to -8.67	?
H-2(b)b		-8.89 to -8.81	+ve
	H-2(a)b	-8.85 to -8.68	+ve
	H-2(a)a	-8.94 to -8.85	-ve
H-2(b)a		-9.00 to -8.89	-ve

6.7.4. H-2(b) Middle inorganic deposit.

Diatom analysis was not possible immediately above the transgressive contact due to sampling error, but above -7.56m OD a strong **M** depositional environment with high frequencies of Paralia sulcata (c. 40-50% TV) and Nitzschia granulata is apparent (Fig.5.14.). M taxa collectively account for c. 60% TV in LDAZ H-2(b)e, and these strongly marine depositional conditions persist until -7.00m OD. At -7.00m OD a significant freshening of the depositional environment is indicated with a sharp decline in frequencies of Paralia sulcata and an increase in the frequencies of Nitzschia navicularis and Nitzschia parvula (LDAZ H-2(b)f). The latter increases to a high of 37% TV at -6.86m OD, and no lithostratigraphic change is apparent over this biostratigraphic boundary.

Sampling error meant that no material was collected between -6.68 and -6.47m OD. Above -6.47m OD there is a sharp decline in frequencies of Nitzschia parvula (LDAZ H-2(b)g). This LDAZ sees an initial increase in salinity, with a fall in the frequencies of Nitzschia navicularis to 18% TV at -6.38m OD, and a rise in the frequencies of Paralia sulcata to 54% TV at the same level. By the opening of LDAZ H-2(b)h however, Nitzschia navicularis is re-established as the dominant taxa, whilst frequencies of Paralia sulcata fall once more. LDAZ H-2(b)h sees a reduction in salinity as frequencies of Nitzschia navicularis rise to >60% TV, and those of Paralia sulcata fall to <20% TV. Frequencies of Nitzschia granulata increase in this LDAZ, and continue to rise in LDAZ H-2(b)i. This LDAZ sees an increase in M influence as frequencies of Nitzschia navicularis decrease and are replaced by those of Paralia sulcata once more.

Above -5.30m OD a slight coarsening is recorded, with a battleship-grey silty-clay with some detrital herbaceous material (stratum 4) passing into a battleship-grey clay with some organic material (stratum 5). This change coincides with a further decline in the frequencies of Nitzschia navicularis and an increase in M taxa to 86% TV by -5.08m OD (LDAZ H-2(b)j). Above stratum 5 a fining of the sediment is observed, with a soft battleship-grey clay with some turfa (stratum 6) which extends to the regressive contact at -4.59m OD. This change in lithostratigraphy coincides with the opening of LDAZ H-2(b)k at -4.94m OD, in which frequencies of Paralia sulcata fall sharply. This decline in M taxa represents the onset of a freshening in depositional conditions which continues until the regressive contact at -4.55m OD. Frequencies of MB taxa increase, with Diploneis didyma rising to a high of 20% TV at -4.72m OD. B taxa also increase with frequencies of Nitzschia navicularis falling, but those of Caloneis fasciata rising to 21% TV at -4.68m OD.

The uppermost LDAZ (H-2(b)l) indicates a further freshening in depositional conditions, with **M** taxa being replaced by **B** taxa, notably Nitzschia navicularis which increases to 67% TV immediately below the regressive contact. There are no significant frequencies of **BZ**, **ZB**, or **Z** taxa recorded immediately below the regressive contact, which has been dated to 4890±130 BP.

Each LDAZ has been assigned a directional movement with respect to the altitude and salinity of the watertable in Table 6.13. below.

Table 6.13. Relative watertable movements for each LDAZ identified in the middle inorganic deposit - H-2(b).

LPAZ	Depth (m OD)	Relative watertable movement
H-2(b)l	-4.67 to -4.64	-ve
H-2(b)k	-4.94 to -4.67	-ve
H-2(b)j	-5.26 to -4.94	+ve
H-2(b)i	-6.04 to -5.26	+ve
H-2(b)h	-6.27 to -6.04	-ve
H-2(b)g	-6.58 to -6.27	?
H-2(b)f	-7.00 to -6.58	-ve
H-2(b)e	-7.54 to -7.00	+ve

6.7.5. H-2(a, b) Upper organic and inorganic deposit.

In H-2(a) the regressive contact described above is recorded at -4.87m OD, where a dark grey silt with some detrital wood (stratum 21) is overlain by a black Phragmites-peat with some detrital herbaceous material and Phragmites (stratum 22). Pollen analysis immediately above the regressive contact (Fig.5.9.) indicates that a Gramineae-dominated environment became established, with rare grains of Chenopodiaceae and Aster-type suggesting the proximity of saltmarsh conditions

(LPAZ H-2(a)h).

At -4.71m OD the lithostratigraphy changes to a yellow or brown clayey-peat with occasional white flecks, which may be broken shells (stratum 23). Overlying this is a yellow or brown slightly clayey detrital peat with some turfa and unidentified shells (stratum 24) which extends from -4.66 to -4.54m OD. This change in lithostratigraphy is reflected by a change in the pollen assemblage with the opening of LPAZ H-2(a)i. This LPAZ extends from -4.80 to -4.55m OD, and is characterised by high frequencies of aquatic taxa, and by a decline in those of Gramineae. At the base of the zone frequencies of Potamogeton and Typha angustifolia increase, so that the combined aquatic taxa total 69% TLP. At -4.71m OD these aquatic taxa fall, but in the two succeeding samples they increase once again, with Lemna, Potamogeton, and Typha angustifolia and Typha latifolia being dominant. These changes appear to indicate a high but fluctuating watertable which eventually decreases towards the top of LPAZ H-2(a)i as the peat surface dries.

In LPAZ H-2(a)j frequencies of aquatic taxa and Gramineae decline, whilst those of Cyperaceae increase to >50% TLP. The associated rise in the frequencies of Filicales which continues in the next LPAZ (H-2(a)k) also indicate a progressive reduction in the altitude of the watertable.

This trend continues in LPAZ H-2(a)k, with a decline and subsequent rise in frequencies of Cyperaceae, and the continued expansion of Filicales. The lack of aquatic taxa in this zone suggest a drying of the peat surface, although the increase of Alnus to a high of 34% TLP at -4.19m OD, combined with the woody lithostratigraphic record, suggests that alder-carr may have been established at, or near to the site at this time. Under these circumstances Filicales may have co-existed with the alder carr.

Frequencies of Cyperaceae fall sharply above -3.96m OD, and the fall of Filicales and the increase in Gramineae delimit the opening of LPAZ H-2(a)l. A wetter environment is suggested by the fall in Filicales frequencies, and the isolated peak in Alnus at -3.86m OD suggests the development of in situ alder carr. Above this level, frequencies of Alnus decline, perhaps because of the rising groundwater conditions indicated by the expansion of aquatic taxa above -3.81m OD. Frequencies of Lemna, Potamogeton, and Typha angustifolia increase to a high of 45% TLP at -3.81m OD and subsequently decline as those of Gramineae increase. The presence of Aster-type and Chenopodiaceae suggest the proximity of saltmarsh conditions throughout LPAZ H-2(a)l.

Between -3.68 and -3.29m OD sampling error has resulted in a break in the stratigraphic record. The opening of LPAZ H2(a)m sees a decline in aquatic taxa, ferns and spores, and the dominance of Gramineae and Cyperaceae. The close proximity of saltmarsh conditions throughout this zone is indicated by high frequencies of Chenopodiaceae, which commonly exceed 5% TLP, and the presence of rare grains of Aster-type and Atriplex-type.

The transgressive contact is recorded at -3.14m OD in H-2(a), and at -3.28m OD in H-2(b), where it has been dated to 3905±205 BP. Here a soft grey clay with some Phragmites and unidentified shells (stratum 3) was recorded extending to a thin brown clay-rich turfa at -2.91m OD (stratum 4). Diatom analysis (Fig.5.15.) indicates that stratum 3 accumulated under a mixed **M**, **MB**, **BM** and **B** environment (LDAZ H-2(b)m). **MB** taxa are dominated by Diploneis didyma (13-28% TV) and **B** taxa by high frequencies of Nitzschia navicularis (c. 35-40% TV), suggesting a low intertidal environment. Above -2.95m OD there is a progressive increase in frequencies of **ZB** taxa which account for 24% TV at -2.91m OD, largely reflecting an increase in frequencies of Synedra capita.

The thin organic deposit recorded in H-2(b) between -2.91 and -2.87m OD is considerably thicker in H-2(a). Here the regressive contact is at -2.80m OD, where a yellow <u>turfa</u> with some clay and <u>Phragmites</u> is recorded overlying a grey or brown <u>Phragmites</u>-rich clay deposit (stratum 33). Pollen analysis immediately above the regressive contact (Fig.5.9.) indicates a Gramineae and Cyperaceae-dominated environment, with Chenopodiaceae and <u>Aster</u>-type suggesting the close proximity of saltmarsh conditions throughout LPAZ H-2(a)m. Sampling error has meant that the transgressive contact was not sampled in H-2(a), and between -2.21m and -2.16m OD a soft grey clay with some <u>turfa</u> (stratum 36) is recorded. This stratum is comparable with strata 5 and 6 of H-2(b).

Diatom data collected above this transgressive contact in H-2(b) indicate a progressive increase in salinity (LDAZs H-2(b)n and H-2(b)m), with a decrease in the frequency of <u>Nitzschia navicularis</u> as the frequencies of **M** taxa increase. Frequencies of <u>Paralia</u> <u>sulcata</u> rise to 63% TV at -2.58m OD, which also indicating the increase in salinity following the end of peat accumulation. However, **M** taxa decline sharply with the opening of LDAZ H-2(a)p, as frequencies of <u>Paralia</u> <u>sulcata</u> fall to >10% TV, suggesting a freshening of the depositional environment. This fall in **M** taxa sees the establishment of a mixed salinity assemblage, with **MB**, **BM**, **B** and **Z** taxa recorded. In particular, high frequencies of <u>Diploneis</u> <u>didyma</u>, <u>Scoliopleura</u> <u>turmida</u>, <u>Nitzschia</u> <u>navicularis</u> and <u>Diploneis</u> <u>ovalis</u> are recorded. This assemblage suggests a mixing typical of estuarine depositional conditions. The opening of LDAZ H-2(b)p at -2.56m OD indicates the onset of the reduction in salinity prior to the regressive contact.

The uppermost LDAZ (H-2(b)q) is characterised by a further reduction in salinity, with an increase in frequencies of **ZB** taxa, notably those of <u>Synedra</u> <u>capita</u>, which rise to 35% TV below the regressive contact. Frequencies of **MB** taxa remain constant, whilst those of **M**, **BM**, and **B** taxa fall slightly.

This represents the final reduction in salinity before the regressive contact at -2.38m OD, which has been dated to 2400±230 BP.

Pollen analysis immediately above this contact indicates a Gramineae- and Cyperaceae-dominated environment became established (H-2(a)n). No saltmarsh indicators are associated with this contact, although frequencies of Filicales increase to 17% TLP at -1.91m OD, suggesting a slight drying of the peat surface may have occurred, although frequencies of aquatic taxa remain unchanged.

Finally, towards the top of LPAZ H-2(a)n there is evidence for an increase in the altitude of the watertable, with frequencies of Typha angustifolia increasing to c. 10% TLP, and those of herb pollen increasing to >98% TLP. The lithostratigraphy indicates the replacement of brown Phragmites-rich peat with some turfa by a yellow or brown clay-rich shell marl with some turfa at -1.71m OD which also suggests an elevation of the watertable occurred during this LPAZ.

Each LPAZ has been assigned a directional movement with respect to the altitude and salinity of the watertable in Table 6.14. below.

Table 6.14. Relative watertable movements for each LAZ identified in the upper organic and inorganic sediments - H-2(a, b).

LDAZ	LPAZ	Depth (m OD)	Relative watertable movement
	H-2(a)n	-2.24 to -1.67	-ve then +ve
H-2(b)q		-2.44 to -2.42	-ve
H-2(b)p		-2.56 to -2.44	-ve
H-2(b)o		-2.67 to -2.56	+ve
H-2(b)n		-2.89 to -2.67	-ve
H-2(b)m		-3.39 to -2.89	+ve
	H-2(a)m	-3.52 to -2.24	+ve/-ve
	H-2(a)l	-4.00 to -3.52	+ve
	H-2(a)k	-4.37 to -4.00	-ve
	H-2(a)j	-4.55 to -4.37	-ve
	H-2(a)i	-4.80 to -4.55	-ve
	H-2(a)h	-4.85 to -4.80	-ve

Chapter Seven: Holocene watertable movements from the East Kent Fens - Intra-site and inter-site scales.

7.1. Introduction.

The evidence for Holocene watertable movements at the site-scale has been discussed in Chapter Six. The next scale of analysis is to determine the significance of these changes by assessing the degree of intra- and inter-site consistency in the watertable record. An analysis of the three main variables used in this study - altitude, age and indicative meaning, enables this assessment. Finally, the evidence for late-Holocene sedimentation recorded in the Hacklinge/Deal area is placed within the context of the wider sedimentary changes recorded within the former Wantsum Channel. This serves to emphasise the need for a three-dimensional approach to the analyses and interpretation of litho-, bio-, and chronostratigraphic data.

7.2. Intra-site variability in watertable changes.

In order to assess the degree of intra-site variability in the current study, the pollen content of the upper organic deposit at each of the sites studied was analysed at two locations. No intra-site comparison of the inorganic sediments was attempted. At both Hacklinge and Marsh Lane a centre and an edge of valley location were selected for comparison. At Sandfield Farm two piston cores (SF-10 and SF-4) were analysed which were 200m apart and located towards the centre of the valley. This analysis was designed to assess the detailed spatial variability in the watertable record from a centre of valley location.

7.2.1. Sandfield Farm.

The directional movement assigned to each LPAZ identified in the upper organic deposit in SF-10 and SF-4 are compared in

Table 7.1. below.

<u>Table 7.1. Relative watertable movements for each LPAZ identified in the upper organic deposit in SF-10 and SF-4.</u>

SF-10 LPAZ	Depth (m OD)	Relative watertable movement	SF-4 LPAZ	Depth (m OD)	Relative watertable movement
j	-1.99 to -1.94	+ve	e	-2.56 to -2.53	+ve
i	-2.01 to -1.99	+ve	d	-2.61 to -2.56	+ve
h	-2.21 to -2.01	?	c	-2.73 to -2.61	?
g	-2.30 to -2.21	-ve	b	-2.83 to -2.73	-ve
f	-2.38 to -2.30	-ve	a	-3.02 to -2.83	-ve

The close agreement between the two sites enables the pattern of watertable changes associated with the formation of the upper organic deposit at this site to be determined with some confidence.

Following the onset of organic accumulation at <u>c</u>. 4600 BP a Gramineae/Cyperaceae environment became established, and a falling watertable led to the drying of the peat surface. This is indicated by the increase in frequencies of Filicales in LPAZs SF-10g and SF-4b. Towards the top of these LPAZs, a small increase in the frequencies of aquatic taxa is recorded, which is more pronounced in SF-4 than SF-10. This increase in aquatic taxa coincides with an increase in tree pollen at both sites, and in particular by an increase in the frequencies of <u>Alnus</u>. The rise of <u>Alnus</u> towards the top of LPAZ SF-10g and SF-4b may reflect the slight elevation of the watertable identified above, and which may have also caused the decline in frequencies of Filicales. Although these changes are small, their occurrence in both cores gives more confidence to their identification.

LPAZs SF-10h and SF-4c indicate that a moist Gramineae-dominated environment became established, with the _in situ_ development of _Phragmites_ reedswamp occurring. LPAZs SF-10i and SF-4d both suggest that an elevation of the watertable affected the site, with standing or slowly moving water indicated by the increase in frequencies of _Lemna_, _Potamogeton_, _Typha angustifolia_ and _Typha latifolia_. This increase in the height of the watertable occurred at _c_. 4100 BP. At SF-4 freshwater conditions appear to have persisted for a longer period than at SF-10, for at the latter the re-colonisation of the site by Gramineae occurred fairly rapidly (LPAZ SF-10j). At SF-4 the increase in tree and shrub pollen frequencies in LPAZ SF-4e may reflect the more open environment which persisted before the transgressive contact.

7.2.2. Marsh Lane.

In contrast to Sandfield Farm, these two sites represent a centre and edge of valley location. The watertable movement assigned to each LPAZ identified in ML-9 and MMON are presented in Table 7.2. below.

Table 7.2. Relative watertable movements for each LPAZ identified in the upper organic deposit at ML-9 and MMON.

ML-9 LPAZ	Depth (m OD)	Relative watertable movement	MMON LPAZ	Depth (m OD)	Relative watertable movement
j	-2.58 to -2.56	?	e	-1.75 to -1.65	+ve
i	-2.64 to -2.58	+ve	d	-1.95 to -1.75	+ve
h	-2.80 to -2.64	?	c	-2.07 to -1.95	?
g	-2.92 to -2.80	-ve	b	-2.15 to -2.07	-ve
f	-2.98 to -2.92	-ve	a	-2.29 to -2.15	-ve

Although the vegetation record varies between the sites, the sequence of relative watertable movement assigned to each LPAZ are almost directly comparable. The onset of organic accumulation at ML-9 indicates a fall in the watertable, with saltmarsh conditions being replaced by a wet freshwater reedswamp characterised by high frequencies of Gramineae (LPAZ ML-9f). At MMON the onset of organic accumulation is dated to 4570±140 BP, and here far wetter conditions are recorded, with high (but declining) frequencies of Lemna in LPAZ MMON-a, and the possible development of an in situ hazel wood. Frequencies of Thelypteris palustris are high in this zone, also suggesting a damp shady environment. The watertable is clearly falling, however, with the progressive decline in frequencies of Lemna and Thelypteris palustris, and the increase in frequencies of Cyperaceae at the opening of LPAZ MMON-b.

The pollen record suggests that dense local herb and grass communities dominated the early period of organic accumulation in ML-9. The lowering of the watertable associated with the regressive contact sees a decline in the frequencies of Gramineae, a rise in those of Cyperaceae, and a slight increase in those of Filicales. The increase in frequencies of Filicales and Cyperaceae is far more pronounced in LPAZ MMON-b, where the former exceed 125% TLP before both decline with the opening of LPAZ MMON-c. These changes coincide with an increase in frequencies of Gramineae and Alnus, and this may suggest a slight elevation of the watertable. A small increase in the frequencies of Lemna is recorded at the opening of the LPAZ MMON-c supporting this suggestion. In the centre of the valley, frequencies of Cyperaceae are also seen to fall, and are replaced by those of Gramineae (LPAZ ML-9h).

At the valley margin, the opening of LPAZ MMON-d sees a more pronounced expansion of Alnus, which rises to >40% TLP. Frequencies of Gramineae and Cyperaceae are low, and the high frequencies of Alnus pollen and the macroscopic remains of wood recorded in the lithostratigraphic record suggest the development of a local alder-carr. This expansion and the subsequent decline of Alnus frequencies may be related to a progressive increase in the height of the watertable, which is also recorded in the centre of the valley by an increase in the frequency of aquatic taxa in LPAZ ML-9i. Here a sharp rise in the frequencies of Lemna and Chenopodiceae suggest an elevation of the watertable and the proximity of saltmarsh conditions.

At ML-9 the increase in frequencies of Lemna occurs as a prelude to the approaching marine/estuarine conditions recorded at -2.56m OD, where the transgressive contact has been dated to 4105±130 BP. The valley-edge vegetation also reflects the continuing rise in the watertable, with the swamping and destruction of the alder-carr, and a small increase in the frequencies of Lemna recorded at the opening of LPAZ MMON-e. The opening of LPAZ MMON-e has been dated to 3980±140 BP which is slightly younger than the date of the transgressive contact in the centre of the valley. Frequencies of Gramineae and Chenopodiaceae increase, indicating the development of an in situ saltmarsh peat prior to the transgressive contact recorded at -1.64m OD. Although the transgressive contact is dated to 4105±130 BP in ML-9, at MMON it is not recorded until 3550±140 BP. Thus, at MMON saltmarsh conditions persisted for a minimum of 300 ^{14}C years (allowing for the standard errors) before inorganic finally replaced organic sedimentation.

7.2.3. Hacklinge.

The watertable movement assigned to each LPAZ identified in the upper organic deposit recorded in H-7 and H-2(a) are presented in Table 7.3. below.

Table 7.3. Relative watertable movements for each LPAZ identified in H-7 and H-2(a).

H-7 LPAZ	Depth (m OD)	Relative watertable movement	H-2(a) LPAZ	Depth (m OD)	Relative watertable movement
g	-1.59 to -1.35	-ve/+ve	n	-2.24 to -1.67	-ve/+ve
f	-2.27 to -1.59	-ve			
			m	-3.52 to -2.24	+ve/-ve
e	-3.73 to -2.27	+ve/-ve	l	-4.00 to -3.52	+ve
d	-4.05 to -3.73	-ve	k	-4.37 to -4.00	-ve
c	-4.40 to -4.05	+ve	j	-4.55 to -4.37	-ve
b	-4.64 to -4.40	-ve	i	-4.80 to -4.55	-ve
a	-4.76 to -4.64	-ve	h	-4.85 to -4.80	-ve

The sequence presented above show some differences between the two sites, although a closer analysis of the data within each LPAZ indicates a more similar pattern of watertable movements than is immediately apparent.

The regressive contact is recorded at -4.77m OD and -4.88m OD in H-7 and H-2(a) respectively. In both of these sites a Gramineae/Cyperaceae-dominated environment with some saltmarsh indicators became established immediately above the regressive contact (LPAZs H-7a and H-2(a)h). This occurred at 4890±130 BP in H-2(b), and following a saltmarsh transition, a wet freshwater environment became established at both sites. This is reflected in the litho- and biostratigraphy by the accumulation of a yellow or brown clayey-peat, and by an increase in aquatic taxa (LPAZs H-7b and H-2(a)i).

Wet conditions appear to persist longer at the edge of the valley (H-2(a)), with high frequencies of Potamogeton, Lemna, Ranunculus-type, Typha angustifolia and Typha latifolia indicating standing or slowly moving water. At H-7 a wet sedge environment became established (LPAZ H-7b), with high frequencies of Myriophyllum-type and Typha angustifolia. The presence of Alnus and Quercus at the base of this LPAZ suggest the local development of an oak-alder fen.

At H-7 the opening of LPAZ H-7c suggests an approach of saltmarsh conditions. Gramineae frequencies rise sharply, with the replacement of the wet Cyperaceae environment of LPAZ H-7b by saltmarsh conditions. This is illustrated by a peak in the frequencies of Typha angustifolia at -4.17m OD, which coincides with the recording of a number of saltmarsh taxa such as Aster-type, Atriplex-type, and other Chenopodiaceae. At H-2(a) however, there is no indication of approaching saltmarsh conditions. Whether the changes recorded in LPAZ H-7c represent a significant increase in the altitude of the watertable, or the operation of local processes is equivocal.

The absence of any comparable changes in the pollen record at H-2(a) indicates that the change in the height of the watertable was not large enough to be recorded at this site. Before the ^{14}C dates were available, it appeared that these changes may have been a reflection of the increase in the marine influence recorded at the down-valley sites with the accumulation of the upper inorganic deposit. However, the ^{14}C dates indicate that the deposition of the upper inorganic deposit in the down-valley sites was penecontemporaneous (c. 4000 BP) with that recorded at H-2(b). A lowering of the watertable is indicated at these down-valley sites between c. 4600 BP and c. 4000 BP, and therefore it is unlikely that the changes observed in LPAZ H-7c represent a significant increase in the altitude of the watertable. It is more likely that they represent an increase in proximity of a small brackish/ marine channel, although such a feature is not recorded in the lithostratigraphic record.

The opening of LPAZs H-7d and H-2(a)j both indicate a relative lowering of the watertable and a drying of the peat surface. This is suggested by an increase in the frequencies of Cyperaceae, and by a small increase in those of Filicales. At H-7 frequencies of Filicales are low (LPAZ H-7d), whilst at H-2(a) they continue to rise to >45% TLP by the top of LPAZ H-2(a)k.

The expansion of Alnus frequencies in LPAZ H-2(a)k suggest the development of alder-carr at or near to the site, and the in situ development of alder carr is apparent in LPAZ H-2(a)l, where a definite wetting of the peat surface occurs. At H-7 this change may be illustrated by the replacement of Cyperaceae by Gramineae, and by a small increase in the frequencies of Chenopodiaceae and Typha angustifolia in the base of LPAZ H-7e.

It appears that the watertable continued to rise towards the transgressive contact, which at H-7 was recorded in LPAZ H-7e, between -3.45 and -3.31m OD. At H-2(a) the approaching saltmarsh conditions are indicated by an increase in the frequencies of Gramineae in LPAZ H-2(a)l. The frequencies of aquatic taxa also increase, notably those of Potamogeton, Lemna, and Typha angustifolia, and then decrease as saltmarsh conditions became established immediately below the transgressive contact at -3.15m OD. This transgressive contact has been dated in H-2(b) to 3905±205 BP.

Above this transgressive contact inorganic sedimentation persisted at both sites until a further regressive contact recorded at -2.62m OD and -2.81m OD in H-7 and H-2(a) respectively. Pollen analysis from the overlying organic deposit illustrates that a Gramineae and Cyperaceae environment became established (LPAZs H-7e and H-2(a)n), with the close proximity of saltmarsh conditions indicated by the continued presence of Chenopodiaceae and Aster-type at both sites. The transgressive contact of this deposit in H-7 is recorded at -2.44m OD and between -2.28 and -2.21m OD in H-2(a) (note sampling error). This organic deposit was considerably thinner in the piston-core H-2(b), and was not dated. Inorganic sedimentation was recorded above this organic deposit until a regressive contact recorded at -2.04m OD in H-7 and -2.17m OD in H-2(a) respectively.

Following the onset of organic sedimentation at 2400±230 BP, pollen analysis indicate that at H-2(a) and H-7 the watertable fell, with frequencies of aquatic taxa at H-7 (notably _Typha angustifolia_ and _Typha latifolia_) decreasing as a Gramineae-dominated environment with some Filicales became established (LPAZ H-7f). A comparable pattern of vegetation changes is recorded at H-2(a), where frequencies of Filicales increase (the opening of LPAZ H-2(a)n). During the latter period of organic sedimentation a final elevation of the watertable is apparent with the expansion of _Typha angustifolia_ in LPAZ H-7g which is coincidental with the deposition of a shell marl recorded in the lithostratigraphy at most sites.

7.3. Assessment of intra-site variability.

Intra-site analyses were attempted in order to assess the detailed spatial variability in the pollen record at a site scale. This assessment is made with reference to the variability apparent in altitude, age and indicative meaning.

7.3.1. Altitude.

Altitudinal differences at an intra-site scale indicate that deposits which accumulated penecontemporaneously are presently recorded at significantly different altitudes. The simplest way to illustrate this is to compare the altitude of the transgressive and regressive contacts of the upper organic deposit for each site (Table 7.4.).

__Table 7.4. Altitude of transgressive and regressive contacts of the upper organic deposit.__

Core	Regressive contact (metres OD)	Transgressive contact (metres OD)
SF-10	-2.38	-1.91
SF-4	-3.03	-2.52
ML-9	-3.02	-2.56
MMON	-2.32	-1.64
H-7	-4.76	?
H-2(a)	-4.87	-3.14

The biggest altitudinal discrepancy between the equivalent contacts at the site-scale is at Marsh Lane (0.71m and 0.92m respectively). The ^{14}C dates from this site indicate that the transgressive contact in MMON is _c_. 300 ^{14}C years younger than in ML-9 and the diachronous nature of this contact may explain part of the altitudinal difference observed. Data for determining the age of the regressive contacts at Marsh Lane are not available due to the age reversal at ML-9 discussed above. At Sandfield Farm the differences in altitude of the regressive and transgressive contacts are 0.65m and 0.61m respectively. At Hacklinge the difference in the former is 0.10m whilst data for the latter are not available due to sampling error.

Larger changes in the altitude of biostratigraphic horizons have been identified by Waller _et al_ (1988). Here a comparison of the altitude of the _Tilia_ decline at Brede Bridge indicated that it was recorded at +0.04m OD near the valley side, and -1.67m OD in the centre of the valley. Altitudinal differences are discussed in more detail in Section 7.5.1. below.

7.2.2. Age.

Establishing any differences in the age of the upper organic deposit is possible only at Marsh Lane. Here the difference in the age of the transgressive contact is at least 300 ^{14}C years. There appears to be large intra-site variability in the age of the transgressive contacts recorded at Marsh Lane, although the database is too small to enable an accurate assessment of this variability.

7.2.3. Indicative meaning.

Within each site a similar sequence of inferred watertable movements is apparent, irrespective of the core's position in the valley. One clear exception to this is LPAZ H-7c which is not recorded in H-2(a), and it has been suggested that this LPAZ probably reflects the operation of local processes.

To a degree the taxonomic variability encountered in the pollen record reflects the relative position of each core in the valley. Frequencies of tree pollen are generally higher in the edge of valley locations, most notably at Marsh Lane (MMON) and Hacklinge (H-2(a)) where frequencies of Alnus reach high values (LPAZ MMON-d and H-2(a)k-l) compared with the centre of valley locations. Presumably the high frequencies of Alnus in marginal locations indicate the development of local alder carr.

7.4. Inter-site comparison.

7.4.1. Methods of inter-site comparison.

The next stage of analysis is the assessment of the evidence for watertable movements at an inter-site scale. In order to achieve this the data discussed above are compared using age as the independent variable (Fig.7.1.). Here each LAZ has been plotted in the form of a continuous chronology of watertable movements for each site.

Before discussing these data in detail two points concerning Fig.7.1. must be made:

i. The first is that the length of each individual LAZ is only approximate. No attempt has been made to establish rates of sedimentation for each deposit, because of the large within- and between-deposit variability in sedimentation rates. For example, the approximate rate of sedimentation for the lower organic deposit in SF-10 was c. 1.7mm radiocarbon years per annum ($^{14}C\ a^{-1}$), but during the accumulation of LPAZs SF-10a and SF-10b the rate of sedimentation was c. 0.28mm $^{14}C\ a^{-1}$. In contrast the rate of sedimentation for LAZs SF-10c to SF-10e was c. 1.52mm $^{14}C\ a^{-1}$. A similar variability is apparent in the analysis of MMON, with rates of sedimentation varying between 0.92mm $^{14}C\ a^{-1}$ and 0.33mm $^{14}C\ a^{-1}$.

ii. The second point to make with respect to Fig.7.1. is that the ^{14}C dates used have not been calibrated. Were they to be then an analysis of this type would be severely complicated due to the large age ranges for each sidereal date. Indeed, the resolution afforded by the litho- and biostratigraphic data is far greater than that currently available using ^{14}C dating techniques.

The relative watertable movement of each LPAZ are plotted in Fig.7.1. (a-f), whilst the data for the inorganic sediments are plotted in Figs.7.1. (g-h). An attempt has been made to determine a continuous chronology for watertable movements at an inter-site scale through combining these data, and is presented in Fig.7.1. (i). In establishing this chronology the methodology presented in Section 6.2. is applied.

7.4.2. Relative watertable movements at an inter-site scale.

The earliest evidence of watertable movements in the study area is recorded at H-2(b), where diatom data indicate that in LDAZ H-2(b)a a freshening of the sedimentary environment occurred prior to the onset of organic accumulation. A thin organic deposit accumulated under these conditions, although whether the deposit recorded here is in situ is equivocal (Section 6.3.). An increase in the altitude of the watertable is recorded in LPAZ H-2(a)b, where organic is replaced by inorganic sedimentation at c. 6450 BP. This phase of inorganic sedimentation was brief, and saw a progressive reduction in salinity above the transgressive contact until a regressive contact was recorded. In Fig.7.1.(i) no clear watertable tendency has been assigned to this period, as the evidence is limited and inconclusive.

At c. 6450±105 BP the negative watertable tendency first tentatively identified in H-2(b)d continued, and organic replaced inorganic sedimentation. During and after this period diatom data from SF-10 indicate that there was first an increase and then a decrease in salinity before the onset of organic sedimentation at 5975±75 BP.

Pollen data from all three sites indicate that the relative altitude of the watertable was falling during the early period of organic accumulation. At all sites there was a replacement of saltmarsh conditions by a wet freshwater environment, which progressively dried as the watertable continued to fall. At ML-9 the decline in aquatic taxa occurred at 5825±80 BP and at SF-10 slightly later at 5655±150 BP.

Pollen data from H-2(a) during this period also indicate a high, but probably falling watertable (LPAZ H-2(a)c-d), although the end of this aquatic episode has not been dated. The opening of LPAZs SF-10e and H-2(a)g suggest the onset of a positive watertable tendency, although the data from ML-9 is not conclusive. At SF-10 this positive watertable movement resulted in the replacement of organic by inorganic sedimentation at 5550±110 BP, and which also occurred at ML-9 slightly later at 5290±75 BP. It is interesting to note that a peat recorded at Sandwich has been dated to 5315±100 BP (Shephard-Thorn (1975), Section 2.3.3.), although there are no supporting palaeobotanical data for this date.

There is no age determination for the end of organic sedimentation at H-2(a, b), but diatom data from SF-10 and H-2(b) provide information concerning the nature of within-deposit changes in the watertable during the deposition of the thick overlying inorganic deposit. These data have not previously been compared, and are accordingly discussed in detail below.

A comparison of Fig.7.1.(g) and Fig.7.1.(h) reveals a contrasting pattern of salinity changes. At H-2(b) the onset of inorganic sedimentation saw deposition under strongly **M** conditions, with the diatom assemblage being dominated by frequencies of Paralia sulcata (LDAZ H-2(b)e). In contrast, in the down-valley location of SF-10 a more mixed environment with some **MB**, **BM**, and **B** taxa was recorded. Why there should be such a strong **M** environment recorded at H-2(b) compared with the down-valley site at SF-10 is unclear, and suggests a simple model of onshore/offshore increase or decrease in salinity is inappropriate at this time.

There followed a freshening episode, which was recorded at both locations. At SF-10 this is illustrated by an increase in the frequencies of Scoliopleura turmida and then Nitzschia navicularis (LDAZs SF-10g and h). At H-2(b) there was an increase in frequencies of Nitzschia parvula and Nitzschia navicularis, and a decline in those of Paralia sulcata (LDAZ H-2(b)f). The dramatic decline in frequencies of Nitzschia navicularis in LDAZ SF-10i and Nitzschia parvula in LDAZ H-2(b)g are followed by an increase in the frequencies of Paralia sulcata. Following the opening of these LDAZs a more similar pattern of salinity changes between these sites can be seen, most clearly in the co-variance of the frequencies of Paralia sulcata.

Considering Fig.7.1.(i) the changes recorded in the lower part of the middle inorganic deposit are cautiously interpreted as first a positive tendency (immediately above the transgressive contact), which is followed by a negative tendency (the freshening of LDAZs SF-10g-h and H-2(b)f).

LDAZs SF-10j and H-2(b)h are comparable, largely on the basis of the changing frequencies of Paralia sulcata. At the downstream location, strong M conditions persist with an increase in frequencies of Nitzschia granulata, whilst upstream at H-2(b) frequencies of Nitzschia navicularis replace those of Paralia sulcata. This has been interpreted as a decrease in salinity, but whether this is a reflection of a change in salinity due to the upstream position of H-2(b) relative to SF-10 is not known. Accordingly, in Fig.7.1.(i). no indicative tendency is assigned to this period.

LDAZs H-2(b)i-j and SF-10j-k suggest an increase in salinity, with frequencies of Paralia sulcata increasing once again, a strong M environment becoming established at both locations. These conditions persist until LDAZ H-2(b)K-l, where the onset of a reduction in salinity is recorded. This is also found in LDAZs SF-10l-m, where frequencies of Paralia sulcata fall as those of BM and B taxa increase. These changes indicate that a freshening of the depositional environment occurred at the opening of LDAZs H-2(b)k and SF-10l, which persisted until organic replaced inorganic sedimentation.

This change in sedimentation occurred first at H-2(b) at 4890±130 BP, and between 320 and 250 ^{14}C years later at MMON (4570±140 BP) and SF-10 (4640±110) BP. These changes in the diatom content, lithology and age indicate that a negative watertable movement began sometime before 4890±130 BP at H-2(b) and SF-10, and persisted for much of the early period of organic accumulation.

At H-2(a) and H-7 the onset of organic sedimentation saw the establishment of a saltmarsh and then freshwater aquatic communities. High frequencies of tree pollen, including Alnus, Betula, Quercus and Corylus were also recorded, and may reflect an increase in regional pollen rain as a result of the open- or semi-open water conditions suggested by the high frequencies of aquatic taxa. Tree pollen frequencies account for c. 30% TLP in LPAZs H-2(a)h-i and H-7b, and the absence of similar assemblages at the other sites suggests that these LPAZs accumulated during the final phases of inorganic sedimentation at Marsh Lane and Sandfield Farm.

Following the onset of organic accumulation, all other sites (except LPAZ H-7c) record a period dominated by a falling watertable. In general this saw the development of a Gramineae/Cyperaceae environment with an increase in the frequencies of Filicales. At the downstream sites no clear indicative movement has been assigned to LPAZs ML-9h, MMON-c, SF-4c and SF-10h, but following this period an increase in the frequencies of aquatic taxa provides clear indication of an increase in the altitude of the watertable.

At SF-10 a dramatic increase in frequencies of Lemna occurred at 4135±90 BP, with a change from organic to inorganic sedimentation taking place at 4020±70 BP. The transgressive contact has been dated in ML-9 to 4105±120 BP, which is similar to the date for the rise in aquatic taxa recorded in SF-10. At MMON a similar increase in frequencies of aquatic taxa and the first appearance of saltmarsh indicators below the transgressive contact has been dated slightly later to 3980±140 BP. Upstream at Hacklinge, the opening of LPAZs H-2(a)l and H-7e also indicate an increase in the altitude of the watertable, with a decline in frequencies of Filicales.

Organic sedimentation persisted at H-2(b) until 3905±205 BP, whilst at the marginal site of MMON organic sedimentation kept pace with the rate of watertable rise for a further 300 ^{14}C years.

Fig.7.1.(i). indicates that a negative watertable tendency has been assigned between c. 5000 BP and c. 4250 BP where the first indication of a rise in the watertable is identified. After this time a positive tendency of watertable movements has been defined by the progressive switch to inorganic sedimentation, and by the diatom data collected from the upper inorganic deposit at H-2(b) and SF-10, both of which indicate a continuing increase in salinity. This persists until c. 3400 BP, when a thin organic deposit is recorded at Hacklinge.

The diatom data from H-2(b) and the pollen data from H-2(a) indicate that during this period saline conditions persisted, despite the freshening of the diatom assemblage recorded in LDAZ H-2(b)n. The pollen data indicates that a saltmarsh peat developed, with no significant frequencies of freshwater taxa recorded.

No ^{14}C dates are available for this deposit, but a positive watertable movement must have occurred shortly after c. 3000 BP, with a M environment established in LDAZ H-2(b)o. Evidence for a positive watertable movement during this period are recorded elsewhere in the East Kent Fens. In the Lydden Valley Halliwell and Parfitt (1985) have dated a spread of carbon "pot boiler" sealed beneath a greasy clay to 3030±90 BP. Furthermore, Godwin (1962) has dated a fine organic detritus mud to 3105±110 BP, which suggested an increase in waterlogging and the presence of a marine influence at this time (Section 2.3.3.).

However, following this period, a freshening of the depositional conditions is apparent, and these conditions persisted until the replacement of inorganic by organic sediments in H-2(b) at 2400±230 BP. Organic sedimentation was also recorded at this time from Wingham, where Godwin (1962) has dated a coarse detritus mud with remains of Equisetum, Cladium, and Menyanthes to 2340±130 BP. Litho- and biostratigraphic data from H-7 and H-2(a) indicate that there is one further increase in the altitude of the watertable, which saw the deposition of a thin shell marl. Diatoms analysed from this deposit indicate that it accumulated under **BZ** or **Z** conditions. Pollen analysis above this deposit indicate a continuing reduction in the altitude of the watertable, with frequencies of aquatic taxa declining in LPAZ H-7g. The age of this final elevation of the watertable is not known.

7.5. Discussion.

One of the aims of the litho-, bio- and chronostratigraphic sampling strategy has been to determine the three-dimensional response of a defined sedimentary system to changes in the relative altitude of the watertable. This discussion section is divided into three sub-sections which consider the variability recorded in the three variables collected from this area - altitude, age and indicative movement.

7.5.1. Altitude.

The completion of detailed lithostratigraphic studies in a three-dimensional context at the site-scale at Hacklinge, and subsequently at an inter-site scale through the incorporation of data from Marsh Lane and Sandfield Farm, has illustrated a large altitudinal variability in the sediments recorded. Indeed, it would be possible to sample a transgressive or regressive contact from almost any altitude between c. -0.50m OD and -7.00 to -8.00m OD, and hypothetically possible to collect almost any sequence of transgressive and regressive contacts between these altitudes. Whilst this would require a strange sampling design, it does serve to illustrate that the location of data collection within the study area can have a profound effect on the altitude of the transgressive or regressive contacts recorded, and also perhaps on its age. This will then affect any subsequent correlation of lithostratigraphic data on the basis of altitude, or the use of altitude in the construction of former positions of sea-level.

A number of possible explanations may be proposed for this altitudinal variability. The first is that these sediments initially accumulated at the same altitude, but that they have been altered by post-depositional processes such as differential compaction of the underlying Holocene sediments has occurred. For example, Waller (1987 :281) has noted that

> "Differences between the altitude of the regressive overlap, between Brede Bridge and Brede Levels, may .... reflect the greater compressibility of the underlying sediment. Hence the greater compaction occurring in the finer sediments upstream, than in the coarser deposits of the lower Brede (though the overburden is greatest downstream)."

In the current study the form of the pre-Holocene surface has been determined through the seismic refraction survey, and this provides an opportunity to assess this suggestion. It is interesting to note that between hand-core 6 and 13 at Marsh Lane there are no major changes in the altitude of either the upper or the lower organic deposit, despite an apparent increase in the thickness of the Holocene sediments below these deposits of approximately 5-6m (c. 30%).

At an intra-site scale however, the major changes in altitude are recorded towards the valley edges, where the altitude of the transgressive and regressive contacts generally increase as the pre-Holocene surface also rises. These altitudinal changes will probably reflect both the altitude of the pre-

Holocene surface (and the thickness of underlying Holocene sediments), as well as the former gradient of the inter-tidal zone or peat surface. Given the confined width of the valley, a relatively steep gradient to these surfaces might be expected.

At Sandfield Farm the upper and lower organic deposits are generally recorded at a higher altitude than those at Marsh Lane, despite a similar thickness of Holocene sediments determined by the seismic refraction survey. Given the more seaward location of Sandfield Farm it might be expected that the lower inorganic deposit would be coarser than those recorded at Marsh Lane, in which case differential compressibility of the underlying sediments may explain the altitudinal differences observed. However, the lithostratigraphy does not indicate a consistent increase in particle size at Sandfield Farm compared with Marsh Lane, at least to a depth of c. -8.00m OD, although there is a possibility that coarser sediments may be present at depth.

When altitudinal data from Hacklinge are considered, the differential compressibility of the sediments appears to be more likely as an explanation for some of the altitudinal discrepancies observed.

Seismic data from the Hacklinge area were poor due to the thick organic deposits, and therefore the detailed form of the Chalk sub-crop in this area is not known, although it is unlikely that it is deeper in this location than at the downstream sites. The lithostratigraphic survey indicates that whilst the middle inorganic deposit is of comparable thickness and composition to that recorded at Marsh Lane and Sandfield Farm, the lower organic deposit is considerably thicker at H-2(a) (1.10m) compared with that recorded at ML-9 (0.36m) and SF-10 (0.28m). Therefore, despite the age gradient for the regressive contact of the upper peat, it would appear that some of the altitudinal difference of this upper regressive contact may be due to the the variable thickness of the lower organic deposit. However, this fails to explain the differential altitude of the regressive contact for the lower organic deposit.

An alternative explanation for the altitudinal differences observed may be that differential land subsidence has occurred in the area as a result of mining activity. This was mentioned briefly in Section 3.2.1. Despite considerable effort to obtain information concerning the evidence for differential subsidence from British Coal none was obtained. That differential subsidence in the area has occurred is beyond doubt, and at present landfill operations are ongoing at Worth in order to raise the level of the Lydden Valley and prevent flooding. In addition, there are several ongoing legal disputes between landowners and British Coal concerning the possibility of differential subsidence in the area.

Although the levelling data suggested that no differential subsidence had occurred within the area over the last 15 years, this does not preclude the possibility of subsidence prior to this date. Lithostratigraphic data collected from the area can be used to study the possibility of such subsidence prior to this date. Fig.4.19. illustrates the lithostratigraphy of the Lydden Valley Transect 1, and there is a pronounced increase in the altitude of the ground surface to the east of hand-core LV2. Therefore there appears to be evidence for a significant lowering of the landsurface in the area of Hacklinge, and whilst this is probably due to the effects of differential compressibility of the underlying Holocene sediments (as well as differing drainage histories?), it would also suggest that differential subsidence related to coal-mining activities may have occurred in this area.

7.5.2. Age.

Eighteen ^{14}C dates collected from the study area provide an absolute chronology for sedimentation and watertable movements. Two objectives of the dating strategy were to determine the spatially variable response of a defined sedimentary basin to changes in the height of the watertable, and to assess the use of transgressive and regressive contacts in the analysis of watertable and sea-level changes.

Whilst noting the problems caused by the large standard errors in this type of analysis, there remain significant age differences recorded for similar lithostratigraphic deposits within the area under study. In part these differences reflect up-valley and down-valley age gradients, but the patterns observed are not always as simple. In addition, the use of biostratigraphic data indicate that the dating of transgressive and regressive contacts provide only an approximation of the chronology of watertable movements. These data are summarised in Table 7.5. below.

Table 7.5. Intra- and inter-site age differences in the study area. RC = Regressive contact, TC = Transgressive contact, DA = Decline in aquatic taxa, RA = rise in aquatic taxa, NA = Not available.

Deposit	Inter-site	Intra-site
RC Lower organic	680 ^{14}C years	NA
DA Lower organic	170 ^{14}C years	NA
TC Lower organic	260 ^{14}C years	NA
RC Upper organic	320 ^{14}C years	NA
RA Upper organic	155 ^{14}C years	NA
TC Upper organic	555 ^{14}C years	555 ^{14}C years

One of the difficulties in this study was the requirement for a large number of ^{14}C dates, as both the within-deposit and transgressive and regressive contacts had to be dated, and this limited the number of intra-site dates available. However, whilst the database is small, it does illustrate the potential degree of variability which can be recorded within a very small area.

The two main conclusions from the above discussion are that there are significant intra- and inter-site age gradients in the area under study. It should be noted however, that this type of sedimentary system may not be comparable with other larger sedimentary systems such as the East Anglian Fenlands or the Sommerset Levels, and that some of the variability recorded in the current study probably may reflect the restrictive nature of the infilled-valley in which the Holocene sediments accumulated.

7.5.3. Indicative meaning.

In Chapters One and Six the importance of vegetation succession in coastal areas was discussed. The restricted number of contemporary sedimentary analogues for the palaeoenvironments discussed in this thesis (eg Ranwell 1974) hinder any detailed comparison with such communities. The classic seral succession from saltmarsh to acid raised bog has not been identified in the current study. However, it is possible to identify three broad types of vegetation community associated with transgressive or regressive contacts and a rising or falling relative watertable.

It should be noted that these three types of vegetation community are not always recorded, and in some instances it has been necessary to interpret changes in the frequencies of other taxa, such as Alnus, as being indicative of a change in the relative altitude of the watertable. However, this is one of the flexibilities of an approach where the constraint of the transgressive or regressive contact is abandoned.

i. The first community identified is the saltmarsh community identified by Godwin and Godwin (1933), and widely recorded elsewhere in close association with transgressive or regressive contacts. In the current study pollen preservation associated with the transgressive and regressive contacts was typically very poor, and therefore it was rare to record high frequencies of saltmarsh taxa. However, there was generally a clear increase in frequencies of Gramineae, and a smaller increase in the frequency of saltmarsh indicators such as Chenopodiaceae and <u>Aster</u>-type below and above these contacts.

ii. The second type of community identified is that characterised by high frequencies of obligate and non-obligate aquatic taxa. This type of community represents either the second or penultimate stage of a vegetation succession or retrogression recorded in association with a rising or a falling watertable immediately below or above a transgressive or regressive contact. High frequencies of aquatic taxa are commonly associated with an increase in the frequencies of tree pollen, perhaps reflecting the open- or semi-open habitat associated with standing pools of freshwater and a more regional pollen rain.

Considerable differences in the frequencies of aquatic taxa are recorded within the area, so that for example, the increase in aquatic taxa recorded above the regressive contact of the lower inorganic deposit varies between approximately 30% TLP at H-2(a), 40% TLP at SF-10 and 80% TLP at SF-10. In addition, the composition of the aquatic summary groups vary, so that whilst at SF-10 a mixed assemblage of <u>Typha latifolia</u>, <u>Typha angustifolia</u>, <u>Potamogeton</u> and <u>Lemna</u> is recorded, at both ML-9 and H-2(a) a deeper water community characterised by <u>Lemna</u>, <u>Typha latifolia</u> and <u>Nymphaea</u> is recorded. Similar variability is apparent during the rise in aquatic taxa identified immediately below the transgressive contact of the upper organic deposit. Here frequencies of aquatic taxa vary from 150-200% TLP in SF-10 and SF-4, to 20-25% TLP at ML-9 and MMON, and 45% TLP at H-2(a). Once again the composition of the aquatic taxa summary groups vary, this time with high frequencies of <u>Lemna</u> recorded in SF-10 and SF-4, as well as in ML-9 and to a lesser extent MMON. In contrast, at H-(2)a frequencies of <u>Lemna</u> are comparatively low, with those of <u>Potamogeton</u> dominating the aquatic sum. These changes may represent different degrees of waterlogging within the valley, and caution against placing too much emphasis on the direct comparison of % values for taxa in this type of sedimentary environment.

iii. The third type of vegetation community, which is indicative of a relative drying of the peat surface, is dominated by Gramineae and/or Cyperaceae and high frequencies of Filicales. As with the aquatic taxa the justification for this interpretation has made in Section 6.5.2. At an intra- and inter-site scale frequencies of Filicales also vary widely. For example, considering the high frequencies of Filicales recorded during the formation of the upper organic deposit, these are seen to vary between a high of 220% TLP at SF-4, 140% TLP at MMON and 50% TLP at H-2(a). In all cases the frequencies of Filicales appear to be higher in edge of valley compared to centre of valley locations.

<u>7.6. Physical evolution of the study area during the late-Holocene.</u>

The adoption of a three-dimensional approach to data gathering, combined with a move away from the dependence on altitude as an essential variable for analysis, have illustrated the temporal and spatial transience of the sedimentary record derived from any single location within the small sedimentary system identified in the Hacklinge/Deal area. The interplay of these factors is also illustrated when consideration is given to the patterns of sedimentation observed at a larger spatial scale associated with the progressive infilling of the valley during the Holocene.

Whilst the base of the infilled-valley identified in the Hacklinge/Deal area is between -17m and -20m OD, the valley sides appear to level out on its northern and eastern margins where they abut the Lydden Valley. The Chalk sub-crop in these areas is approximately -2m to -3m OD, and therefore once sea-level had reached this height, the restrictive nature of the pre-Holocene surface on the pattern of sedimentation would have been replaced by the open undulating surface of the Lydden Valley.

Indeed, it is probable that following this time the infilled valley identified in this study first became part of the larger sedimentary system of the Wantsum Channel. Therefore, a whole range of variables previously operating at a very local scale and connected with the confined valley, would have been replaced by a new set of variables associated with a very different sedimentary system.

At what time this event occurred is not known, although the distribution of archaeological artifacts described by Halliwell and Parfitt (1985 - see Section 2.3.3.) suggest that this event occurred at about 3000 ^{14}C years BP. A comparison of the spatial extent of these artifacts indicates that their distribution closely delimits the configuration of the infilled valley identified in this study. The clay identified by Halliwell and Parfitt (1985) overlying the Chalk sub-crop near the coal tip was deposited sometime after 3030±90 BP, by which time inorganic sedimentation (the upper inorganic deposit) was occurring at both Marsh Lane and Sandfield Farm.

That organic sedimentation should persist at Hacklinge after 2400±230 BP, whilst no significant organic sediments accumulated at Marsh Lane and Sandfield Farm is of some interest. These thick upper organic sediments are spatially restricted to the immediate vicinity of Hacklinge. Therefore, it would appear that the confined nature of the pre-Holocene surface at Hacklinge may have acted as a block to marine incursions after 2400±230 BP.

Elsewhere in the former Wantsum Channel intercalated peats containing >50% organic material by volume were recorded at between -3.00m and +1.00m at Stewart's Folly, whilst organic clays (>25% organic material by volume) were recorded in Deerson Valley as well as the Goshall Valley between -1.50m and -0.50m OD. Furthermore, surface peats were recorded in marginal valley locations in Deerson Valley extending between 0.00m OD and +1.50m OD. These data suggest that the rate of watertable rise during this period in the Wantsum Channel fluctuated, slowing occasionally so as to enable organic material to accumulate. Reference has been made above to organic sedimentation at Wingham which has been dated to 2340±130 BP (Godwin 1962). However, no absolute age determinations are available for the other organic deposits recorded in his study, and the absence of clear altitudinal patterns preclude the correlation of these data with those collected from the Hacklinge/Deal area.

In conclusion therefore, whilst prior to c. 3000 BP the infilled valley identified in this study most probably existed in isolation from the main Wantsum Channel, when seen within the broader context of archaeological data from the Lydden Valley as well as other lithostratigraphic data collected from the Wantsum Channel, the need for a three-dimensional approach to data collection and analysis at a variety of spatial scales becomes apparent.

Chapter Eight: Holocene crustal movements in Southeast England.

8.1. Introduction.

This Chapter analyses the evidence for Holocene crustal movements in Southeast England, combining the new data collected from the East Kent Fens with those discussed in Chapter Two from the Thames Estuary and East Sussex and West Kent. No data from the Essex coast are suitable for the analysis of crustal movements, as all ^{14}C dates have been classified as Group 4a or Group 4b dates, and therefore the correction to a palaeotide level is not possible.

The Chapter begins by describing the evidence for Pre-Quaternary and Quaternary crustal movements in Southeast England. This provides a context for the discussion of the Holocene crustal record. Section 9.3. discusses the previous evidence for Holocene crustal movements in the UK, and in Southeast England in particular. The new and existing data from Southeast England are then analysed using three techniques in order to re-assess the evidence for Holocene crustal movements in this area. The Chapter concludes by discussing the limitations of the approaches adopted, and by identifying future research requirements necessary before the pattern of Holocene crustal movements in Southeast England can be resolved.

8.2. Pre-Quaternary and Quaternary evidence for crustal movements in Southeast England.

During much of the Pre-Quaternary, Southeast England has undergone long periods of subsidence with intermittent periods of uplift (Dunham 1972). In addition, differential crustal movements within Southeast England, particularly between the Wealden District in the south and the more stable northerly areas of North Kent and South Essex, have had an important effect on the geological evolution of the area.

The rock platform underlying Essex, Kent and Sussex is of Lower Palaeozoic, Devonian and Carboniferous age. In general Mesozoic rocks rest on a Carboniferous platform under Kent, and a Devonian platform under London itself. During the Hercynian (280 Ma) and possibly Caledonian (390-420 Ma) orogenies these rocks were extensively deformed and uplifted (Dunham 1972). Uplands formed by this uplift were subsequently planed down to form the London Platform, which forms part of the Anglo-(London)-Brabant Massif. During the Jurassic this Platform was a relatively stable landmass, whilst to the south the Weald underwent subsidence, and 1.5km of Jurassic sediments were deposited. Along the present south coast these Jurassic sediments consisted of Portland Beds, Kimmeridge Clay and Corallian Beds up to a thickness of at least 530m (Lake and Shephard-Thorn 1987).

During the Late-Cretaceous a major transgression occurred, and a progressively deeper sea formed over much of Southeast England. Under these conditions the Lower Greensand, followed by the Lower and Upper Gault, and finally the Chalk accumulated (Edmunds 1935, Lake and Shephard-Thorn 1986, Jones 1981). At the end of the Cretaceous period there followed uplift and slight deformation, with the result that the Tertiary sediments sit unconformably over the Chalk. During Lower Eocene times the Lower London Tertiaries were deposited in the north of Kent, whilst in Wealden areas Eocene deposits are largely absent (except to the south of Chichester), due to their non-deposition or subsequent erosion. Pliocene formations are absent from much of the Wealden area, but in the north of Kent and in Essex the London Clay was deposited under deep water, fully marine conditions.

Whilst there appears to be evidence to support the contention of long-term subsidence in southern England (West 1972), which is demonstrated by the long periods of marine deposition described above, Smith (1985, 1989) and Preece <u>et al</u> (1990)

have argued that evidence from the English Channel suggest "broad uplift in southeast England and the neighbouring continent during the past few million years". Preece *et al* (1990) have argued that the contemporary altitudes of late Miocene/Pliocene peneplains and associated deposits indicate

> "a doming of southeast England - northern France, which locally may have been as much as 400m...(and which has)... continued, albeit intermittently, for over a million years".

Importantly, their calculations of crustal uplift are based on an analysis of Pleistocene littoral deposits, which are constrained by a series of assumptions. These include the use of the interglacial eustatic values determined by Shackleton (1987), the assumption that the littoral deposits accumulated under the highest sea-level stand of any interglacial, and that "uplift is assumed to have been directionally constant and linear" (Preece *et al* 1990). Furthermore, the authors have corrected each index point to the contemporary Holocene spring tidal range, although they have recognised the possibility of changing palaeotidal regimes associated with the opening of the Strait of Dover.

Any interpretation of the evidence for pre-Holocene sea-level and crustal changes is severely complicated by the alternating glacial- and hydro-isostatic loading and unloading which have affected the rest of the UK and the Southeast of England, and by the limited nature of the sea-level database. Even in the discipline of Holocene sea-level changes, where a comparatively large database of well defined and well dated sea-level index points exist, and where some of these complicating factors are far reduced, many issues remain unresolved.

8.3. Holocene crustal movements in the UK and Southeast England.

Any sea-level index point is believed to have formed at an altitude which approximates the MHWS at the time of formation. The altitude of any sea-level index point recorded today will be a function of the age of that deposit, the altitude of MHWS at the time of its formation, and the net crustal movements which have occurred since it became part of that crust. In addition, since its deposition, the altitude of the deposit will also have been altered by processes such a compaction of the sediment itself, and compaction of the underlying sediments.

The simplest way of describing this relationship is to define the rate of change in relative sea-level as a function of the rate of change in eustasy and the rate of change in crustal movements. In the first instance it is assumed that local processes are held constant. Therefore, the rate of change in relative sea-level can be defined as

$$\frac{dR}{dt}=\frac{dE}{dt}-\frac{dI}{dt} \qquad (1)$$

and the rate of change in crustal movements as

$$\frac{dI}{dt}=\frac{dE}{dt}-\frac{dR}{dt} \qquad (2)$$

where dR equals the rate of relative sea-level change, dE equals to the rate of eustasy, and dI equals the rate of crustal movement. When the solution of eqn.2 is positive there is uplift, and subsidence when it is negative.

Relative sea-level and relative crustal changes have often been studied through the direct altitudinal comparison of different sea-level curves derived from different areas. In order that such a comparison reflect changes in the rate of relative sea-level or crustal movements, it is necessary to consider the comparative rate of change, or gradient, of any relative sea-level or crustal residual curve (eqn 1) under consideration.

Various methods have been used to separate the eustatic from the crustal component of relative sea-level movements in the UK and Southeast England. These different approaches are discussed in the following section, where three approaches are used to re-assess the evidence for Holocene crustal movements in Southeast England. Each of these approaches has different problems, and an attempt is made to highlight these in each case. The use of three different, but related approaches, is designed to assess the robustness of the results arising from any individual analysis.

Before the advent of ^{14}C dating there was general agreement, based on geomorphological evidence and relative dating techniques, for a crude north/south contrast in Holocene uplift and subsidence within the UK (Wright 1914, Daly 1934). Godwin (1945) established a pattern of differential crustal movements within the UK through a comparison of the contemporary altitudes of the Boreal Atlantic Transition (B.A.T.) "transgression contact" in coastal locations in Britain and the southern North Sea. Godwin (1945, Fig.23.) concluded that the higher altitude of the B.A.T. transgression contact in Somerset and Wales, compared with Southampton, the East Anglian Fenlands and the south-eastern North Sea coasts, suggested possible differential subsidence between these areas.

Following the advent of ^{14}C dating, Churchill (1965) compared the altitude of coastal deposits in the UK which formed at approximately 6500 ^{14}C years BP. He concluded that there was both a north/south and an east/west component to the pattern of Holocene crustal movements in the UK. In particular, Churchill (1965) suggested that differential east/west subsidence of approximately 6.10m had occurred since this period. However, these conclusions cannot now be accepted, given the problems inherent in Chuchill's choice of datum (see Section 1.5.1.), and his assumption that the Bristol Channel area had remained stable during the Holocene.

Akeroyd (1972) analysed the altitude of archaeological and historical data recorded in Southern Britain, and established a relative sea-level diagram complete with age and altitude error boxes. However, in this study no attempt was made to separate crustal from eustatic factors, and therefore the discussion referred only to relative and not absolute crustal movements. D'Olier (1972) also analysed the evidence for subsidence in the Thames Estuary, but again failed to separate the eustatic and crustal variables.

Devoy (1977, Fig.39.) compared two relative sea-level curves from the Lower Thames Estuary with curves presented from the Essex coast (Greensmith and Tucker 1973), the northwest coast of France (Morzadec-Kerfourn 1974), the Atlantic coast of France (Ters 1973), and from the Netherlands (Jelgersma 1961). As proposed by Godwin (1945), the comparison of relative sea-level curves in this manner afforded the possibility of separating the eustatic from isostatic factors.

This comparison revealed a confusing and inconsistent pattern of change through time, although Devoy (1977 :195) concluded that "each event shown in the Thames curve can be correlated with a similar phase in another area". However, this matching of curves was purely subjective, and no explanation for the inconsistent relationship between the curves was proposed, nor was any attempt made to separate the eustatic from crustal variables.

This attempt had a number of serious limitations. For example, each relative sea-level curve had been derived from differing sedimentary environments, with the use of material collected from different ecological contexts. Thus, for example, Greensmith and Tucker (1973) used a number of dates from shells in their calculation of relative sea-level changes on the Essex coast and this, compounded by other problems in their data, restricts the use of their data in such a comparison (Section 2.4.1.). In addition, Jelgersma (1961) based her relative sea-level curve on dates determined from the bottom of basal peats. No adjustment for the different indicative altitudinal range of these deposits relative to the transgressive contacts dated elsewhere was made, thereby making a comparison with the data collected in the Thames Estuary inappropriate.

Whilst Devoy (1977) was unable to identify differential absolute crustal movements between these areas, he was able to identify differential "downwarping" within the Lower Thames Estuary. Through a comparison of the relative sea-level curve from Tilbury with that of the other locations within the Lower Thames Estuary, Devoy (1977) suggested differential crustal movements may have occurred between Crossness and Tilbury. The possibility of within-Estuary differential crustal movements is discussed in detail below, as a comparison of the data from the rest of Southeast England with the present data is made in the following sections.

Devoy (1977 :201) cited the differential altitude of TII and TIII, which are seen to dip progressively eastward, as evidence for differential crustal movements within the Thames Estuary. However, as discussed in Section 2.3.2., altitudinal data from the Lower Thames Estuary should only be used with caution, and the suggestion of post-depositional differential downwarping does not explain the age anomalies observed for both TII and TIII. In addition, the evidence for differential crustal warping is based on a two-dimensional lithostratigraphic plot (Devoy 1977, Fig.32.). This illustrates selected cores, of which only eight contain altitudinal data concerning TIII and

TII, all of which were collected by commercial techniques, and for which the altitudinal data may be in error. Furthermore, the altitude of the intercalated organic facies are extrapolated beyond Tilbury dipping in an easterly direction, although there are no data to support this.

Devoy recognised that the changes in altitude probably reflected a combination of factors, including relative subsidence, changes in the tidal amplitude and river discharge, as well as the operation of differential compaction and consolidation within the Estuary. Devoy (1982) later argued that

> "any figures for inter-areal subsidence (in Southeast England) based upon sea-level data would be misleading".

In conclusion, Devoy (1977) presented only a limited discussion of the evidence for absolute crustal movements within Southeast England, and assumed that the pre-Holocene geological record of long term subsidence probably persisted during the Holocene. More recent research has suggested that Southeast England may in fact have undergone a more complex pattern of crustal movements during the Holocene.

Flemming (1982), for example, attempted to establish the pattern of crustal uplift and subsidence in the UK during the Holocene, using a linear regression analysis of 143 ^{14}C sea-level index points. Flemming (1982) made certain simplifying assumptions, such as assuming a linear crustal component (uplift/subsidence) throughout the Holocene, and also calibrated his calculations by using the present position of the UK zero isobase predicted by Rossiter (1967) (which was based on the analysis of tide gauge data). However, Flemming (1982) was severely restricted by data limitations, notably along the south coast of England. Indeed, his model predicted contemporary Holocene crustal uplift in Kent and Sussex of between +1.23 and +1.73mm a^{-1}, which Flemming (1982) believed was a reflection of constraints in the original data and not necessarily reality.

Shennan (1987, 1989) further analysed this problem by subtracting a eustatic value from the altitude of each sea-level index point. This eustatic value was derived from Morner's (1984) supposed "eustatic" sea-level curve for the North Sea region. This represented a positive attempt to separate the crustal from eustatic variables, which had previously been attempted by Morner (1969).

Morner (1969, 1976, 1984) has presented an oscillatory sea-level curve for the Holocene, which he has proved could act as an approximation of the trend in "global eustatic" sea-level during this period (Fig.8.1.). Morner (1969) used his eustatic curve in order to analyse the isostatic history of a number of coastal areas in northwest Europe and elsewhere in the world, and noted that

> "If the eustatic curve is true, it must in comparison with every true shoreline displacement curve also give a true isostatic curve".
>
> Morner (1969 :426)

However, a number of points concerning the data used in the construction of this curve should be made.

i. Firstly, the curve is based on material collected from a range of palaeoenvironments, in particular from isolation contacts and organic deposits overlying former shorelines. Establishing the indicative altitudinal range of an isolation contact is dependent on the identification of the altitude of the lip of the sedimentary basin in which the sediments are accumulating. In this way a change from a marine to a limnic sequence can be dated and related to a former sea-level (the altitude of the lip of the sedimentary basin). However, the problems in achieving this are significant, as it requires a detailed understanding of the form of the sedimentary basin in which the sediments have accumulated.

ii. In addition, many of the sites were levelled to a local datum, often determined from mean sea-level at the site under consideration, and not from established benchmarks.

Despite these problems, Shennan (1987, 1989) has also used Morner's "eustatic" sea-level curve in an exploratory sense, in which case it need not be an absolute representation of reality. Furthermore, the use of this eustatic curve can be used as a constant against which relative changes in crustal movements can be compared from area to area, in the same way that any calculated exponential function could be used.

The results of Shennan's analyses (Shennan 1987, 1989) have shown that the south of England and Wales have undergone recent linear net subsidence, and areas in Northern England non-linear net uplift. In Southeast England (South Kent and Sussex, excluding the Thames Estuary), Shennan (1989) has identified evidence for linear net crustal subsidence of between -0.11 ± 0.08 and -0.66 ± 0.19mm a^{-1} from 8750 - 0 BP and 6250 - 0 BP. However, Shennan also noted that "the distribution of samples through time is limited", and that in general the database of sea-level index points from Southeast England was poor.

Within the Thames Estuary, Shennan (1989) identified a general rate of linear net subsidence between 4000 - 0 BP of -1.90 ± 0.32mm a^{-1}, but noted that this calculation was strongly influenced by the use of the origin as a data point. From 6000 - 4000 BP no crustal movement was apparent, whilst net uplift was apparent from 8500 - 6000 BP. Shennan (1989) noted that Greensmith and Tucker (1980) had identified differential crustal movements within the area, associated with a tectonic hinge structure, but that this would not readily explain the non-linear model proposed.

Shennan (1989) suggested that the non-linear net crustal trend observed in the Thames Estuary may have been caused by a change in the palaoeotidal range since 8500 BP, a suggestion first proposed by Devoy (1977, 1979). This suggestion would require an increase in palaeotidal range of c. 3m between 8500 - 6000 BP. Alternately, Shennan (1989) suggested that the pattern may reflect the effects of a collapsing forebulge at differential rates within the Estuary, although he has noted that the detailed understanding and modelling of a collapsing forebulge had yet (and remains) to be completed.

A number of points must be made at this juncture.

i. Shennan (1987, 1989) has used a linear function to describe the pattern of net crustal movement over the last c. 5000 ^{14}C years BP. However, in a discussion of the approach adopted by Flemming (1982), Shennan (1989) noted that "a linear model of uplift was assumed, whereas geological theory of glacio-isostatic recovery shows a curvilinear function". Indeed, Shennan (1989) noted that in his own study the use of a linear function was sometimes inappropriate (eg in the Thames Estuary).

ii. Secondly, in order to calculate approximate contemporary rates of crustal uplift/subsidence, the linear regression has been shown passing through zero uplift/subsidence at zero time, despite considerable data deficiencies in the last 2 - 3000 ^{14}C years BP. However, the linear regression from the Thames Estuary which demonstrates net subsidence between 0 - 4000 BP is "greatly affected by using the origin as a data point". The use of the origin as a datapoint is justified, however, as it is implicit in the correction of sea-level index points to a single datum.

iii. Thirdly, Shennan's analysis has involved the use of values, (the altitude of a relative sea-level index point and a eustatic correction), the trend of which is then summarised by either a linear regression equation, or by purely visual means. A more direct way of analysing trends through time might be to compare the rate of change in relative sea-level between areas. This recognises the fundamental aspect of relative sea-level change, - that it is a function of the rate of change in eustasy and isostasy (eqns. 1, 2). If it is assumed that eustasy has remained constant over space (for example in the North Sea region), any difference in the rate of change in relative sea-level histories should be a reflection of changes in the rate of relative crustal movements between areas, as well as the operation of local processes.

More recently an alternative model-based approach has been proposed (eg Lambeck et al 1990, Peltier 1991) in order to predict the pattern of past relative sea-level change in the UK. This approach is based on the computer modelling of the geophysical parameters of the Earth's crust, which are combined with models of deglaciation. For Southeast England a curvilinear reduction in the rate of relative sea-level rise is predicted by Lambeck et al (1990). Such an approach is heavily dependent on the initial input parameters, and in particular an accurate understanding of the pattern of deglaciation in the UK and in Fennoscandia. The resolution of these models is, however, comparatively coarse during the Holocene.

8.4. A re-assessment of the evidence for Holocene crustal movements in Southeast England.

8.4.1. Introduction.

In the preceding section, a number of different methods of analysing the crustal component of relative sea-level data has been discussed. In the following section, the data from the

East Kent Fens, the Thames Estuary, and East Sussex and West Kent are analysed using three of these techniques.

a). The first technique involves the simple comparison of relative sea-level data.

b). The second involves the use of Morner's regional eustatic curve for the North Sea region, as proposed by Shennan (1987, 1989). These analyses are completed in parallel in Sections 8.4.3a-c.

c). The third technique attempts to compare the differential rate of change in relative sea-level between areas. The database used consists of all Group 2 and Group 3 dates described in Chapters Two and Six, divided by area into the Thames Estuary, the East Kent Fens, and East Sussex and West Kent.

8.4.2. Age and altitude errors.

One of the aims of the current study has been to assess the degree of altitudinal and temporal age variability recorded in a small spatial area, where the effects of differential tidal regimes and crustal movements, for example, are held constant. Therefore, the following section begins by presenting the ^{14}C dates from the East Kent Fens in order to assess the degree of inter-site variability recorded at a local scale. The age/altitude errors recognised through this assessment are then used to constrain the interpretation of data from elsewhere in Southeast England.

Whilst considerable effort has been made to establish appropriate age and altitude errors for different types of ^{14}C sample, the approach adopted here does not try to separate the different components of what is in effect a cumulative error. Instead, it attempts to determine the cumulative variability which can be expected in terms of age and altitude from sediments recorded in a small study area.

Material analysed from the East Kent Fens encompasses much of the time period covered by the other data from Southeast England (2000 - 6500 ^{14}C BP), as well as a broad altitudinal range (-1.50 to -9.50m OD). The material studied is typical of that analysed from other sites, consisting of intercalated organic and inorganic sediments. The organic sediments vary in composition from Phragmites-rich peats, to woody peats or well humified turfa, whilst the inorganic fraction consists of a range of particle sizes and composition, varying between organic-rich clays and coarse sands. These are typical of the deposits from which data collected elsewhere in Southeast England have been derived.

Eighteen ^{14}C dates have been collected from the East Kent Fens, and fifteen of these have been classified as Group 2 or Group 3 dates. These dates have been corrected to MHWS, which at Deal is +2.70m OD, and plotted on a simple time/altitude graph in Fig.8.2. The altitudinal and temporal variability illustrated for any point in time in Fig.8.2. provides an approximation of the variability expected from this and other sedimentary environments in Southeast England.

Between c. 6500 and 2400 BP, sea-level index points are recorded within a ±1m altitudinal band of any summary relative sea-level curve. The graphical representation of age and altitude errors is complex procedure. The plotting of each index point with an individual age and error box can also lead to an extremely confusing visual representation of the data (eg Akeroyd 1972, Kidson and Heyworth 1982, Devoy 1982). In the following study no age/altitude errors are presented, but it is stressed that subsequent calculations, based on the use of the mean ^{14}C dates are not meant to be absolute, and recognition of the potential age/altitude errors described above is inherent in any interpretation of these data. Emphasis is therefore placed on the cautious interpretation of both age and altitude data throughout the current study.

8.5. The subtraction of a eustatic constant, and the visual comparison of relative sea-level data.

In this section a eustatic constant, derived from Shennan's (1989) smoothed version of Morner's eustatic sea-level curve (Fig.8.1.), is subtracted from each sea-level index point. For each region, the relative sea-level data are presented, in addition to the calculated net negative crustal residuals. Morner's smoothed regional eustatic sea-level curve for the North Sea region has also been shown on each of these Figures.

The exact procedure involved in the calculation of the crustal residuals was as follows:

1. Each sea-level index point was corrected to MHWS, based on data from the nearest tide gauge station and derived from the Admiralty Tide Tables.

2. Each index point was then corrected for the difference between MSL and OD.

3. The appropriate eustatic value was then subtracted from the altitude of the corrected sea-level index point.

The results of this procedure for each area are presented in Figs.8.3. - 8.5., and are discussed below.

8.5.1. Thames Estuary Fig.8.3.

Fourteen Group 2 and Group 3 ^{14}C dates from transgressive and regressive contacts have been recorded from the Thames Estuary. This is fewer than the number of data points used by Shennan (1987, 1989), in which thirty-six ^{14}C dates are used. A number of ^{14}C dates used by Shennan (1987, 1989) are derived from within organic deposits, and are not associated with transgressive and regressive contacts. The correction to a former MHWS is inappropriate for over half of the dates used in Shennan's analyses (1987, 1989) as they have no defined relationship to a palaeotide-level.

The temporal span covered by the dataset is restricted to c. 8000 - 2900 BP, with an altitudinal range of c. -4.50 to - 18.00m below MHWS. In general the sea-level index points indicate a linear increase in relative sea-level between 8000 - 5000 BP. After 5000 BP the altitudinal variability increases, and no clear change in relative sea-level is apparent. Of note is the date recorded at 3850±80 BP recorded from Tilbury at a depth of -5.21m OD (-8.49m MHWS) which appears anomalous. This date is derived from a transgressive contact, and has been classified as a Group 2 date. However, the long duration of TIII recorded at Tilbury has been discussed in detail in Section 2.5.3., where it was noted that its duration is double that recorded at Crossness, whilst its thickness is markedly less than that recorded at the other sites. These comparisons cast doubt over the quality of this data point, despite the supporting litho- and biostratigraphic data.

This is not the only anomalous date collected from Tilbury. The date described above, as well as a slightly younger Group 4a date of 3940±110 BP recorded at -4.88m OD (-8.16m MHWS), are both at a critical position in the net uplift/subsidence plot presented by Shennan (1989, Fig.8f.). In Shennan's interpretation they generate the largest negative crustal residuals recorded between c. 3200 and 5000 - 5500 BP, and anchor the end point of his linear regression at c. 4000 BP. The latter Group 4b date used by Shennan (1987, 1989) has no detailed supporting litho- or biostratigraphic data, and has not been collected from a transgressive or regressive contact (Godwin et al 1962). This date was not used in the current study because of these data deficiencies.

The net crustal residuals calculated in this study indicate that between c. 8000 - 5000 BP there is a suggestion of slight net crustal uplift. This supports the conclusion proposed by Shennan (1989) of net crustal uplift in the Thames Estuary during this period. Between 5000 - 2800 BP there is no departure from a linear trend discernible in the pattern of residuals. This suggests that during this time period there was net crustal stability in the Thames Estuary. This interpretation differs from that proposed by Shennan (1987, 1989) who identified net crustal stability between 6500 - 4000 BP, followed by linear net crustal subsidence 4000 - 0 BP.

The assumption of a linear trend of net crustal subsidence between 4000 - 0 BP made by Shennan (1989) is based on the fact that the trend in residuals must pass through zero at the present day. A considerable increase in the rate of net crustal subsidence and relative sea-level rise must have occurred since 2800 BP in order to resolve these functions to zero at the present day. Alternative hypotheses for the apparent discontinuity between the relative sea-level and crustal movements between 2800 - 0 BP are discussed in Section 8.7.

8.5.2. The East Kent Fens Fig.8.4.

Fifteen Group 2 and Group 3 ^{14}C dates are recorded from the East Kent Fens, which provide an altitudinal and temporal range of between c. -4.50 to -11.00m below MHWS and 2400 to 6500 ^{14}C years BP. Between 6500 - 4800 BP relative sea-level appears to have risen, and then remained approximately constant between c. 4500 and 2400 BP.

Considering the pattern of the net crustal residuals, the data suggest crustal stability between c. 6500 and 2400 BP. Once again there is a marked discrepancy between the altitude of the most recent date (2400±230 BP) and present sea-level. An increase in the rate of crustal subsidence must have occurred (ignoring other factors such as sediment compaction - see Section 8.7.) in order to account for the 5m difference between the position of MHWS 2400 BP and its present level.

8.5.3. East Sussex and West Kent Fig.8.5.

Seventeen dated transgressive and regressive contacts (with known altitudes) from this area have been identified. These dates fall into two distinct groups, one between c. 6000 - 5000 BP and another between 4000 - 2000 BP. Altitudinally these data extend between -27m and -2m below MHWS, but are clustered between -10.00 and -6.00m below MHWS and -4.00 and -2.00m below MHWS. There is one outlier to this pattern from a basal peat dated to 8770±50 BP recorded from Langney Point.

Relative sea-level appears to have risen in a linear trend between 6000 - 5000 BP, after which the rate of relative sea-level fell sharply, sometime between 5000 - 4000 BP. Between 4000 - 2000 BP relative sea-level change was stable. Once again there is an absence of data between 2000 BP and the present, but an increase in the rate of relative sea-level rise must be invoked between 2000 - 0 BP.

Considering the trend in the crustal residuals, a reduction in the rate of net crustal subsidence must have occurred between 5000 - 4000 BP. This change appears to have been followed by relative crustal stability. Between 2000 - 0 BP a slight increase in the rate of net crustal subsidence must have occurred.

8.6. A comparison of net crustal values for Southeast England.

The relative sea-level data and crustal residuals of the three areas discussed above are illustrated in Fig.8.6. A comparison of these data enable changes in the rate of net crustal movement to be determined, although a re-emphasis of the age and altitude errors is relevant at this point.

Between 8000 - 4600 BP all areas demonstrate apparent net crustal stability, although there is the possibility of slight crustal uplift being recorded in the Thames Estuary between 8500 - 6000 BP. The Thames data depart from the trend apparent in the East Kent Fens and East Sussex and West Kent only prior to c. 6500 BP, when no data from these latter sites are available. A definite conclusion concerning the possibility of net crustal uplift during this period cannot be made until more data from all three areas has been collected.

After c. 5000 BP the data suggest that the rate of net crustal subsidence in the East Kent Fens and the Thames Estuary slowed relative to East Sussex and West Kent. In the former areas the rate of net crustal subsidence slowed at c. 4800 BP, and was followed by relative crustal stability until c. 2400 BP. Meanwhile, East Sussex and West Kent experienced high rates of net crustal subsidence until c. 4000 BP, when the rate of net crustal subsidence also slowed. From c. 4000 - 2000 BP all areas underwent relative net crustal stability. From 2000 - 0 BP East Sussex and West Kent must have undergone a slight increase in the rate of net crustal subsidence, whilst the Thames Estuary and the East Kent Fens must have experienced similar, but relatively higher rates of net crustal subsidence until the present day.

Finally, the data point from Langney Point, which appears to be a reliable sea-level index point, may suggest a different overall pattern of net crustal movements. For net crustal uplift to have occurred in East Sussex and West Kent before c. 6500 BP, as recorded in the Thames Estuary, one must invoke a change in palaeotidal range in excess of 5m. It is unlikely that this will have occurred, and it suggests that the Thames Estuary may have undergone a different crustal history prior to 6500 BP relative to East Sussex and West Kent. If the Langney Point date is reliable, it would imply that the apparent net crustal stability in East Sussex and West Kent between c. 6000 - 5000 BP may in fact represent part of a longer term curvilinear reduction in the rate of net crustal subsidence.

8.7. A comparison of calculated rates of relative sea-level change in Southeast England.

An alternative approach to the analysis of crustal movements in Southeast England is to calculate the rate of change in relative sea-level through time. The simplest assumption that relative sea-level is a function of the relative rates of change in isostasy and eustasy, would mean that the differences observed between regions reflect changes in their relative rates of crustal movement, although it is recognised that local processes will also be reflected.

In order to calculate the rate of relative sea-level change through time it has been necessary to establish a smoothed summary of each dataset. This was completed by calculating a smoothed SPLINE function, which was then differentiated. In order to make the observed data compatible with the present day, an additional data point at zero metres altitude and zero ^{14}C years age was added to each dataset.

The proposed approach is based on the analysis of changes in the rate of relative sea-level, and therefore absolute rates of crustal uplift/subsidence cannot be calculated (an advantage of the use of a eustatic value). The calculation of absolute rates would require the subtraction of the rate of observed relative sea-level change from the rate of eustatic sea-level change. This has not been attempted in the current study.

The main problem in the approach is the need to establish a summary curve for the relative data, in order that a rate of change may be calculated. These rates are strongly related to the form of the smoothed SPLINE function, and small changes in this function can have important implications for the rate of change in relative sea-level. This is an inherent problem when attempting to smooth data in this way. The main aim of using the SPLINE function was that it was a good approximation of the trend in relative sea-level data. Accordingly, various degrees of smoothing were calculated for each dataset until an adequate summary was obtained. The relative sea-level data, and the smoothed SPLINE function for each dataset is presented in Figs.8.7-9.

In addition, the calculated rates of change are in ^{14}C years, and not sidereal years. Because of the elastic nature of the ^{14}C timescale, these are not real rates of change, and it would therefore be inappropriate to present these data as absolute values. Here these data are used in a comparative sense, and as such the elasticity of the ^{14}C time scale is constant between regions at any point in time. Accordingly, these data are used to determine relative rates of change between areas, and not to indicate absolute values for the rate of change in relative sea-level. These data enable a direct comparison of rates of modelled relative sea-level change during the Holocene in Southeast England (Fig.8.10.). It should be noted that the deep Langney Point date was not used in this study because of the absence of other supporting data from this time period in East Sussex and West Kent, as well as in the East Kent Fens and the Thames Estuary.

Between 8000-5000 BP all three sites underwent a reduction in the rate of relative sea-level rise. The difference between these rates suggests changes in the rate of crustal movements between these areas during this period. In this situation these changes are interpreted as indicating differing rates of relative crustal subsidence. This is recorded in a time transgressive manner, occurring first in the Thames Estuary, then in the East Kent Fens, and finally on the East Sussex and West Kent coasts. After about 4000 BP the Thames Estuary, followed by the East Kent Fens, underwent an increase in the rate of relative subsidence. In contrast, East Sussex and West Kent continued to undergo a reduction in the rate of relative subsidence until approximately 2800 BP, after which the rate of relative subsidence in this area also increased.

Data interpretations during the recent Holocene (the last c. 2000 ^{14}C years BP) are difficult due to the lack of data, although it appears that in all areas there was an increase in the rate of crustal subsidence towards the present day. This rate of relative crustal subsidence was greater in the Thames Estuary and the East Kent Fens relative to East Sussex and West Kent.

The consistent nature of the changes observed suggest that the changes owe themselves to the operation of regional and not local processes. These changes conform to a dominant North-South control. However, it is stressed that the calculated rates are dependent on the form of the SPLINE function, as well as the distribution of relative sea-level data through the Holocene in each area, and that this approach has been used in an exploratory sense. These conclusions are therefore tentative, but may be compared with those determined through the direct comparison of relative sea-level data and through subtracting a eustatic constant.

8.8. Discussion.

Three main techniques of data analysis have been used to determine the evidence for crustal movements in Southeast England during the Holocene. The results of each approach are summarised below.

i. Comparison of relative sea-level data (Fig.8.11.) illustrates a linear increase in relative sea-level throughout Southeast England between c. 8000 - 5000 BP. In East Sussex and West Kent relative sea-level continued to rise until c. 5000 - 4000 BP, and then became stable. After c. 2400-2000 BP relative sea-level must have increased in all areas, rising faster in the Thames Estuary and the East Kent Fens relative to East Sussex and West Kent. Crustal instability within Southeast England, apparent from the differences in relative sea-level histories, is therefore only apparent between c. 5000 - 4000 and 2400-2000 - 0 BP.

ii. Analysis of the trend in crustal residuals (following the subtraction of a eustatic value) is presented in Fig. 8.6. There is evidence for slight net crustal uplift in the Thames Estuary between 8000 - 6500 BP. Evidence from other areas indicates a linear crustal trend between c. 6500 - 5000 BP. Between 5000 - 2000 BP the Thames Estuary and the East Kent Fens were crustally stable. In contrast, East Sussex and West Kent underwent net crustal subsidence between c. 5000 - 4000 BP, before a period of net crustal stability between 4000 - 2400 BP. After this period there must have been an increase in the rate of net crustal subsidence in all areas, which was larger in the Thames Estuary and the East Kent Fens relative to East Sussex and West Kent.

iii. Differences in the rate of relative sea-level change within Southeast England are presented in Fig.8.10. These differences can be interpreted in terms of changes in the rate of crustal subsidence. The rate of relative sea-level rise falls sharply after c. 6800 BP in the Thames Estuary. Evidence for a fall in the rate of sea-level rise is also apparent in the East Kent Fens from c. 6000 BP. In East Sussex and West Kent there is a fall in the rate of relative sea-level rise after c. 5000 BP. These changes suggest a diachronous reduction in the rate of crustal subsidence, commencing first in the Thames Estuary, then the East Kent Fens, and finally in East Sussex and West Kent. This reduction in the rate of crustal subsidence is followed by an increase in the rate of crustal subsidence after c. 4200 BP in the Thames Estuary, c. 3800 BP in the East Kent Fens, and c. 3000 BP in East Sussex and West Kent.

The evidence for crustal movements in Southeast England varies according to the technique of analysis used. That the results differ in detail suggests that the robustness of each technique is questionable.

Whichever approach is adopted, one must consider the rate of change in either the relative sea-level data, or the pattern of crustal residuals. This can be done by eye, as in the case of analysing the trend of crustal residuals, or by the fitting of a numerical function such as a linear regression equation, or a SPLINE function. The former requires the breakdown of the crustal record into a series of discrete time blocks, during each of which a linear crustal trend is assumed. More desirable, and more difficult, is the fitting of a non-linear expression to each dataset. However the changes in rates of crustal movement between areas when using this approach must only be interpreted as first approximations, as they are so strongly dependent on the form of the SPLINE function itself.

At the present stage, clear evidence for crustal movements within Southeast England, based on all three approaches, is only apparent between c. 5000 - 4000 BP, and c. 2400 - 0 BP. At all other times a linear function appears to describe adequately the rates of change observed (with the exception of the possibility of slight net crustal uplift in the Thames Estuary).

A consideration of the relative rates of crustal movement between the areas does suggest the possibility of a more complex pattern of crustal movements in the Southeast of England. Whether these more subtle changes are a function of reality, or an artifact of the approach adopted, can only really be determined following the collection of more empirical data from critical time periods. These periods are between 2000 - 0 BP in all areas, between 5000 - 4000 BP in East Sussex and West Kent, and before 6500 BP in all areas.

The lack of relative sea-level data during the last 2000 years is a serious constraint on all analyses. The increase in relative sea-level which must have occurred between c. 2400 - 0 BP suggests that a large increase in the rate of crustal subsidence must have occurred, especially as a eustatic origin for the increase in relative sea-level is unlikely (the general eustatic sea-level rise having been completed well before this time). Other causes for this pattern might include a change in the palaeotidal regime, although possible causes for such a change during the recent Holocene are not clear. A further explanation for the changes observed might be the effects of differential compaction, but this process would be unable to account for all the altitudinal differences observed. No single explanation for the patterns observed can be drawn until the nature of that pattern is known in more detail. The collection of sea-level index points younger than c. 2000 BP from southeast England is clearly required.

With respect to previous analyses of the evidence for crustal movements in Southeast England, the patterns discussed above suggest some important differences. Most important is the indication that Southeast England has not been dominated by simple net crustal subsidence during the Holocene. Rather, a far more complex pattern is apparent, both with respect to the region as a whole, and to the differing coastal units described above. The possibility of net crustal uplift in the Thames Estuary supports the suggestion of Shennan (1987, 1989), as does the evidence for crustal stability immediately after 6500 BP in this area. However, net crustal stability appears to have dominated the period 6500 to 2800 - 2400 BP in the Thames Estuary and the East Kent Fens. Crustal stability may also have been apparent in East Sussex and West Kent during this period, although there appears to have been a brief period of net crustal subsidence 5000 - 4000 BP in the latter area. All areas indicate subsidence after c. 2800 - 2000 BP.

Although the notion of global "eustasy" is no longer recognised as valid, nevertheless the subtraction of a eustatic constant does enable an approximation of net crustal values, as well as allowing the direct comparison of crustal residuals between areas. An alternative approach might involve the use of another constant, which does not claim to be eustatic, against which relative sea-level data from throughout the U.K. might be compared. In the current study emphasis has been placed on analysing differences between areas, and net crustal values should be interpreted as approximations which may be more useful as a means of between-area comparison, rather than necessarily providing absolute values for net crustal movements.

In conclusion, the patterns described in this Chapter are not sufficiently resolved to enable causative processes to be inferred at this stage. Only when more data have been collected during the strategic time periods identified above will any definite pattern of change be identifiable, and only then should a process, or processes, be proposed for the patterns observed.

Chapter Nine: Tendencies of Sea-level Movements in Southeast England.

9.1. Introduction.

Chapters Six and Seven described the evidence for local tendencies of watertable movements and sea-level changes in the East Kent Fens. This Chapter discusses the evidence for tendencies of sea-level changes at the broader spatial scale of Southeast England. ^{14}C dates discussed in Chapter Two from the Essex coast, the Thames Estuary, and East Sussex and West Kent are used.

The methodology involved in the tendency approach has been outlined in Section 1.5.2. Here it was noted that a distinction must be drawn between the type of data used in establishing a chronology of tendencies of sea-level movements, and one designed to analyse the evidence for crustal movements. In the latter an emphasis is placed on establishing the relationship between a dated level and a former sea-level. In the former emphasis is placed on establishing the indicative meaning of a dated deposit, without the same requirement of altitudinal control.

Datasets of differing composition are analysed in this Chapter. In addition, tendencies of sea-level movements are analysed using both ^{14}C and sidereal years. The first stage of analysis involves the simple plotting of those ^{14}C data indicative of a clear increase or decrease in the marine influence. This involves the use of all Group 2, 3, and 5a dates. These are presented on both ^{14}C and sidereal time-scales. The next stage of analysis is to enhance these data through the incorporation of Group 1, 4a and 4b dates. Again these are presented on both ^{14}C and sidereal timescales.

Whilst it is recognised that most, if not all of the Group 1, 4a and 4b dates indicate only periods of organic or inorganic sedimentation, it is assumed that these have accumulated under periods of negative or positive marine tendencies. It is recognised that at this scale of analysis the potential for within-deposit changes in the direction of the watertable, for example, are ignored. Thus, as discussed in Chapters Six and Seven, the evidence for tendencies of watertable and sea-level changes in the East Kent Fens are far more complex than that suggested by the gross lithology.

The approach adopted here is designed as a first approximation of the tendencies of sea-level movements in Southeast England. A more definitive statement must await an increase in the number of ^{14}C dates with supporting biostratigraphic data, and a recognition that there is a far more complex record of watertable, and probably sea-level changes, than that apparent from the simple analysis of transgressive and regressive contacts.

9.2. Calibration.

A common feature of sea-level studies when dealing with ^{14}C data has been the use of a ^{14}C time-scale. In Section 3.6. it was illustrated that the ^{14}C time-scale is elastic, due to the non-parallelism of the ^{14}C and sidereal calenders. However, the use of a ^{14}C time-scale in sea-level analysis has prevailed, largely because of the difficulties in presenting and analysing large numbers of calibrated dates. It should also be noted that where time series are being compared, then the effects of these differences do not matter, as this inconsistency is spatially constant through time.

Although dealing with calibrated ^{14}C dates in time/altitude analyses are difficult, the tendency approach provides a more amenable mechanism whereby calibrated ^{14}C dates can be analysed. The use of cumulative frequency histogram analyses of ^{14}C dates, plus their associated one or two standard age errors, has long been established in sea-level research (see Chapter One). Past approaches have been based on the cumulative probability (using the associated one or two standard errors) of a date indicative of a positive or a negative tendency of sea-level being recorded at a particular time. As the calibration of a ^{14}C date to the sidereal time scale involves the calculation of the probability of any particular date occurring within any given (sidereal) time period, calibrated dates are highly suitable to the cumulative probability approach of tendency analysis.

The mechanisms of calibration and calculating the cumulative probability values are discussed below. Each ^{14}C date was calibrated to a sidereal time scale using the CALIB program designed by Stuiver and Reimer (1986). This program calculates the probability of any sample having formed over a particular time range. This period is equal to the calibrated Gaussian distribution associated with each ^{14}C date. The calibrated form of this probability distribution is determined at a yearly interval spanning the range of the calibrated date.

The approach adopted in this study uses the entire calibrated Gaussian distribution of the original ^{14}C date, and not just the one or two standard errors. These data were exported from the CALIB program to a .prb file containing two columns of data (sidereal years and probability) for each ^{14}C date. Because these data files generated a probability value on a yearly interval, the .prb files were too large for easy handling, and therefore nine years from every ten were deleted. It was assumed that a single year in ten would be representative of that particular decade. Given the resolution of the ^{14}C technique, this was thought to be an acceptable summary.

A master spreadsheet was established in the program VPP, containing a single column of sidereal dates at ten yearly intervals, eg 1000, 990, 980, 970 etc, extending from AD 1000 to 7000 BC. Each .prb file was then matched against this master timescale at the appropriate point. Having completed this, the cumulative probability of a date indicative of a positive or negative marine tendency occurring during any ten year interval was calculated. This involved the addition of the probability values in each row (i.e. ten yearly interval). Two datasets were generated for each region which contained all those .prb files indicative of a positive or a negative marine tendency using firstly Group 2, 3, and 5 dates, and secondly dates from all groups.

A problem with the approach employed here is the limited time span of the calibrated dataset. It was only possible to calibrate ^{14}C dates using the CALIB program which were younger than 7000 BC, and therefore only a partial calibrated chronology for each area can be proposed.

In the rest of this Chapter reference is made to both ^{14}C and sidereal dates. To avoid confusion, ^{14}C dates are presented as years BP, and sidereal dates in years BC. For each of the regions discussed, a sequence of tendencies is described. These are abbreviated, and an example of each abbreviation is given below:

E1N	Essex Tendency 1 Negative
E2P	Essex Tendency 2 Positive
T1N	Thames Tendency 1 Negative
T2P	Thames Tendency 2 Positive
EKF1P	East Kent Fens 1 Positive
EKF2N	East Kent Fens 2 Negative
S1P	East Sussex and West Kent 1 Positive
S2N	East Sussex and West Kent 2 Negative

In the following section an attempt is made to establish a chronology of local sea-level tendencies in each of the areas studied using both the ^{14}C and sidereal timescale. Where possible these chronologies are based primarily on the patterns derived from the analysis of Group 2 and Group 3 dates, as it is these which provide the clearest indication of the tendency of sea-level.

9.3. Results - The Essex coast.

All dates from the Essex coast have been classified as Group 4a or 4b dates, and therefore only one local tendency diagram has been produced. The ^{14}C chronology is presented in Fig.9.1., and the sidereal chronology in Fig.9.2.

With the exception of the oldest ^{14}C date recorded at 7516±250 BP, five tendencies of sea-level movement can be identified from the Essex coast between c. 5000 - 1000 BP, which reflect the gross lithostratigraphic units of the lower clay, lower peat, middle clay, upper peat, and upper clay.

E1P. 6000 - 5300 ^{14}C BP, 5000 - 4100 BC.

The earliest positive sea-level tendency is recorded from Mar Dyke where a single date from a piece of drifted wood in estuarine silt has been recorded at 5740±80 BP. This date should be used with caution, as it is a single date and provides only a maximum age for the deposition of this deposit. However, it does suggest that estuarine conditions may have existed at this time. A lower clay is recorded beneath the lower peat in much of the Crouch Estuary to the north of Mar Dyke, also suggesting the possibility of a positive marine tendency prior to the formation of the lower peat.

E2N. 5300 - 3400 ^{14}C BP, 4100 - 1800 BC.

From c. 5300 - 3400 BP (4100 - 1800 BC) a negative tendency was recorded. This was associated with a prolonged period of organic sedimentation and the formation of the lower peat. In a few instances dates are from what are described as basal peats directly overlying head, but the absence of supporting biostratigraphic data prevent their classification as Group 1 dates.

E3P. 3400 - 2300 ^{14}C BP, 1800 - 0 BC.

A switch from organic to inorganic sedimentation heralded the beginning of a positive marine tendency, and which persisted from c. 3400 - 2300 BP (1800 - 0 BC). A succession of Group 4b dates associated with organic deposits found within the middle clay are recorded. Three Group 4a dates are also recorded within this period, although they are all from basal peats, and may well have accumulated under rising groundwater conditions. Once again, supporting biostratigraphic data for these dates are lacking.

E4N. 2300 - 1400 ^{14}C BP, 0 - 600 AD.

A brief negative marine tendency associated with a return to organic sedimentation is recorded from c. 2300 - 1400 BP (0 - 600 AD). This appears to correspond with the thin upper peat recorded in the Crouch Estuary and Mar Dyke.

E5P. 1400 - ? ^{14}C BP, 600 - ? AD.

One Group 4b date is recorded from the upper clay which overlies the upper peat, indicating a further period of inorganic sedimentation, tentatively interpreted as a further positive marine tendency. The two very young dates from what was believed to have been a pre-historic fish weir (see Table 2.2.3) have not been included in this study. More data are required from this period, although the apparent dominance of inorganic sedimentation may restrict the possibility of securing such data.

9.4. Results - The Thames Estuary.

Six clear local tendencies of sea-level movements are identifiable in Figs.9.3. and 9.4., where all Group 2 and 3 dates from the Thames Estuary are presented in ^{14}C and sidereal years. When these data are enhanced through the inclusion of all Group 1, 4a and 4b dates (Figs.9.5. and 9.6.) a slightly more confused pattern emerges.

<u>T1P. pre 7400 ^{14}C BP.</u>

The first tendency of sea-level changes recorded in the Thames Estuary is positive, and is indicated by a series of Group 1 dates and one Group 2 date (7830±100 BP). During this period the basal peat Tilbury I accumulated under rising groundwater conditions, and was replaced by inorganic estuarine or marine sedimentation associated with Thames I.

<u>T2N. 7400 - 6900 ^{14}C BP.</u>

There followed a negative marine tendency, which lasted from <u>c</u>. 7400 - 6900 BP, associated with the formation of the organic deposit Tilbury II. At West Thurrock, Broadness Marsh and the Dartford Tunnel, Tilbury II accumulated as a basal deposit. That this deposit is intercalated within the inorganic sediments of Thames I and Thames II indicates that a negative tendency did indeed occur during this period.

<u>T3P. 6900 - 6400 ^{14}C BP, 6000 - 5300 BC.</u>

From <u>c</u>. 6900 - 6400 BP (6000 - 5300 BC) there followed a positive marine tendency, under which the inorganic marine/estuarine deposit Thames II accumulated. Inorganic sedimentation during this period was very fast, with <u>c</u>. 3m of sediments being deposited at Tilbury.

<u>T4N. 6400 - 4200 ^{14}C BP, 5300 - 3000 BC.</u>

A major negative marine tendency was recorded in the Thames Estuary during this period, and the extensive organic deposit

Tilbury III accumulated. One Group 1 date from this period was recorded from Crossness at 5640±85 BP.

T5P. 4200 - 3500 ^{14}C BP, 3000 - 1800 BC.

During this period a positive marine tendency was recorded, and this was associated with the end of organic sedimentation (Tilbury III) and the deposition of Thames IV. The exact duration of T5N and T4P are unclear, as illustrated in Fig.9.5. and 9.6., where a sequence of Group 4a dates are also recorded during this period. These data suggest that the changes in sedimentation during this period occurred under a gradual transition from a negative to a positive marine tendency.

T6N. 3500 - c. 2900 ^{14}C BP, 1800 - c. 1000 BC.

A negative tendency was recorded in the Thames Estuary during this period. Lithostratigraphically this period equates with the development of the organic deposit Tilbury IV. The end of this tendency is poorly defined, and has only been dated in two locations (Tilbury and Stone Marsh). Group 4b dates are recorded after these two dates from Tilbury (Godwin et al 1965) and from Littlebrook. The dates from the latter are from the same deposit recorded in Bore 3 and 4 (Devoy 1977, Fig.16.), and it is assumed that the deposit dated is comparable with the organic deposit Tilbury IV.

Following this tendency only a few dates are available for analysis, although on the basis of the lithostratigraphic record there appears to be evidence for at least one more positive marine tendency (Thames IV) and one more negative tendency (Tilbury V).

9.5. Results - The East Kent Fens.

The data from the East Kent Fens provide a coherent sequence of dates, which indicate six local tendencies of sea-level movements. The alternation of positive and negative tendencies reflect the gross lithostratigraphy of the area. As all dates have been classified as either Group 2, 3, 5a or 5b, only two Figures (Fig.9.7.and Fig.9.8.) are presented.

EKF1P. Pre 6450 ^{14}C BP, Pre 5200 BC.

The earliest positive marine tendency which has been dated in the East Kent Fens is associated with the transgressive contact of the deepest organic deposit recorded at Hacklinge. A deep organic deposit was also recorded in Marsh Lane and Sandfield Farm, but was not dated.

EKF2N. 6450 - 5600 ^{14}C BP, 5200 - 4600 BC.

Following the brief period of inorganic sedimentation associated with the development of the lower inorganic deposit at Hacklinge, the main lower organic deposit recorded throughout the East Kent Fens formed. For most of its time this deposit accumulated under a negative marine tendency.

EKF3P. 5600 - 5100 ^{14}C BP, 4600 - 4000 BC.

During this period a positive marine tendency was recorded, and the middle inorganic deposit accumulated. Although only two dates exist for this change in tendency, the change is lithostratigraphically continuous throughout the area.

EKF4N. 5100 - 4300 ^{14}C BP, 4000 - 3000 BC.

There followed a negative marine tendency associated with the development of the upper organic deposit. It is probable that this tendency ended slightly earlier than the age range given above, as the duration of this tendency is strongly influenced by the comparatively young date for the end of the upper peat formation recorded in Marsh Lane (MMON).

EKF5P. 4300 - 3300 ^{14}C BP, 3000 - 1800 BC.

During this period a positive marine tendency was recorded from within the East Kent Fens. This saw the replacement of the upper organic deposit by the marine/estuarine deposits of the upper inorganic deposit.

EKF6N. 3300 - ? ^{14}C BC, 1800 - ?

Whilst inorganic deposition persisted in the down-valley locations, a further thin intercalated peat (not dated), and a final regressive contact (2400±200 BP) were recorded at Hacklinge. The negative tendency recorded here is therefore a simplification of the overall lithostratigraphic pattern recorded in the East Kent Fens, and reflects the pattern of ^{14}C date collection.

9.6. Results - East Sussex and West Kent.

The chronologies of sea-level tendencies from East Sussex and West Kent are presented in Figs.9.9. - 9.12. Five local tendencies of sea-level changes have been identified, although their identification requires careful consideration of the lithostratigraphic data.

S1P. 8800 - 6500 ^{14}C BP.

A positive marine tendency is recorded during this period, although only one supporting Group 3 date exists. Three Group 4b dates from basal peats indicate that organic sedimentation was replaced by inorganic sedimentation sometime after c. 8800 BP. This positive tendency appeared to persist until c. 6500 BP, although deep organic deposits are recorded in the Combe Haven (Smyth 1986) which may indicate a change in marine tendency during this interval.

S2N. 6500 - 5800 ^{14}C BP, 5500 - 4800 BC.

A negative marine tendency is apparent during this period, with regressive contacts being recorded in the Combe Haven and at Brede Bridge. This period of organic sedimentation persisted at Brede Bridge until c. 1830±80 BP when the (eroded) transgressive contact of this deposit was dated at Old Place (Waller 1987). Organic sedimentation in the Combe Haven was shorter-lived, and the transgressive contact was recorded here at 5780±80 BP. A thin organic deposit was also recorded during this period by Tooley and Switsur (1988) from Horsemarsh Sewer Bore 4, but for which only the transgressive contact has been dated (see below).

S3P. 5800 - 5500 ^{14}C BP, 4800 - 4300 BC.

During this period a positive marine tendency occurred, with two Group 2 dates recorded. These were associated with the transgressive contact in the Combe Haven at 5780±80 BP and the transgressive contact of the thin organic deposit recorded in Horsemarsh Sewer Bore 4.

S4N. 5500 - 3400 ^{14}C BP, 4300 - 1800 BC.

During this period only dates indicative of a negative marine tendency are recorded, although there is a serious data deficiency for much of this period (eg 5000 - 4000 BP). The early dates during this period mark the onset of a prolonged period of organic sedimentation in the Combe Haven and Horsemarsh Sewer and in the valleys leading to Romney Marsh such as the Rother and the Pannel. The limited data recorded during this period is probably a reflection of the continued organic sedimentation recorded at Combe Haven, and the persistent inorganic sedimentation recorded in Lottbridge Drove during this period. Organic sedimentation begins in the latter location at 3750±40 BP, whilst organic sedimentation also began in Tishy's Sewer at c. 3500 - 3400 BP. Also during this period organic sedimentation elsewhere in the Romney Marsh area was recorded, as reflected by the number of Group 4a dates recorded during this period.

S5P. 3400 - 2100 ^{14}C BP, 1800 - 0 BC.

A switch to a positive marine tendency is recorded during this period, with the end of the prolonged period of organic sedimentation described above. Transgressive contacts are recorded at Lottbridge Drove and Tishy's Sewer, as well as some time later in the Combe Haven. One Group 3 date was recorded at Broomhill Church at 2600±50 BP, although the broader significance of this change in sedimentation is not known. The exact duration of this positive tendency is not known, as a number of Group 4a dates are recorded which may suggest a more complex pattern of tendency changes.

For example, Figs.9.11. and 9.12. suggest that this tendency may have ended at c. 3000 BP (1200 BC), to be replaced by a negative tendency which persisted until c. 2200 BP (400 BC). Following this there is a suggestion of a further switch to a positive tendency until c. 2100 BP (100 BC), followed by a final negative tendency after c. 2100 BP (100 BC).

However, data from this period consists almost entirely of Group 4b dates, which lack supporting biostratigraphic, and in most cases, lithostratigraphic data. More dates are required from this period which have these supporting data before a more definite pattern of sea-level tendencies after c. 3000 BP (1200 BC) can be established.

9.7. Inter-regional comparisons - tendencies of sea-level movements in Southeast England during the Holocene.

The next and final scale of analysis involves the synthesis of data collected at the inter-regional scales from Essex, the Thames Estuary, the East Kent Fens, and East Sussex and West

Kent. This synthesis is attempted by the visual comparison of the data described above. Any attempt at a purely objective comparison is liable to ignore the essential lithostratigraphic data described for each region, and place an unrealistic emphasis on the original data. This is illustrated in the case of East Sussex and West Kent, where the discrete clustering of dates reflects the sampling pattern employed in this area during the past, and not necessarily the reality of sedimentary and sea-level change.

In order to aid in the visual comparison of data, each dataset has been broken down into two simplified tendency diagrams, one based on a ^{14}C and one based on a sidereal timescale (Figs.9.13. and 9.14.). These summary tendency figures are based mainly on the evidence derived from the analysis of Group 2 and Group 3 dates. A comparison of these chronologies indicate that the patterns generated through a use of the sidereal time scale does not differ significantly from that generated through the use of uncalibrated ^{14}C dates. The duration of individual tendencies does alter slightly, but the sequence of changes remains similar within and between areas.

A consideration of Fig.9.13. and 9.14. suggest that the evidence for synchronous changes in the tendencies of sea-level in Southeast England is equivocal. The most striking pattern to emerge is the close similarity between the record of sea-level tendencies recorded in the Thames Estuary and that of the East Kent Fens. This pattern is in contrast to the pattern of sea-level tendencies recorded in Essex and the East Sussex and West Kent, which are also very similar.

From c. 8000 - 6500 BP positive sea-level tendencies are recorded in most areas. The exception to this is the Thames Estuary record, where a negative tendency (associated with the development of Tilbury II) is recorded. It is unlikely that positive tendencies continued uninterrupted in other areas throughout this period. For example, attention has been drawn to the presence of deep un-dated peats both in East Sussex and the East Kent Fens which may be similar in age to Tilbury II. In addition, organic deposits have been recorded offshore the Essex coast, and dated to 7516±250 (Greensmith and Tucker 1973). Therefore the apparent dominance of positive tendencies between 8000 - 6500 BP is in part a reflection of the pattern of data collection, and not necessarily reality.

All areas except Essex recorded a negative tendency at c. 6400 BP. In the Thames Estuary this tendency extended uninterrupted until c. 4200 BP, but in Essex, the East Kent Fens and in East Sussex and West Kent, a brief but significant positive marine tendency is recorded between c. 5800 - 5100 BP. This tendency, which deposited up to 2.5m of inorganic marine/estuarine deposits in the East Kent Fens and the Combe Haven, was not recorded in the Thames Estuary. The crustal record during this period (Sections 8.4.-8.7.) suggests that no differential crustal movements occurred in Southeast England during this period. Any possibility of relative net crustal uplift in the Thames Estuary was completed by at least 6500 BP. Although Devoy (1977) recognised the continual presence of river inwashing during the formation of Tilbury III, no consistent litho- or biostratigraphic patterns were identified which might reflect this positive tendency recorded elsewhere.

The registration of this tendency in three out of four areas suggests that the processes responsible operated at a regional scale. This suggests a eustatic origin for this tendency, and that the absence of this tendency in the Thames Estuary may be due to the operation of local factors. These might include variable sediment supply and differing rates of peat growth within the region during this period.

Negative tendencies are recorded in all areas between c. 5100 - 4300 BP, when a positive tendency is recorded in the

Thames Estuary and the East Kent Fens. After this time the relative chronology of the Thames Estuary and the East Kent Fens, and that of the East Sussex and West Kent and Essex, are in direct contrast. In the former a positive tendency persisted until c. 3400 BP, and was followed by a further negative tendency. In the latter a negative tendency persisted until c. 3300 BP, and was followed by a positive tendency which lasted until c. 2000 BP.

Three hypotheses are proposed for the pattern of tendencies described above.

i. The first involves the operation of differential crustal movements within Southeast England during this period. This would require an increase followed by a decrease in relative subsidence in the Thames Estuary and East Kent Fens between c. 4300 - 2800 BP. Such a pattern of crustal movements was not apparent in Chapter Eight, where the only major change in relative crustal history between East Sussex and West Kent, and the East Kent Fens and the Thames Estuary during this period was an increase in the rate of subsidence in the former between 5000 - 4000 BP. However, a negative tendency is recorded in East Sussex and West Kent during this period. It would appear unlikely, therefore, that the patterns observed were caused by differential crustal movements within Southeast England.

ii. The second hypothesis is that the patterns observed owe themselves to the variable operation of local sedimentary processes. However, exactly what local processes would operate both in a small depositional environment such as the East Kent Fens, as well as in the much larger Thames Estuary to produce a similar sequence of tendencies is unclear.

iii. A final hypothesis is that the tendencies observed are an artefact of the methodology involved in initial data collection and subsequent analysis, and that they do not reflect the reality of changing tendencies of sea-level.

It has been noted above that the clustering of dates in Southeast England has been strongly influenced by the pattern of initial data collection. For example, the lack of dates from all areas prior to c. 6500 BP reflects the difficulties of collecting samples of that age from depth. In addition, the strong dependence on Group 4a dates in East Sussex and West Kent after c. 4000 BP has been noted.

A more detailed consideration of the sequence recorded in the East Kent Fens between c. 4000 - 2000 BP illustrates this dependence on ^{14}C data. Here the final negative tendency recorded in the East Kent Fens is from the upper regressive contact recorded at Hacklinge. However, in the rest of the infilled valley inorganic sedimentation persisted under what was probably marine/estuarine depositional conditions (although the diatom record is poor).

9.8. Conclusion.

In conclusion, the tendency approach is limited in a number of ways.

i. Firstly, the tendency approach requires large datasets, although typically it is used with relatively small datasets, which are often unequally distributed through time and over space.

ii. Secondly, it has been largely dependent on the use of transgressive and regressive contacts. As discussed in Chapters Six and Seven a transgressive or regressive contact represents only one point in time when inorganic marine/estuarine deposition replaces that of fresh/brackish terrestrial deposition. The use of Group 2 and 3 ^{14}C dates date only one point of a time transgressive process. The variable sedimentary response of a single depositional environment has been discussed in Chapters Six and Seven above. The identification of age gradients of varying duration associated with both lithostratigraphic and biostratigraphic changes within organic and inorganic deposits (see Chapter Seven) cast doubt on whether the tendency approach can be expected to resolve discrete patterns of sea-level tendencies through time.

No single hypothesis can be used to explain the patterns discussed above. It is likely that the patterns reflect both local and regional processes, but that the separation of these influences is not possible because of both the quality and temporal distribution of data available.

Chapter Ten: Conclusions.

10.1. Introduction.

Chapter 10 concludes this thesis by summarising the results of this study, and by assessing the extent to which the initial research aims outlined in Chapter One have been met. Each of the sub-sections 10.2. - 10.7. refers to each of the initial research aims outlined in Chapter One. The Chapter concludes by considering future research avenues.

10.2. Assessment of existing methodologies in Holocene sea-level studies.

Previous Holocene sea-level research has been characterised by three main research objectives and methodologies.

i. The first has been that of establishing the form of relative sea-level changes during the Holocene at a variety of spatial scales. This has primarily involved the use of time/altitude graphs. Although early studies of this nature claimed to be able to identify discrete rises and falls in relative sea-level, as defined by a single line, detailed local studies have suggested that this may not be possible, and that the use of a single sea-level band to describe relative sea-level data is more appropriate (Shennan 1982).

ii. The second has been in establishing the evidence for tendencies of sea-level changes. This methodology developed in response to the desire for a more rigorous approach to data analysis (Geyh 1969, 1971, Geyh and Streif 1970), and to enable the statistical presentation of ^{14}C dates collected from a range of palaeoenvironments (Roeleveld 1974, Morrison 1976, Shennan 1982, Tooley 1982, Shennan et al 1983). This approach has two main attributes:

a) Firstly, it is not dependent on the use of altitude, a key variable in the time/altitude analysis of sea-levels, but one which can be strongly affected by local factors.

b) Secondly, it is able to use dated material from a range of palaeoenvironments, as each date is not required to have an altitudinal relationship with a former sea-level.

However, whilst this approach is not dependent solely on the use of transgressive and regressive contacts, nevertheless these data have formed the basis of most previous analyses. This is in part a reflection of the inheritance of a ^{14}C database collected for the analysis of both relative sea-level and crustal movements, as well as a failure of researchers to explore the full potential of the methodology. The biostratigraphic record clearly demonstrates that a transgressive or regressive contact represents only one point in a time transgressive process of watertable and sea-level change (eg Tooley 1978). The logical conclusion to this is that any dating methodology concerned with the timing of sea-level events must consider within- and not just between-deposit changes.

iii. The third area of sea-level research has been the separation of the eustatic from the crustal component of relative sea-level data. This has previously been attempted by the direct comparison of relative sea-level data from separate areas, or by the subtraction of a eustatic constant from the relative sea-level record (eg Morner 1969, Shennan 1987, 1989).

Having identified these three main approaches to the analysis of past sea-level changes, this thesis has attempted to review critically and apply, where appropriate, each of these approaches to data collected from the current study area. The detailed results of these applications are summarised in the appropriate sections below.

10.3. The existing evidence for sea-level changes in Southeast England and the East Kent Fens.

In Chapter Two a selective review of previous sea-level research in Southeast England was completed. This was selective in that it concentrated on the screening and classification of existing ^{14}C dates. 113 ^{14}C dates were classified into five groups and two sub-groups according to their quality and indicative meaning as sea-level index points (Table 10.1.). This classification provided the chronological basis for the current study.

Table 10.1. Sea-level index points from Southeast England before the completion of this study.

Group	Location			
	Essex	Thames	E.Kent Fens	E.Sussex W.Kent
1	0	6	0	0
2	0	8	0	10
3	0	6	0	9
4a	22	17	4	17
4b	11	0	1	0
5a	0	0	1	1
5b	0	0	0	0

A review of the evidence for sea-level changes in Southeast England has illustrated the wide range of palaeoenvironments from which sea-level data have been collected, as well as the widely ranging quality of data available (note the limited number of Groups 1, 2, 3, 5a and b ^{14}C dates). The sedimentary environments identified include the estuaries of the Crouch and

Blackwater on the Essex coast, the Thames Estuary, the complex sedimentary environment of Romney Marsh, Pevensey Levels and the confined valleys of the Combe Haven and that identified in the East Kent Fens. A clear need for more detailed litho- and biostratigraphic analyses from all areas was identified, most notably from the Essex coast.

10.4. The pattern of Holocene sedimentation in the East Kent Fens.

The quality of any sea-level study is only as good as the lithostratigraphic foundations on which all subsequent analyses depend. To this end, this thesis has presented new lithostratigraphic data collected at two spatial scales within the East Kent Fens.

When research began only limited previous lithostratigraphic analyses had been completed in the study area. Accordingly, a large scale lithostratigraphic survey was completed in order to identify the potential of the area, and to establish the range of palaeoenvironments in existence. These were found to vary from the predominantly high energy inorganic palaeoenvironments which typified sites located within the course of the former Wantsum Channel (eg North and South Poulders), to the quiet shallow water sedimentary environments of Deerson Valley, Stewart's Folly and the Lydden Valley. Of these only the latter provided a sufficiently deep sedimentary sequence so that a chronology of sea-level changes over at least the last 5000 ^{14}C years could be established. Understanding the detailed form of the sediments recorded at each site involved the use of a three-dimensional approach to data collection, with a close sampling interval of between 30-50m being common.

Following the selection of the Lydden Valley for more detailed analyses, a second scale of lithostratigraphic analysis was completed. During this analysis it became clear that an understanding of the form of the pre-Holocene surface was required in order that the former relationship of the sites to the coast could be established. To achieve this an extensive seismic refraction survey was completed (Long et al in press).

A large S-wave velocity contrast between the Cretaceous Chalk and the Holocene sediments enabled the detailed form of the pre-Holocene sub-crop to be established. The seismic survey identified an infilled-valley of pre-Holocene age incised to a depth of c. -18m below surface (c.-16 to -17m OD), and up to 400m in width.

Three sites were selected from within this infilled-valley for further litho-, bio- and chronostratigraphic analyses. At Hacklinge, Holocene sediments were recorded to a maximum depth of c. -11m OD, and a maximum of seven inorganic and six organic deposits were identified. At Marsh Lane and Sandfield Farm three organic and three inorganic deposits were recorded, and were sampled to a depth of c. -9m OD.

The seismic survey helped to resolve an apparently confusing lithostratigraphic pattern recorded in the Lydden Valley into a meaningful distribution of sediments, which were seen to vary in an up-valley direction as the perimarine zone was approached and the organic sediments increased in thickness. Thus, inorganic sedimentation dominated the lower two sites (Sandfield Farm and Marsh Lane) with only thin organic sediments recorded, whilst at Hacklinge thicker organic sediments were encountered. Finally, the seismic survey also established the clear relationship between the sites under study and the open coast, as well as the former Wantsum Channel.

Having completed the lithostratigraphic and seismic survey, piston-cores and monolith samples were collected from the three sites described above. These consisted of a low-, mid-, and up-valley location (Sandfield Farm, Marsh Lane and Hacklinge respectively). The sampling strategy was designed to enable the three-dimensional reconstruction of bio- and chronostratigraphic changes in both up-valley and across-valley manner.

10.5. Palaeobotanical evidence associated with sedimentary changes at transgressive and regressive contacts recorded in the area under study.

Pollen and diatom analyses have been used to establish the nature of sedimentary changes associated with transgressive and regressive contacts recorded in the study area. This was necessary in order that the former altitudinal relationship of the contacts to a past sea-level might be established. A saltmarsh transition between inorganic and organic deposits was recorded in a total of 21 out of 25 lithostratigraphic contacts analysed (Table 10.2).

Table 10.2. Number of lithological contacts demonstrating a saltmarsh transition through pollen analyses.

Site	SF-10	SF-4	ML-9	MMON	H-7	H-2(a,b)
Number contacts.	4	2	4	2	5	8
Number showing no saltmarsh transition.	1	0	2	0	0	1

10.6. Palaeobotanical evidence for changes in vegetation communities as proxy data for changes in the altitude and salinity of the watertable.

A consideration of the tendency approach in Section 1.5. led to the proposition that previous approaches to data collection have not realised the full potential of the tendency approach.

In particular, the dependence on transgressive and regressive contacts in tendency analyses have limited the conclusions of this approach. This study has sought to explore this potential, by moving away from the exclusive use of transgressive and regressive contacts, and by assessing the evidence for within-deposit changes in the height and salinity of the watertable.

Whereas the previous analysis of any individual intercalated peat bed would perhaps have identified two tendency data points (the transgressive and regressive contact), the detailed analysis and spatial correlation of Local Assemblage Zones has enabled a large increase in the number of tendency data points for each deposit. Through considering the relative position of any core to the marine influence, an attempt has been made to identify not only the most suitable place within a sedimentary basin from which to date a positive or a negative tendency of sea-level, but also the specific point within any individual deposit where that tendency is first recorded. This approach has enabled the proposition of a continuous pattern of watertable and sea-level tendencies from the East Kent Fens, which is in part independent of the gross lithological pattern of transgressive and regressive contacts.

10.7. An absolute chronology for the pattern of Holocene watertable movements in the study area.

Twenty ^{14}C dates were collected from the study area, and these provided data concerning the pattern of relative sea-level and watertable movements in the study area over the last c. 6500 ^{14}C years BP. This represents a substantial addition to the existing database of sea-level index points from Southeast England (c. 18%). The collection of ^{14}C dates was designed both to provide data for the analysis of crustal movements in Southeast England (i.e. from transgressive and regressive contacts), as well as to date changes in the height of the watertable, based on pollen data. These dates were also collected in order to assess the detailed three-dimensional response of a defined sedimentary basin to changes in the elevation of the watertable and sea-level through time.

A consideration of these data has enabled the establishment of a continuous chronology for watertable and sea-level changes in the study area. At least six positive and six negative tendencies of watertable movements have been identified in the East Kent Fens between c. 6500 and 2000 ^{14}C years BP.

The earliest evidence for watertable movements was recorded at Hacklinge (H-2(b)), where a thin organic deposit accumulated at c. 6400 BP. However, litho-, bio- and chronostratigraphic data suggest that this deposit may not be in situ (Section 6.3.). The earliest clear evidence of watertable movements was recorded at SF-10 and H-2(b), where diatom and pollen data have indicated a reduction in the salinity, followed by a lowering of the freshwater table between c. 6500 and 5700 BP.

At Hacklinge a regressive contact has been dated to 6445±170 BP. Diatom data from SF-10 have shown that between c. 6250 BP and 6000 BP there was a reduction in salinity prior to the regressive contact of the lower organic deposit (dated to 5975±75 BP). Pollen data from this lower organic deposit have demonstrated that a fall in the relative watertable occurred during this period, and evidence for a fall in the watertable during this period is also recorded from ML-9, where the regressive contact of the lower organic deposit has been dated to 5765±150 BP.

Between c. 5700 and 5500 BP a positive watertable movement was recorded at SF-10 and H-2(a), which was associated with a return to marine conditions. At SF-10 the transgressive contact has been dated to 5550±110 BP, although this contact was not dated at H-2(b) due to sampling error. The biostratigraphic data from this period suggest a complex sedimentary response to changes in the salinity and height of the watertable, which is not conformable with the simple on-shore/off-shore movement of marine conditions suggested in Section 6.2.2. For example, there is no evidence for this positive watertable movement at ML-9 during this period, although diatom data from SF-10 and H-2(b) both indicate an initial increase in salinity above the transgressive contact.

From c. 5500 to 5300 BP a brief reduction in salinity was recorded by changes in the diatom flora at both SF-10 and H-2(b), before an increase in salinity once more at c. 5300 BP. In addition to the increase in salinity recorded at these two sites, at ML-9 the transgressive contact of the lower organic deposit has been dated to 5290±75 BP. There followed a period of strongly marine depositional conditions, which persisted between c. 5300 and 4950 BP (with the exception of a possible slight reduction in salinity suggested in LDAZ H-2(b)h).

After c. 4950 BP, diatom data have demonstrated that a reduction in salinity occurred, which was first recorded at H-2(b), and slightly later at SF-10. Regressive contacts have been dated at H-2(b) to 4890±130 BP, at SF-10 to 4640±110 BP, and at MMON to 4570±140 BP. This negative tendency persisted between c. 4950 to 4250 BP, after which there was an increase in the height of the watertable. A rise in non-obligate aquatics, followed by saltmarsh conditions has been dated at SF-10 to 4135±90 BP, and at MMON to 3980±140 BP. The switch to brackish/marine sedimentation associated with the transgressive contact has been dated at SF-10 to 4020±70 BP, at H-2(b) to 3905±205 BP, and at MMON to 3550±140 BP.

Diatom data from SF-10 and H-2(b) indicate that strong marine conditions became established above the transgressive contact, and that these conditions persisted until c. 3300 BP when a reduction in salinity was recorded in H-2(b) followed by the development of a saltmarsh peat. The exact age of this peat has not been established. Diatom data from SF-10 during this period are lacking due to the absence of diatoms in the sediments analysed.

A brief positive tendency then occurred demonstrated by the return to marine depositional conditions, but this was followed by a clear reduction in salinity at c. 2800 BP, which persisted until c. 2150 to 2000 BP. The regressive contact at H-2(b) has been dated to 2400±230 BP. A final change in the height of the watertable was recorded between c. 2150 to 2000 BP, and was demonstrated by an increase in the frequencies of obligate and non-obligate aquatic pollen taxa at Hacklinge (H-7 and H-2(a).

A serious limitation of this approach has been the inability to date the inorganic sediments themselves. Typically the diatom record from these sediments was far better than the comparable pollen record from the organic sediments, with clear changes in salinity being recorded within individual deposits. Despite recent advances in luminescence dating techniques (Berger 1988, Aitkin 1990), it is unlikely that the dating of such events to a resolution comparable with that of ^{14}C dating will be possible in the near future. The full realisation of the methodology proposed in this study awaits the development of such a technique.

10.8. The evidence for Holocene crustal movements in Southeast England.

Data collected from transgressive and regressive contacts in the East Kent Fens has been combined with data from other areas in order to analyse the evidence for crustal movements within Southeast England. Three techniques of data analysis have been used, so that the results and robustness of each can be compared and assessed.

i. The analysis of relative sea-level. Relative sea-level in Southeast England rose from c. -16m OD at c. 7900 BP, to between -6.00 and -5.00m OD by c. 4000 BP. In East Sussex and West Kent relative sea-level continued to rise to c. -2.00m OD by c. 4000 BP. In the Thames Estuary and the East Kent Fens relative sea-level rose slightly after this period to between -6.00 and -4.00m OD by c. 2500 - 3000 BP. In East Sussex and West Kent relative sea-level remained at c. -2.00m OD until c. 2200 BP. After this period relative sea-level must have risen once more to the present day, although data from this period is lacking.

The simple comparison of relative sea-level data between areas has suggested that differential crustal movements within Southeast England have occurred between 5000 - 4000, and 2000 - 0 BP. During these periods East Sussex and West Kent appear to have undergone a different crustal history to that of the Thames Estuary and the East Kent Fens. Other than during these two periods, existing data suggested that all areas appear to have had a similar crustal history.

ii. The subtraction of a eustatic value. The subtraction of a eustatic value based on Morner's regional/eustatic sea-level curve for the North Sea region (after Shennan 1987, 1989), has provided a more detailed pattern of net crustal movements during the Holocene. In the Thames Estuary, for example, there was support for Shennan's conclusion suggesting net crustal uplift from 8000 - 6500 BP of c. 2.50m to 3.00m. From 6500 - 5000 BP all areas appear to have been crustally stable. However, between 5000 - 4000 BP East Sussex and West Kent appear to have undergone net crustal subsidence of c. 2.00m, whilst the East Kent Fens and the Thames Estuary remained crustally stable. From c. 2200 - 0 BP East Sussex and West Kent appear to have undergone subsidence of c. 2.50m, compared with c. 4.00 - 5.00m in the East Kent Fens and the Thames Estuary.

It has been noted above (Section 8.6.) that whilst factors such as changes in the palaeotidal range and sediment compaction may have affected these values, nevertheless it is unlikely that these factors would be sufficient to account for the patterns observed. For much of the Holocene the data from the Thames Estuary and the East Kent Fens suggest that these areas were crustally stable (eg between c. 6500 - 2200 BP). This approach has suggested that important differential crustal movements have occurred during the Holocene within Southeast England, and that no simple linear function can be used to describe the pattern of net crustal movements.

iii. A comparison of rates of relative sea-level change.

Finally, an attempt has been made to compare the rate of change in relative sea-level between areas, and to explain the resulting differences as a function of their different relative crustal histories. Assuming that eustasy was constant spatially in Southeast England at any time, the differences in rates of relative sea-level change between areas have been interpreted cautiously as evidence for differences in the rate of crustal movements. The approximate rates of relative sea-level change in the three areas are summarised in Table 10.3.

This approach has suggested a north/south control on the pattern of crustal movements, with a pronounced reduction in the rate of crustal subsidence recorded first in the Thames Estuary (after c. 6500 BP), then in the East Kent Fens, and finally in East Sussex and West Kent. This was followed by an increase in the rate of relative subsidence after c. 4000 BP, recorded first in the Thames Estuary, then in the East Kent Fens, and finally in East Sussex and West Kent.

Table 10.3. Approximate rates of relative sea-level change in Southeast England (metres per ^{14}C year).

Period	Thames	East Kent Fens	East Sussex, West Kent
8-7000	-0.0035 to -0.0034	No data	No data
7-6000	-0.0034 to -0.0029	-0.0034 to -0.0032	No data
6-5000	-0.0029 to -0.0019	-0.0032 to -0.0025	-0.0034 to -0.0032
5-4000	-0.0019 to -0.0012	-0.0025 to -0.001	-0.0032 to -0.0021
4-3000	-0.0012 to -0.0014	-0.001 to -0.0006	-0.0021 to -0.0004
3-2000	-0.0014 to -0.0016	-0.0006 to -0.001	-0.0004 to -0.0003
2-1000	-0.0016 to -0.0017	-0.001 to -0.0014	-0.0003 to -0.0008
1-0	-0.0017 to -0.0018	-0.0014 to -0.0021	-0.0008 to -0.0012

Throughout these analyses there has been a recognition of potential time/altitude errors. Whilst the use of simple mean ^{14}C dates facilitates easier data analyses, any results must be interpreted with these errors in mind. Therefore, the most conservative conclusions arising from this study support the results derived from the first two approaches. Both these suggest that differential crustal movements within Southeast England are only recorded between c. 5000 - 4000 BP, and 2000 - 0 BP, when the relative rate of crustal subsidence in East Sussex and West Kent was first higher, and then lower than in the other areas under study.

All three approaches were severely restricted by the limited database, and in particular by the absence of dates from Southeast England prior to 6500 BP, as well as after 2000 BP. In addition, data from East Sussex and West Kent are required from 5000 - 4000 BP. The one date from Langney Point of 8770±50 BP suggests the possibility of early Holocene differential crustal movements between this area and the Thames Estuary, and emphasises the need for more dates of this age from Southeast England.

10.9. The evidence for tendencies of sea-level changes in Southeast England.

Following the classification of ^{14}C dates from Southeast England, evidence for local and regional tendencies of sea-level changes have been analysed using a ^{14}C and sidereal time-scale. The sequence of tendencies was identical using both time-scales, although the duration of individual tendencies was seen to vary. This did not significantly alter the interpretation of the data.

The most striking pattern to emerge was the close similarity between the record of sea-level tendencies recorded in the Thames Estuary and the East Kent Fens. This pattern was in direct contrast with that recorded in East Sussex and West Kent, which were also very similar. The main similarities in the pattern of tendencies of sea-level changes in Southeast England are summarised in Table 10.4. below.

Table 10.4. Approximate periods of similar sea-level tendencies in Southeast England.

Period (^{14}C years BP)	**Tendency**	**Comment**
6800 - 6400	Positive	Not Essex (no data)
6400 - 5800	Negative	Not Essex
5800 - 5100	Positive	Not Thames
5100 - 4300	Negative	All areas

Three hypotheses have been proposed to explain the contradictory pattern of tendencies observed within Southeast England.

i. Differential crustal movements between these areas. A comparison of the evidence for differential crustal movements between these areas has failed to identify a consistent relationship between the pattern of sea-level tendencies and the patterns of differential crustal movements.

ii. Local sedimentary processes. A consideration of the possible influence of variable local sedimentary processes has not explained why areas such as the East Kent Fens and the Thames Estuary, which are very different sedimentary environments, should record a similar pattern of sea-level tendencies, in contrast with those of Essex and East Sussex and West Kent.

iii. Methodological considerations. It has been argued that the tendency approach is strongly influenced by the distribution of data through time, and by the initial pattern of data collection. As a result, some of the differences observed between areas may be a reflection of the methodology of data collection and not necessarily reality.

It is probable that the pattern of sea-level tendencies observed is a function of the complex interaction of local and regional factors. Furthermore, it is also probable that the separation of these factors through the use of the tendency approach may not be possible at present, given the limited nature of the existing ^{14}C database.

It would appear that the use of transgressive and regressive contacts for the analysis of crustal movements are far more robust than they are in the analysis of tendencies of sea-level movements. This study also serves to re-emphasise the need for a clear appraisal of the objectives of any sea-level study.

If the research is concerned with the analysis of crustal movements, then it should focus on determining index points which possess a defined altitudinal relationship to a former sea-level. If it is concerned with establishing a chronology of sea-level changes, then it should concentrate on the combined litho- and biostratigraphic record, and adjust the sampling strategy accordingly.

10.10. Future research.

This thesis represents an attempt to elucidate the pattern of sea-level changes in the East Kent Fens, and to place the patterns observed into a wider geographical context. In this sense the initial research aims outlined in Section 1.2. have each been met. However, many issues concerning the evidence for Holocene sea-level changes in the East Kent Fens and Southeast England remain to be resolved.

The need for more sea-level data during certain critical time periods from Southeast England has been noted in Section 8.8. In the East Kent Fens in particular, data require collecting from between c. 9000 - 6500 BP, and between 2000 - 0 BP. That older material exists in the area is most probable, given the seismic depth determinations, and the presence of deeper peats along the South coast and in the Thames Estuary. The collection of these deep sediments is therefore an important future research objective. In addition, sea-level index points younger than c. 2000 BP also probably exist in the East Kent Fens. For example, at Stewart's Folly and in Deerson Valley intercalated organic and inorganic sediments are recorded above OD, and these require sampling and dating.

There is also a need for the incorporation of existing data (as well as the collection of new data) from the French and Belgian coasts, so that the patterns of crustal movements recorded in Southeast England may be placed within a broader geographical framework. This would enable the analysis of a number of other issues, such as the implications of sediment loading in the Thames Estuary and the Southern North Sea on the pattern of crustal movements along the South Coast.

The analysis of watertable movements may be further refined. For example, the approach needs to be tested in areas where the rate of organic sedimentation is less that that recorded in the East Kent Fens, and smaller samples require submitting for ^{14}C dating. In addition, contemporary studies of the relationship between the watertable and sea-level would greatly enhance the ability to reconstruct past changes in sea-level from changes in vegetation record, although the practical problems in completing such a study are recognised.

In conclusion, sea-level research is based on the careful collection and rigorous analysis of palaeoenvironmental data. The palaeoenvironments under which Holocene coastal sediments accumulated were as complex as any contemporary coastal depositional environment. A failure to appreciate this complexity when dealing with Holocene sea-level data will over-simplify and perhaps even invalidate subsequent interpretations and conclusions.

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