"LATE-QUATERNARY ENVIRONMENTAL CHANGE AT EASTBOURNE, EAST SUSSEX".

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To my family.

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ERRATA :

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NOMENCLATURE.

For a complete botanical nomenclature for the species mentioned in the text, the reader is referred to Clapham, A.R., Tutin, T.G. and Warburg, E.F. 1962. Flora of the British Isles. (2nd edition). Cambridge University Press.

The full nomenclature for the diatoms identified is ;

Diploneis gruendleri (A. Schmidt) Cleve.
Nitzschia navicularis (Breb.) Grunow.
N. punctata (W. Smith) Grunow.
Paralia sulcata (Ehrenberg) Cleve.

A complete zoological nomenclature for the species of Mollusca, Foraminifera and Ostracoda referred to in the text is given in appendix 1.

ABBREVIATIONS.

A.P.	- arboreal pollen.
E.S.C.C.	- East Sussex County Council.
I.G.S.	- Institute of Geological Science.
M.H.W.S. (T.)	- Mean High Water Springs (Tides).
m. O.D.	- metres Ordnance Datum.
p.a.z.	- pollen assemblage zone.

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LATE-QUATERNARY ENVIRONMENTAL CHANGE AT EASTBOURNE, EAST SUSSEX.

S.C. JENNINGS.

This study is an examination of the late-Quaternary palaeo-environments of the Eastbourne area. The principal techniques employed are pollen, Foraminifera, Ostracoda, Mollusca and sediment particle size analyses. The lithostratigraphic investigation, using hand auger and a commercial drilling rig, revealed extensive unconsolidated sediments down to a maximum depth of 33m. which consist of gravels, sand, silt and clay with restricted peat development.

The history of the vegetation has been traced back to the Lateglacial when, it is argued, an unusually thermophilous community which included Alnus prospered. The early Flandrian vegetation was dominated by Corylus and Pinus, the latter genus being replaced by members of the 'Mixed-Oak Forest' before 8,770 ± 50 B.P.. Prior to this date, Juniperus expanded. The nature of the mid-Flandrian vegetation is unclear due to the presence of secondary pollen. However, this secondary pollen has been used to provide information on the nature of sedimentation on Willingdon Levels. In addition, a model of pollen transfer in estuarine sediments is proposed. Poor pollen preservation has allowed an examination of pollen deterioration and its possible use for palaeoenvironmental reconstruction to be attempted. The late-Flandrian vegetation reveals the impact of both anthropogenic factors and coastal changes.

The pattern of Flandrian coastal/sea-level change has been reconstructed through an examination of transgressive and regressive contacts and overlaps and their associated biostratigraphies. In addition to two contacts, three phases of positive dominant tendency and two phases of negative dominant tendency of relative sea-level movement are recognised. It is argued that the coastal sediments at Eastbourne are probably the result of the growth and over-running of depositional features superimposed upon the main Flandrian rise in sea-level, rather than reflecting eustatic oscillations.

The pattern of sedimentation and the vegetation successions are placed within a regional context, and then combined to produce a model of landscape evolution for the late-Quaternary at Eastbourne.

SECTION A. INTRODUCTION

A 1. Primary aims and methodology.

The aim of this research is to reconstruct the late-Quaternary palaeoenvironments of the Levels around Eastbourne, and to analyse the factors responsible for their development. In order to achieve this two broad approaches are adopted namely, the examination of vegetational changes and the investigation of the factors responsible for the deposition of the extensive unconsolidated sediments present in the area. This research is therefore intended to be a contribution both to the understanding of vegetational change and to the evolution of a coastal area in southern England during the late-Quaternary.

The adoption of these two approaches is considered necessary in order to achieve the aim of this research, because the study of vegetational successions, together with lithostratigraphic changes, provide a more complete insight into the nature of palaeoenvironments than would the pursuit of a single approach. However, it is important to establish from the outset that both approaches are not separate and distinct but are, in effect, complementary. Together these approaches allow for a variety of environmental factors to be studied, factors which may be either operating independent of each other or in conjunction. This is well illustrated by the study of the fossil pollen assemblages identified from the sediments sampled at Eastbourne. Most of the pollen will be used to analyse vegetational change (Section C), but reworked pollen of pre-Flandrian age will be used to investigate the pattern of sedimentation (Section D). Indeed, it will be shown that in some cases the type of sediment can influence the character of the pollen assemblage.

The terms 'palaeoenvironment' and 'palaeoenvironmental change' are used in this study to include both vegetational and

lithostratigraphic aspects. It will be proposed that although the development of the environment reflects regional influences, both the vegetation and the evolution of this coastal area through the late-Quaternary also exhibit important local characteristics. It will be suggested that the development of an unusually thermophilous Lateglacial flora and the establishment of coastal barriers during the Flandrian represent probably the most significant aspects of this local environment.

The deposits of the study area have been examined spatially through a sequence of stratigraphic investigations using drilling equipment or, for more sensitive analysis, hand augers. Temporal limits on the sediments are restricted by the lack of organic material, but ^{14}C analysis has been applied to four key lithologic boundaries.

The nature of the sediments of the study area, the methods of recovery of samples and the techniques used to investigate the mode of deposition will be examined in Section B. The results of the sediment particle size, Foraminifera, Ostracoda, Mollusca and diatom analyses are described. Section B will also include a synopsis of previous sub-surface investigations in coastal areas of East Sussex. In addition, the problem of terminology used to describe sedimentological changes in coastal areas and the inferences regarding past sea-levels will be discussed. Such lithostratigraphic changes within coastal deposits have been termed 'contacts' if they are recognised in only a single core, or 'overlaps' if the contacts can be traced from site to site (Shennan, 1982, 1983; Tooley, 1982). Their examination is a fundamental technique in the study of sea-level/coastal changes. The I.G.C.P. Project 61 highlighted the coast of Sussex as being barren in the investigation of Flandrian sea-level change (Devoy, 1982; Tooley, 1982) and therefore this study is intended to provide some much needed information on this topic.

The contacts and overlaps identified within the sediments of the Eastbourne area will be described in Section B, and their implications for the evolution of the coastline will be discussed in Sections E and F. It will be suggested that a complex relationship between coastal processes and eustatic movements has occurred along this part of the coastline during the Flandrian resulting in a sequence of contacts and overlaps that are largely the consequence of changing coastal configuration superimposed upon relative movements of sea-level.

In Sections C and D the results of the pollen analysis will be presented. This is the main technique used in this study to investigate vegetational changes, but supplementary information has been provided by macrofossil analysis.

Pollen analysis has been applied to these coastal sediments despite the preponderance of minerogenic deposits which contain only low pollen concentrations often in a poor state of preservation. As will be explained in Section B, the extensive unconsolidated sediments in the Eastbourne area probably date from the end of the Devensian cold stage and thus present the opportunity to study the development of the vegetation from the Lateglacial. This was considered to be a particularly important opportunity in view of the absence of any previous investigations of the Lateglacial flora of coastal Sussex and because of only the limited understanding of the early Flandrian vegetation (Scaife and Burrin, 1983). Thus, despite the concentration and preservation problems, pollen analysis has been undertaken on these sediments and will be shown to be a valuable technique for the study of palaeoenvironments from largely minerogenic deposits. As will be discussed in Sections C and D, one important aspect of this has been the identification of a secondary pollen component within the pollen assemblages, and an assessment of the use of secondary pollen for palaeoenvironmental reconstruction is made in Section D. From this assessment, the recognition of

secondary grains will be used in this study to aid the reconstruction of the sedimentological history of the area. In addition, in Section D, a model of pollen transfer for an estuarine environment will be described, and the nature and extent of pollen deterioration will be discussed. Possible implications of grain deterioration for palaeoenvironmental reconstruction will be considered.

The data and results presented in Sections B to D will be brought together in Section E to provide a discussion on late-Quaternary environmental change in the Eastbourne area. From this, a model of landscape evolution for this area will be proposed in Section F.

A 2. Description of the study area.

The area covered by this study comprises the lowland immediately to the east and north of Eastbourne and occupies approximately 13km^2. The whole area lies between approximately +5m. to +2m. O.D., but two basic topographic units can be recognised; firstly, the shingle complex on the coast (photographs 1 and 2) and secondly Willingdon Levels (photographs 3 and 4) which lie behind this shingle (Fig. A1 and A2). This is the collective name for all this lowland which is divided into the smaller units of Eastbourne Level, Southbourne Level, Willingdon Level, West Langney Level and Shinewater Marsh.

The western boundary of this area is the steep Chalk escarpment of the South Downs terminating in a sea-cliff at Beachy Head (163m.). To the east and north the area is bounded by the low hills of Weald Clay which attain a maximum height of 35m. and separate Willingdon Levels from the more extensive Pevensey Levels. The sea forms a boundary to the south where it has been responsible for the formation of the shingle complex known as the Crumbles which extends eastwards to Pevensey Levels. The Crumbles also forms a promontory at Langney Point (TQ 642011). Close to

PHOTOGRAPH 1. LANGNEY POINT – THE POINT (LOOKING EAST)

PHOTOGRAPH 2. LANGNEY POINT – THE CRUMBLES SHINGLE (LOOKING NORTH)

PHOTOGRAPH 3. WILLINGDON LEVELS (LOOKING EAST OVER LOTTBRIDGE DROVE)

PHOTOGRAPH 4. WILLINGDON LEVELS (LOOKING SOUTH TOWARDS ST. ANTHONY'S HILL)

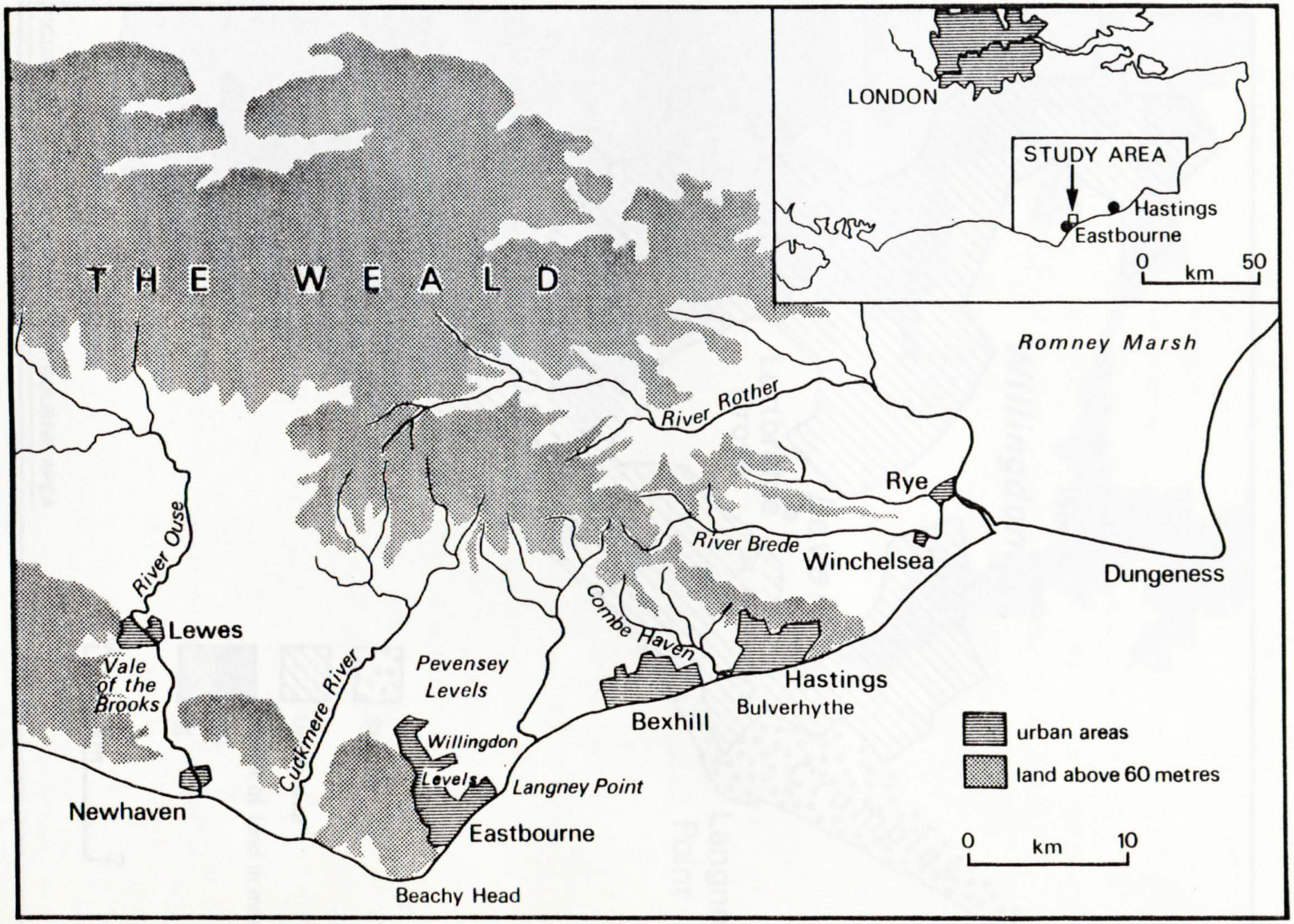

FIGURE A1. LOCATION MAP – REGIONAL CONTEXT

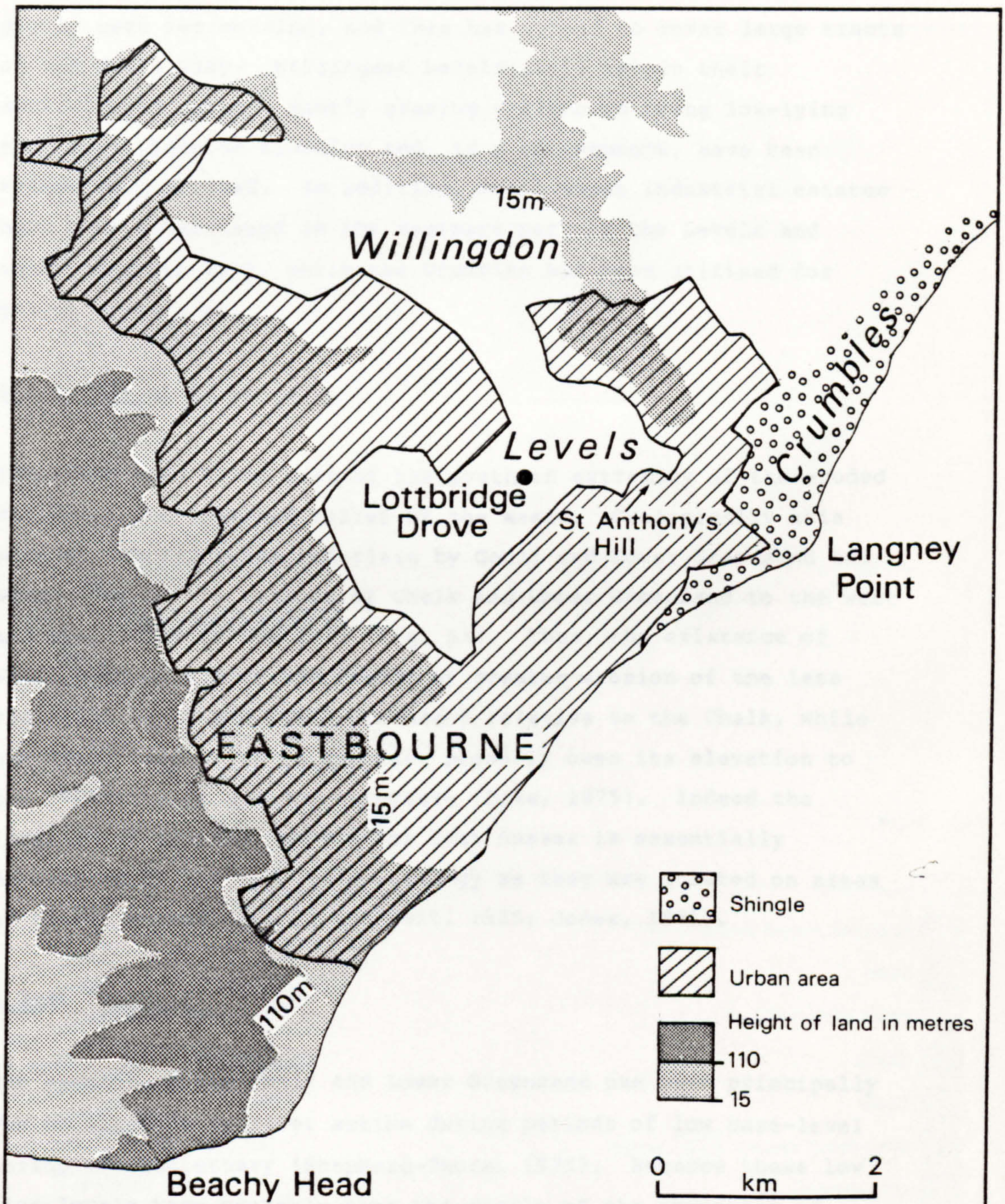

FIGURE A2. LOCATION MAP – EASTBOURNE AREA

the coastline are two small 'islands' of Gault, the most conspicuous being St. Anthony's Hill which rises to about 15m.

This coastal zone, except for much of the Crumbles, has been mostly used for housing, and this has spread to cover large tracts of the Weald Clay. Willingdon Levels still retain their agricultural usage - mostly grazing - although being low-lying they are liable to flooding and, as a consequence, have been extensively ditched. In addition, small light industrial estates have been established in the southern part of the Levels and around Hampden Park, while the Crumbles has been utilised for gravel extraction.

A 2.1. The solid geology.

The study area forms part of the southern extremity of the eroded anticline and inverted relief of the Weald. Geologically this area is complex being underlain by Gault and Lower Greensand and surrounded by the uplands of Chalk and Upper Greensand to the west and Weald Clay to the east (Fig. A3). Thus, the existence of Willingdon Levels is the result of greater erosion of the less resistant Gault and Lower Greensand relative to the Chalk, while the Weald Clay ridge to the east probably owes its elevation to the proximity to a horst structure (Lake, 1975). Indeed the location of all the 'Levels' of East Sussex is essentially determined by the underlying geology as they are located on areas of weaker strata (Milner and Bull, 1925; Jones, 1981).

A 2.2. The drift geology

The erosion of the Gault and Lower Greensand has been principally due to incision by river action during periods of low base-level during the Quaternary (Shephard-Thorn, 1975). Because these low base-levels have probably been the result of the expansion of glaciers and ice-sheets producing glacio-eustatic lowering, the

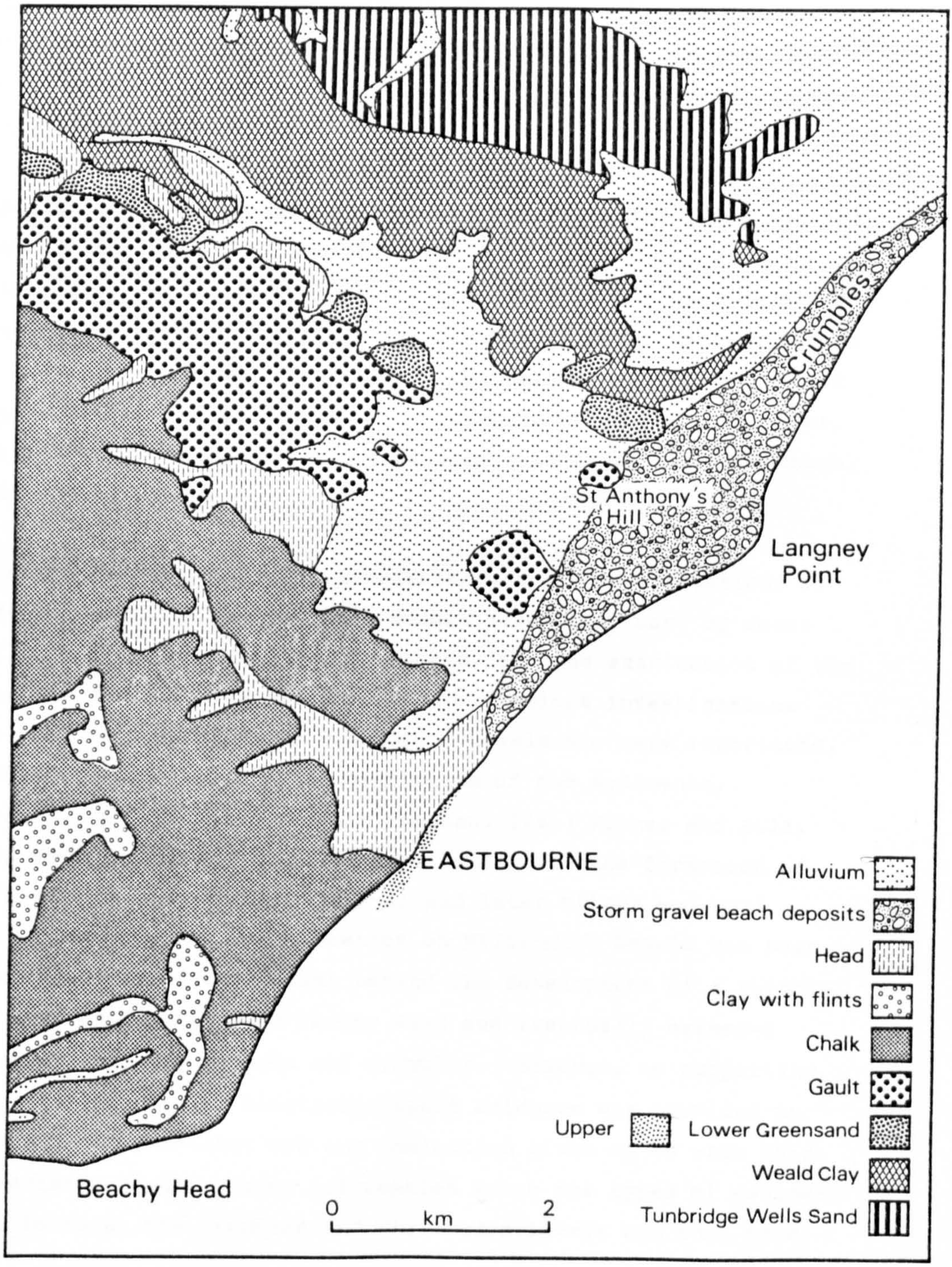

FIGURE A3. EASTBOURNE AREA – GEOLOGY MAP

associated cold conditions in southern England produced soliflucted deposits known as 'Head' (Dines et al., 1940; Gallois, 1965) which, when associated with the coombes of the Chalk escarpment are referred to as 'Coombe Deposits' (Gallois, 1965; Jones, 1981). Such deposits have been recognised on and at the foot of the escarpment near Eastbourne (Bull, 1940; Kerney, 1963) and therefore form important drift material on the western margin of Willingdon Levels.

With the rise in sea-level from the Lateglacial, low-lying coastal areas of East Sussex became the centres of a new depositional environment. This resulted in the infilling of the over-deepened river channels to produce the buried channels found today offshore and underlying present floodplains (Shephard-Thorn, 1975; Auffret et al., 1980). As sedimentation continued, extensive freshwater, brackishwater and marine sediments were laid down (Shephard-Thorn, 1975; Jones, 1981).

The only previous, detailed lithostratigraphic investigations of these sediments in coastal East Sussex have been those by Jones (1971, 1981) in the Vale of the Brooks, and the examination of the sediments at Dungeness (Green, 1968). Previous investigations into the drift material of Willingdon Levels are very restricted, tending to concentrate on a description of the sediments, especially the Crumbles shingle (Redman, 1851; Milner and Bull, 1925; Steers, 1964). In an attempt to explain the formation of Willingdon Levels, Redman (1851-2) and later Milner and Bull (1925) proposed that sedimentation on Willingdon Levels has been the consequence of deposition behind the development of a shingle spit that originated from Beachy Head and eventually extended across to Pevensey to form the Crumbles. However, no supporting lithostratigraphic or biostratigraphic evidence was provided by these authors. Neither was any indication given as to when this sedimentation began. Some information as to the types of sediment to be found at the Crumbles and Willingdon Levels has come from

engineering work, but the borehole records and reports do not provide very much detail on the environment of deposition, and give only extremely limited accounts of the biostratigraphy. Nevertheless, these engineering projects have revealed that the study area contains extensive unconsolidated deposits to a depth of approximately 33m. at Langney Point (Shephard-Thorn, 1975).

Thus Shephard-Thorn's observation in 1975 that 'by and large we remain in some ignorance of our Flandrian deposits', although originally applied to the Weald as a whole, was especially true for the area around Eastbourne.

SECTION B. THE COASTAL SEDIMENTS OF EAST SUSSEX AND DATA FOR THE STUDY OF SEA-LEVEL CHANGE IN THE EASTBOURNE AREA.

The sediments of the study area are not of one type, forming as they do an interbedded sequence of clay, silt, sand and gravel with restricted peat development. In general terms they form a tripartite sequence composed of an organic deposit intercalating minerogenic layers. This pattern is repeated at other low-lying coastal sites in East Sussex (Jones, 1981). However, in detail there are significant inter-site differences such that the establishment of an accurate lithostratigraphy is of paramount importance if meaningful results are to be obtained and correlated.

The study area of Willingdon Levels and Langney Point contains extensive sediments that have been little studied but, being on the coastal margin for much of the Flandrian, lend themselves to an examination of coastal/sea-level changes and the concomitant modification to the vegetation.

B 1. Previous investigations in coastal East Sussex.

Although detailed investigations of the sediments in coastal areas of East Sussex have been limited, nonetheless useful data on the types of sediment to be found and their mode of formation have been obtained.

The work of Redman (1851-2) is one of the earliest attempts at explaining the origin and development of the shingle of the south coast. Mainly with reference to old maps, charts and descriptive accounts, he suggested a 'counter-balancing character' for the coast between the Thames and Portland whereby areas of degradation are matched by considerable accretion, mostly of shingle, in other locations. Redman showed these shingle barriers rest upon (Quaternary) clay and sand which have continued to accumulate to

their leeward, the most notable example being Romney Marsh in the protection of Dungeness.

Understandably, because of its size, the deposits that form Romney Marsh have received particular attention. Green (1968) describes the sequence of sediments and analyses their depositional history. He interprets the development of Romney Marsh as being one of sediment accumulation behind offshore sand banks and later shingle spits so that marine and estuarine facies pass up into freshwater peats and alluvium. Green describes the ness itself as composed mostly of flint derived from the chalk further west and brought to the area by longshore drift. This flint forms numerous ridges interpreted by Lewis and Balchin (1940) as marking former coastlines developed under conditions of changing sea-levels. The original ness was probably formed close to Fairlight and then extended eastwards to its present position (Lewis, 1932).

The Blue Clay of Romney Marsh, which Green suggests may be stratigraphically related to the Buttery Clay of the Fenlands, is overlain by a peat containing tree trunks which marks a change to a freshwater environment. In the 'post-peat period' of about 2,000 years, Green contends that sedimentation has been influenced by changes in sea-level, the breaching of shingle barriers, changes to the courses of rivers and finally by inning and draining that had begun by the 9th century (Cunliffe, 1980).

This general sequence of events finds support in the work of Eddison (1983a, b) who states that the arrival of shingle may date back to around 6,000 B.P. However, Shephard-Thorn suggests that the original barriers were mostly composed of sand with large quantities of shingle being a later addition (pers. comm.).

From a detailed programme of hand augering, Jones (1971, 1981) has studied the sediments in the Vale of the Brooks between Lewes and Newhaven. Jones regards the lithostratigraphy as forming a

tripartite sequence with an upper silt and silty clay, a peat and peaty clay, and a lower layer of clayey sands and gravel. Moreover, Jones (1981) argues that such a lithostratigraphy is common to other coastal areas of south east England. Burrin (1982) has reviewed these sediments in the light of engineering projects. He maintains that the original threefold division may still be recognised, but the sediments are more complex than previously stated, especially in the upper minerogenic horizons.

Moffat (1984) has described the upper sequence from a site on Pevensey Levels, an area of extensive lowland that is still largely unresearched although the I.G.S. possess some borehole data.

Smyth (1985) has produced a lithostratigraphy for the Combe Haven Valley between Bexhill and Hastings. Extensive hand augering revealed approximately 4m. of peat with thin clay layers, overlain by 1m. of clay and silty clay. Below the peat, blue clay is intercalated by lower, less extensive peats, and borehole records held by Southern Water show a basal peat overlying gravel at approximately -16m. O.D. Further research is currently being undertaken on these sediments.

As will be discussed in Section B 2, engineering projects have been very useful in providing general information, especially on the deeper sequencies that cannot be reached by hand augers. Much of the lithostratigraphic detail from Dungeness was obtained from boreholes involved in the construction of the nuclear power stations. East Sussex County Council has carried out extensive sub-surface investigations mainly for road improvement schemes. These have greatly added to our knowledge of coastal sediments in many areas, for example around Winchelsea.

The amount of data now contained in borehole logs by E.S.C.C. (and local councils), the I.G.S., Southern Water and by private

contractors is an important source of information for any stratigraphic investigation for this area, provided that caution is exercised if detailed information is taken from them.

B 2. Site selection and sample extraction.

A wide range of investigative techniques was used to analyse the lithostratigraphy of the Eastbourne sediments. Preliminary investigations using engineering borehole logs provided a general picture of the unconsolidated sediments of this area. A commercial drilling rig and hand auger were used to establish a detailed lithostrathigraphic record and to obtain samples of the sediments.

Borehole records played an important role in the early stages of this study. Normally, for site selection purposes, extensive hand augering would be carried out in the proposed study area in order to investigate the most promising sedimentary sequencies. However, one of the main objectives was to locate and sample the deepest sequencies because they were likely to contain the oldest deposits. These were beyond the reach of the hand augering so that borehole logs obtained for engineering purposes were the only source of information on these deposits. They provided a useful assessment of the sediments to be found in the area. In all 110 logs were analysed, usually in the presence of the log compilers, but only general information has been extracted from them. This is because many engineering projects do not usually require the detailed recording in the field of all stratigraphical changes that is necessary for the accurate reconstruction of palaeoenvironments.

In this study, lithostratigraphical diagrams are based on data obtained from augering or from drilling undertaken specifically for this purpose. Where information has been taken from existing borehole logs - and this has been kept to a minimum - this is acknowledged either in the text or on the diagram.

To sample the deeper sequencies, a commercial Wayfarer drilling rig was employed. Two boreholes were sunk, one at Langney Point (BH.1) and the other at Lottbridge Drove (BH.2) on Willingdon Levels (see figure A2).

B 2.1. Langney Point (TQ 642011).

The site at Langney Point was chosen for investigation because borehole logs held by Ove Arup and Partners indicated the presence of extensive unconsolidated sediments to a depth of approximately -29m. O.D.. Of particular interest was a deeply buried organic layer of early Flandrian age (see Table B1).

Table B1. Depth of organic layer at Langney Point.

Extent of organic layer : -24.8m. O.D. to -28.3m. O.D.
Depth of sample : -24.9m. O.D. Date : 8,760 ± 75 B.P.
Depth of sample : -27.3m. O.D. Date : 9,510 ± 75 B.P.

(Source - Shephard-Thorn, 1975)

This deeply buried organic layer appears to be more extensive at this site than at other known coastal locations in south east England (Shephard-Thorn, 1975).

Records of this type indicate that along the present-day coast of Sussex, peat growth was in evidence during the early Flandrian. By studying this deposit, an insight into the nature of the vegetation from this time should be gained. This deep peat/organic layer at Langney Point is overlain by littoral deposits culminating in the Crumbles Shingle. A study of these deposits was undertaken in order to establish sea-level tendencies and to gain further biostratigraphic information.

No exploratory sub-surface investigations were carried out because hand augering could not penetrate the surface shingle. Therefore, this site was chosen purely on information from borehole records.

B 2.2. Lottbridge Drove (TQ 614016)

In 1980 East Sussex County Council drilled a number of boreholes at Lottbridge Drove on Willingdon Levels for a proposed extension to a rubbish tip. These boreholes, supplemented by hand augering, encountered a peat layer which had formed on clays and silts. Below these, a basal layer of angular flints in a matrix of clay, chalk and sand was located. Overlying the peat was a stiff orange-mottled clay.

This find was of particular interest for two reasons. First, Lottbridge Drove is only 3km. from Langney Point and, therefore, both sites probably have an inter-related history. By obtaining information from two sites in close proximity a more complete picture of environmental change can be constructed. This is especially important with respect to establishing sea-level tendencies. It was thought that Lottbridge Drove, being inland of Langney Point, may contain the equivalent landward facies of sequencies deposited further seaward. Thus, if lithostratigraphic overlaps could be identified (see this section) there existed the prospect that they might be traced across the present coastal area and thereby establish their spatial limits. Second, the basal layer resembles a solifluction deposit (Lake, pers. comm.) and thus provided the possibility of studying a Lateglacial sequence.

On Willingdon Levels hand augering (using a Gutz auger) has provided the bulk of the stratigraphic information, although reference to existing logs has been a valuable additional source of data. The lithostratigraphic records presented have been obtained by a programme of hand augering consisting of 56 sites taking in the cross- and long-profiles of the Levels. The aim was to trace the peat bed since this represented the most interesting

horizon. Although the hand augering often found bedrock, this was not always possible, but the investigation by E.S.C.C. at Lottbridge Drove using a drilling rig provided information on the deeper sequencies. Therefore one borehole was commissioned for this study because the rig provided large samples and was able to penetrate the basal gravel layer.

For both sites, the engineering rig produced cores of 100mm. diameter (called U.100's). Most of the samples for pollen analysis, sediment size, macrofossil and diatom analysis were taken from them. The cores were extruded into plastic guttering and sealed with two layers of 'Fablon'. Sampling was undertaken from the centre of the cores where the risk of contamination and disturbance should be at a minimum. All the U.100's were carefully cut in two so that one half could be used for pollen work and for macrofossil extraction. The remaining half-core was saved for the other methods employed. The outer layer of each core was always discarded.

B 2.3. The problems of sample extraction.

Any research must be based upon reliable data that has been obtained by accurate field work using the most appropriate techniques available. Interpretation and correlation with other areas is meaningless if the original data is equivocal. Problems relating to the acquisition of the original data will vary depending upon the nature of the research and the area in which it is undertaken. It is, therefore, important to make clear any limitations arising from sampling techniques and analysis so that truly objective results can be achieved. Thus, it is acknowledged that the use of a commercial drilling rig to extract cores from the deeper sediments is not an ideal sampling technique. The problems of logging the depths and of disturbance to the samples are compounded the deeper the drilling, although these are problems shared by hand augering.

The Langney Point borehole had the additional problem that the upper 21m. of sediment was too unconsolidated for extraction by U.100s, but bag samples were regularly taken over this phase. However, from 21.76m to 33.40m. (below ground surface) continuous sampling was possible. Unfortunately on occasions incomplete sampling in the chamber occurred and, in the removal of infill after each core had been extracted, a small amount of unsampled material was sometimes accidentally removed. The maximum amount of unsampled material lost between cores was 80cms. In all there are seven breaks in the stratigraphy due to incomplete sampling. This amounts to 2.8m. of lost material.

For the Lottbridge Drove borehole continuous sampling was possible to bedrock at approximately -9m. O.D.. Although there was some incomplete sampling this never amounted to more than 35cms. between cores. An exception was a 'missing' 70cms. from the middle of the solifluction deposit where a band of large flints could not be collected by the U.100 sampler.

Errors are inherent in drilling of this nature, but they were minimised by careful logging of the cores at the time of drilling. Before each new U.100 sampling chamber was introduced, the depth of the borehole was measured, thereby ensuring an accurate level. Also, casing was used throughout to reduce contamination. No alternative method of extracting the deeper sediments was possible and the main objective of both boreholes - to sample the deepest layers - was achieved. The preservation of laminae and individual lenses of different textured sediment within some of the Langney Point samples is evidence that the drilling rig did not disturb the stratification.

B 3. The lithostratigraphy of the Eastbourne sediments.

The results from the boreholes and hand augering undertaken for this study are illustrated in figures B2, B6, B3* and B4*. Some of the lithostratigraphic information on the cross-profile (Fig. B4) has been obtained from borehole records of Lottbridge Drove held by E.S.C.C.. These contain important data about the lower sequencies, especially the basal gravels, which the hand augering was not able to collect. Figure B1 illustrates the location of the hand augering and BH.1 and BH.2. From figures B2 and B6 it appears that the basin of Willingdon Levels contains unconsolidated sediments to a depth of approximately 12 metres at Lottridge Drove and 33m. at Langney Point.

B 3.1. The Langney Point lithostratigraphy.

The Langney Point borehole (BH.1) provided U.100 samples from which the lithostratigraphy of this site was constructed. Four units are recognised that make up the Langney Point formation;

Unit 4. The Crumbles Shingle.

Unit 3. The Upper Minerogenic Sequence.

Unit 2. The Crumbles Peat.

Unit 1. The Lower Minerogenic Sequence.

These four units were initially determined by field inspection with further detail obtained by particle size analysis. Figures B5(a) and B5(b) illustrate the results of this analysis. The Hydrometer method was employed which, although not a precise technique, does provide a good indication as to sediment size (Kaddah, 1974). The ratio of sand, silt and clay was calculated according to the U.S.D.A. system of classification with the hydrometer readings taken at 40 seconds, 4 minutes and 2 hours as developed by Bouyoucos (1951).

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* Note : In jacket on back cover.

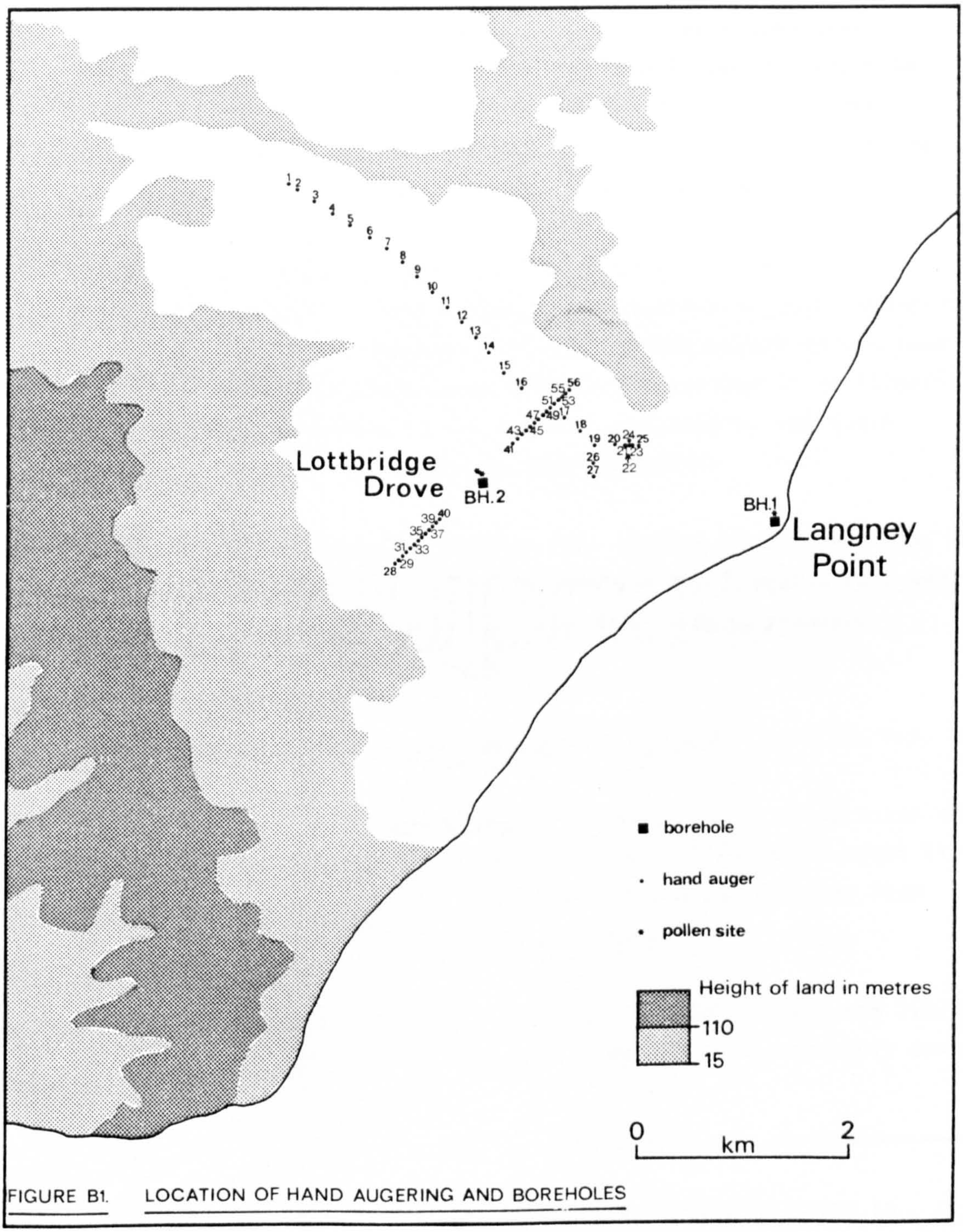

FIGURE B1. LOCATION OF HAND AUGERING AND BOREHOLES

Unit 1. The Lower Minerogenic Sequence - L.M.S. (-29.1m. O.D. to -24.82m. O.D.)

This consists of clay and sandy clay which rests upon Lower Greensand. Unit 1 is sub-divided into two facies according to particle size; L.M.S. (sandy clay) and L.M.S. (clay). The coarser nature of the lower sandy clay facies appears to be the result of the incorporation of weathered Greensand.

Unit 2. The Crumbles Peat (-24.82m. O.D. to -24.7m. O.D.)*

The Crumbles Peat is thin (12cms.) and consists of very compacted plant macrofossils. Earlier borehole investigations by Ove Arup and Partners which encountered this unit described it as 'lignite' and ^{14}C determinations of two samples submitted by the I.G.S. revealed an early Flandrian age (see Table C1).

The boundary between the Crumbles Peat and the overlying U.M.S. is sharp - 1 to 2mm.. The transition between the Crumbles Peat and the underlying Lower Minerogenic Sequence is more gradual, occurring over a depth of 2cms.

Unit 3. The Upper Minerogenic Sequence - U.M.S. (-24.7m. O.D. to -3.7m. O.D.).

This unit consists of considerable depths of clay, sandy clays and sand. These, together with the overlying shingle layer (Unit 4) indicate a coarsening upwards in the sedimentary sequence from above the Crumbles Peat to the ground surface.

This unit is sub-divided into two facies; U.M.S. (clay) and U.M.S. (sand). The lower U.M.S. (clay) is composed of a relatively coarse

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* Note : The depths quoted above replace the depths given in Jennings and Smyth (1982).

FIGURE B2. THE LANGNEY POINT LITHOSTRATIGRAPHY

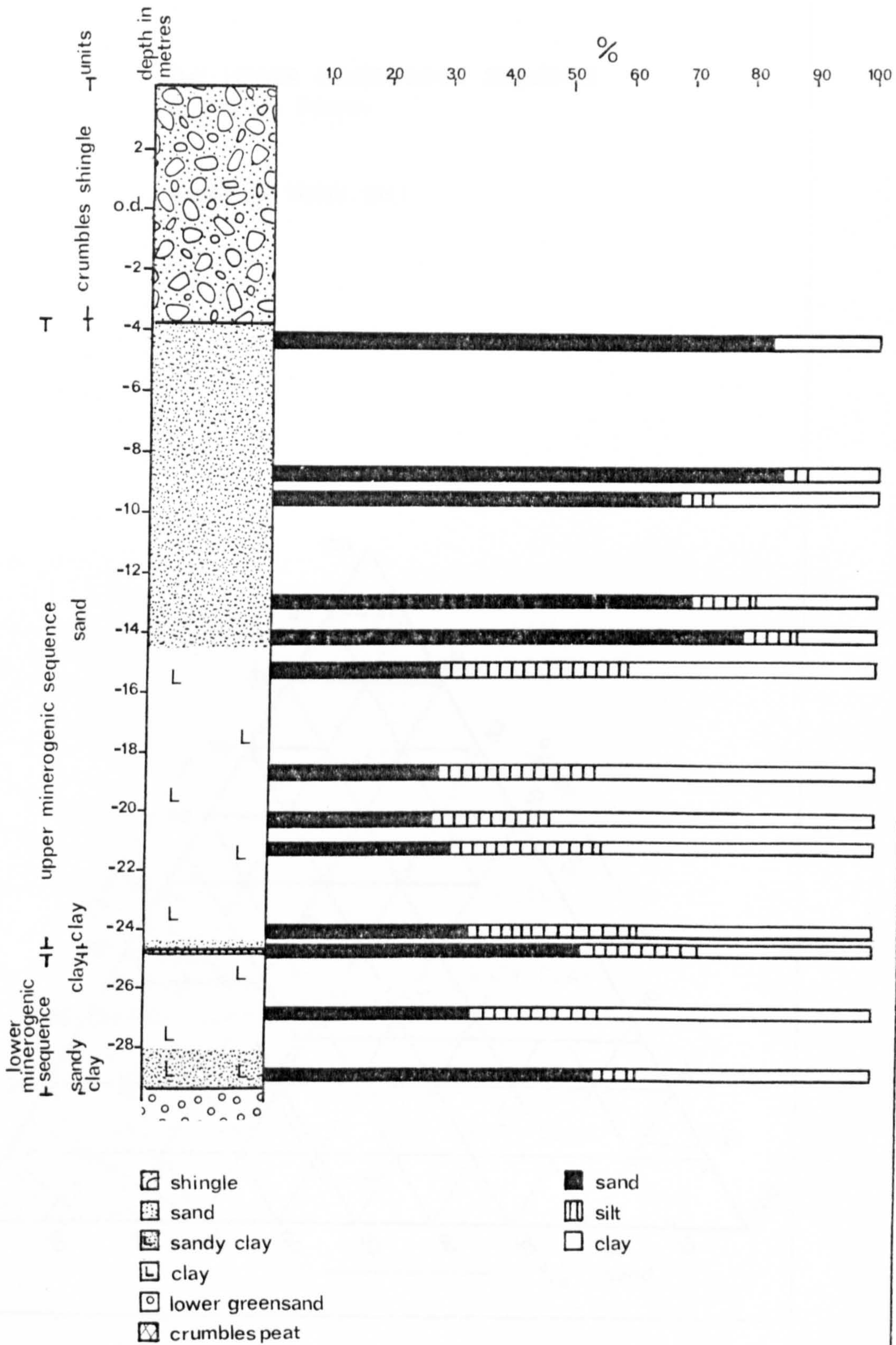


FIGURE B5a. SEDIMENT SIZE ANALYSIS

THE LOWER MINEROGENIC SEQUENCE
(LANGNEY POINT)

SAMPLES FROM BH.1.

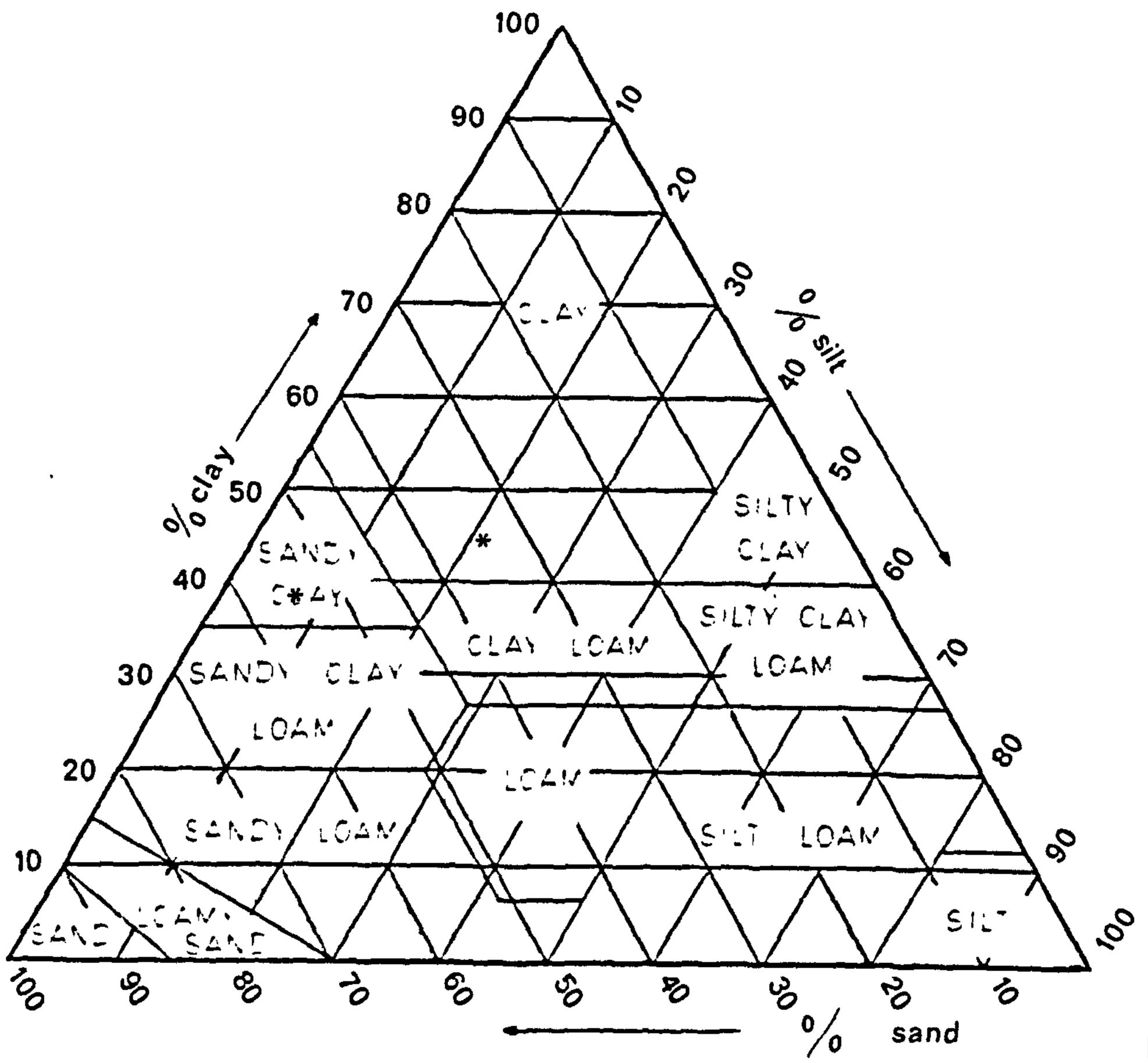
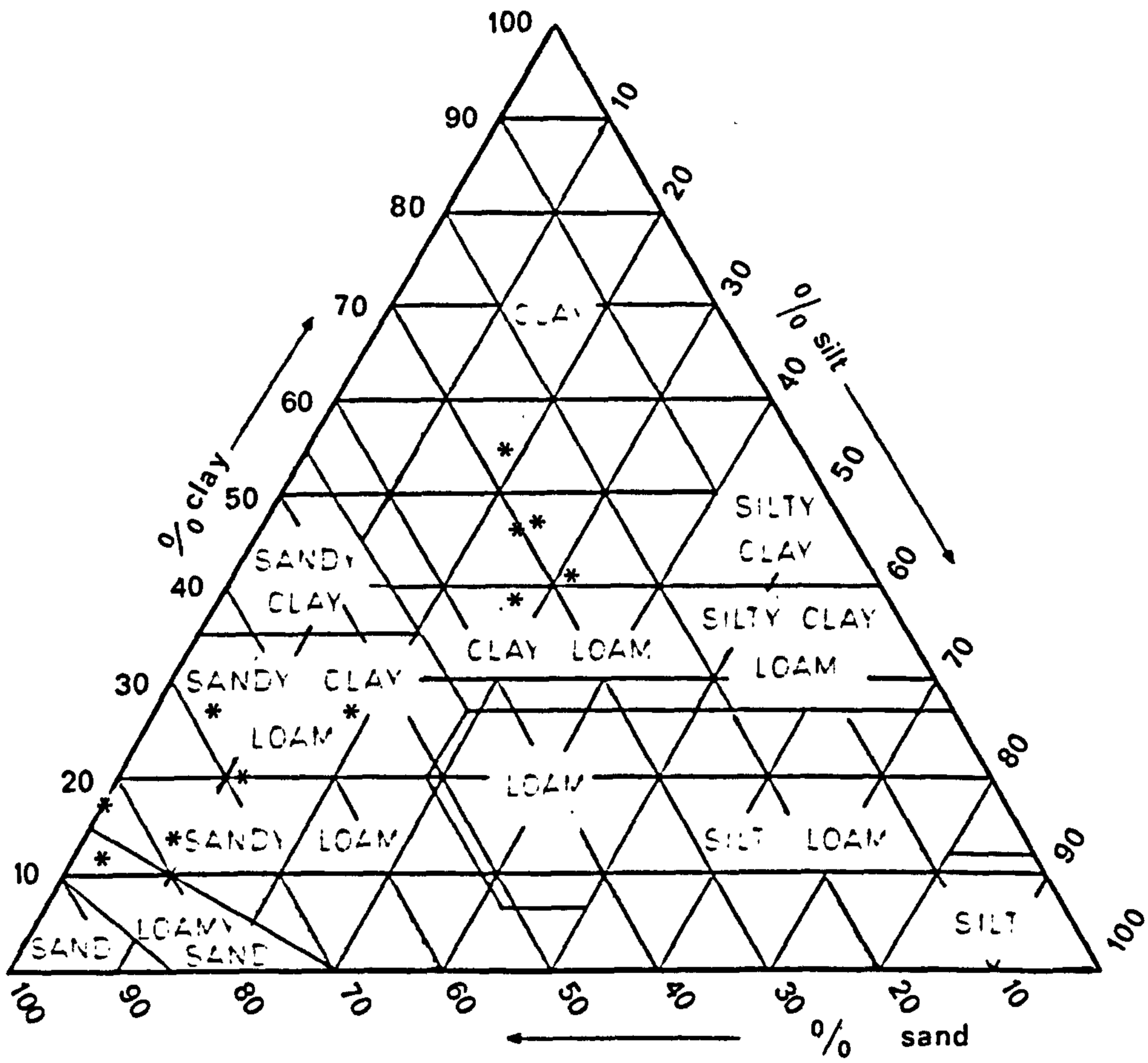


FIGURE B5b. SEDIMENT SIZE ANALYSIS

THE UPPER MINEROGENIC SEQUENCE

(LANGNEY POINT)

SAMPLES FROM BH.1.



layer (52% sand) immediately above the Crumbles Peat, but this abruptly passes up into a much finer sequence which then establishes the pattern of coarsening upwards. These lower sediments, from -24.5m. O.D. to -15.2m. O.D., are composed mostly of clay (maximum 54% clay). However, at -14.2m. O.D. the percentage of clay suddenly falls to 13% as sand sized particles become the dominant texture. This marks the boundary between the U.M.S. (clay) and the U.M.S. (sand).

Within the U.M.S. (clay), laminae and individual thin lenses of fine sand were observed in the upper part of the cored sample, particularly between -17.9m. O.D. to -17.46m. O.D.. The colour of the U.M.S. (clay) is predominantly blue-grey, but between -20.28m. O.D. to -19.6m. O.D. it is black. Within this latter zone, thin lenses of finer grained material occur.

Unit 4. The Crumbles Shingle (-3.7m. O.D. to +4.3m. O.D.)
The upper 8m. consist of well rounded shingle mostly composed of flint but containing small amounts of material from the western reaches of the Channel (Milner and Bull, 1925; Steers, 1964; Beaver, 1968; Highley, 1975). It is this deposit which forms the extensive accumulation of shingle from Eastbourne eastwards across part of Pevensey Levels of which Langney Point is a small promontory. This shingle is part of the extensive beach sediments that are found along the present coast of Sussex and Kent.

An appraisal of all logs available shows that the Crumbles Shingle becomes thinner in a landward direction, decreasing from a maximum thickness of 9.80m. at approximately Mean High Water Springs (M.H.W.S.) to around 5m. further inland close to St. Anthony's Hill. On Willingdon Levels the Crumbles is buried by fine grained sediments (Fig. B3).

Commercial borehole logs from the Crumbles agree well with this lithostratigraphy, although the extent of the deep peat/organic

layer may vary locally. For example, the organic layer from Langney Point that was dated by the I.G.S. extended from -24.78m. O.D. to -28.28m. O.D. (Shephard-Thorn, 1975) which is considerably more than was found in this study even though the boreholes were within 10m. of each other. A discussion of possible reasons for variations of thickness of the Crumbles Peat stratum is presented in Section E.

B 3.2. The Willingdon Levels lithostratigraphy.

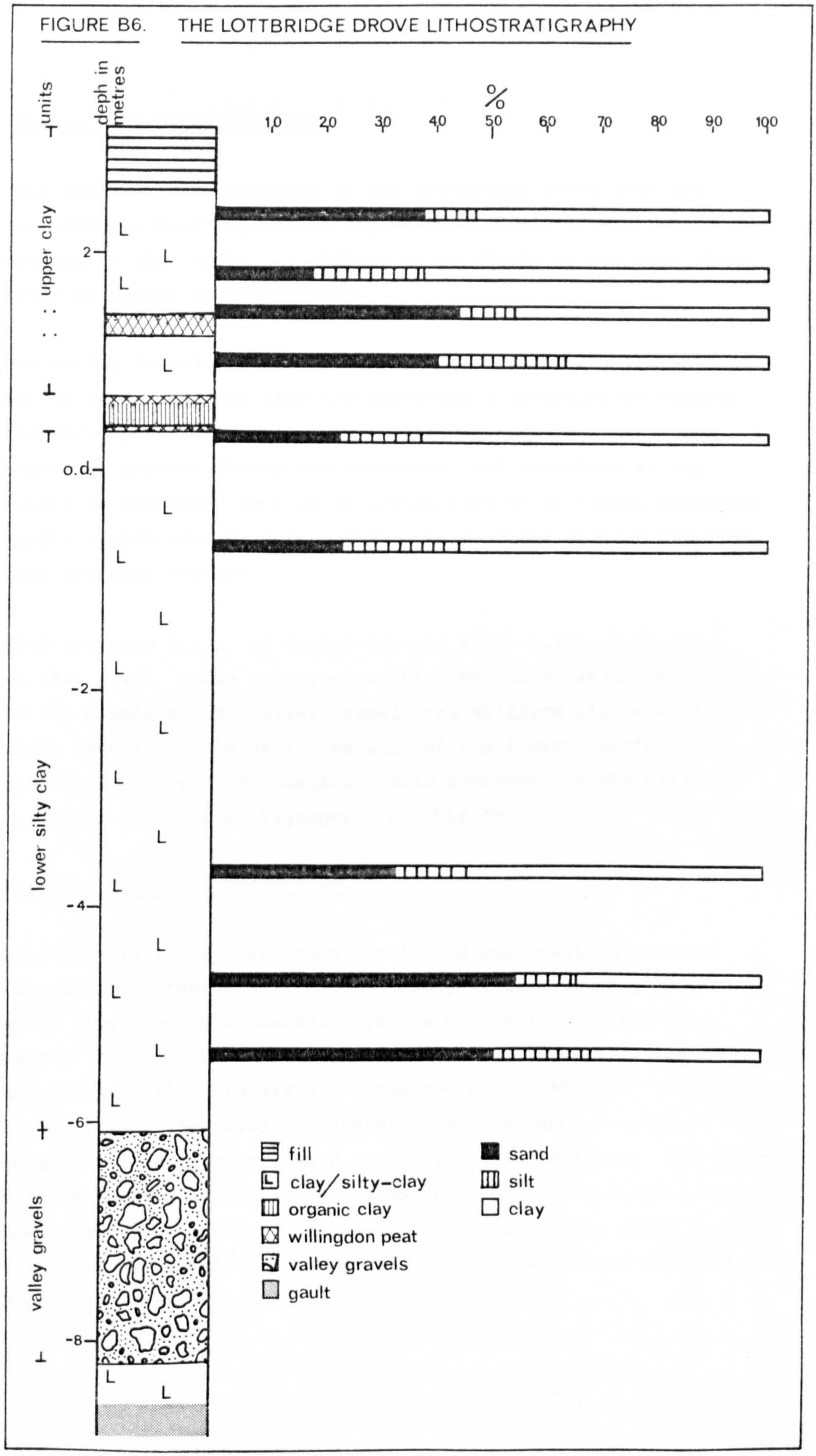
The borehole for this study (BH.2) was sunk at Lottbridge Drove (Fig. B1) after an examination of existing logs. The results of the lithostratigraphic survey of this site and the resulting long- and cross-profiles of Willingdon Levels are shown in figures B3, B4 and B6.

Figures B3 and B4 suggest that the lithostratigraphy revealed by this sub-surface investigation is generally uniform throughout the Levels but with local differences. Division of the sediments is thus facilitated and this is important because the deposits of Willingdon Levels (and other low-lying tracts of the East Sussex coast) are often referred to simply as 'alluvium' (e.g. Redman, 1851-2; Milner and Bull, 1925; Burrin, 1982). A four-fold sequence of the lithostratigraphy for Willingdon Levels is proposed, based upon their stratigraphical position and their texture, the analyses of which are illustrated by figures B6, B7(a) and B7(b).

The four units that make up the Willingdon Levels formation are ;

Unit 4. The Upper Clay.
Unit 3. The Willingdon Peat.
Unit 2. The Lower Silty Clay.
Unit 1. The Valley Gravels.

FIGURE B6. THE LOTTBRIDGE DROVE LITHOSTRATIGRAPHY



Unit 1. The Valley Gravels.

This deposit is encountered in the Lottbridge Drove area and probably the Head deposit on the western margin of the Levels belongs to this unit. It appears to be absent in the east where Lower Greensand is encountered.

The Valley Gravels consist of angular flints and comminuted chalk set in sand, silt and clay and resembles a solifluction deposit. However, the stratified nature of the sequence indicates that water was present during its formation, and therefore it may better be described as a solifluction flow or as 'chalk meltwater muds', a term used by Kerney (1963) to describe similar deposits from southern England.

BH.2 recorded 2.11m. of Valley Gravels from -8.19m. O.D. to -6.08m. O.D.. These rest upon a thin horizon of weathered Gault. In the middle of the Valley Gravels the drilling rig encountered large angular flints which, because of their size, could not be recovered by the U.100 sampler. This accounts for the break in the litho- and biostratigraphies at this depth.

Unit 2. The Lower Silty Clay.

This unit is found throughout the Levels and consists of soft (although stiffening with depth) fine grained blue-grey clay or sandy clay loam, the coarser layer being confined to the lower part of this unit. The transition from this deposit to the underlying Valley Gravels or to the bedrock is abrupt. The extent of the Lower Silty Clay is determined by the depth to these underlying horizons and, as a consequence, is variable. The upper surface is usually marked by the position of the Willingdon Peat, but where this is absent the Lower Silty Clay either forms the land surface immediately behind the Crumbles or grades into the Upper Clay further inland.

FIGURE B7a. SEDIMENT SIZE ANALYSIS

THE LOWER SILTY CLAY (LOTTBRIDGE DROVE)

SAMPLES FROM BH.2.

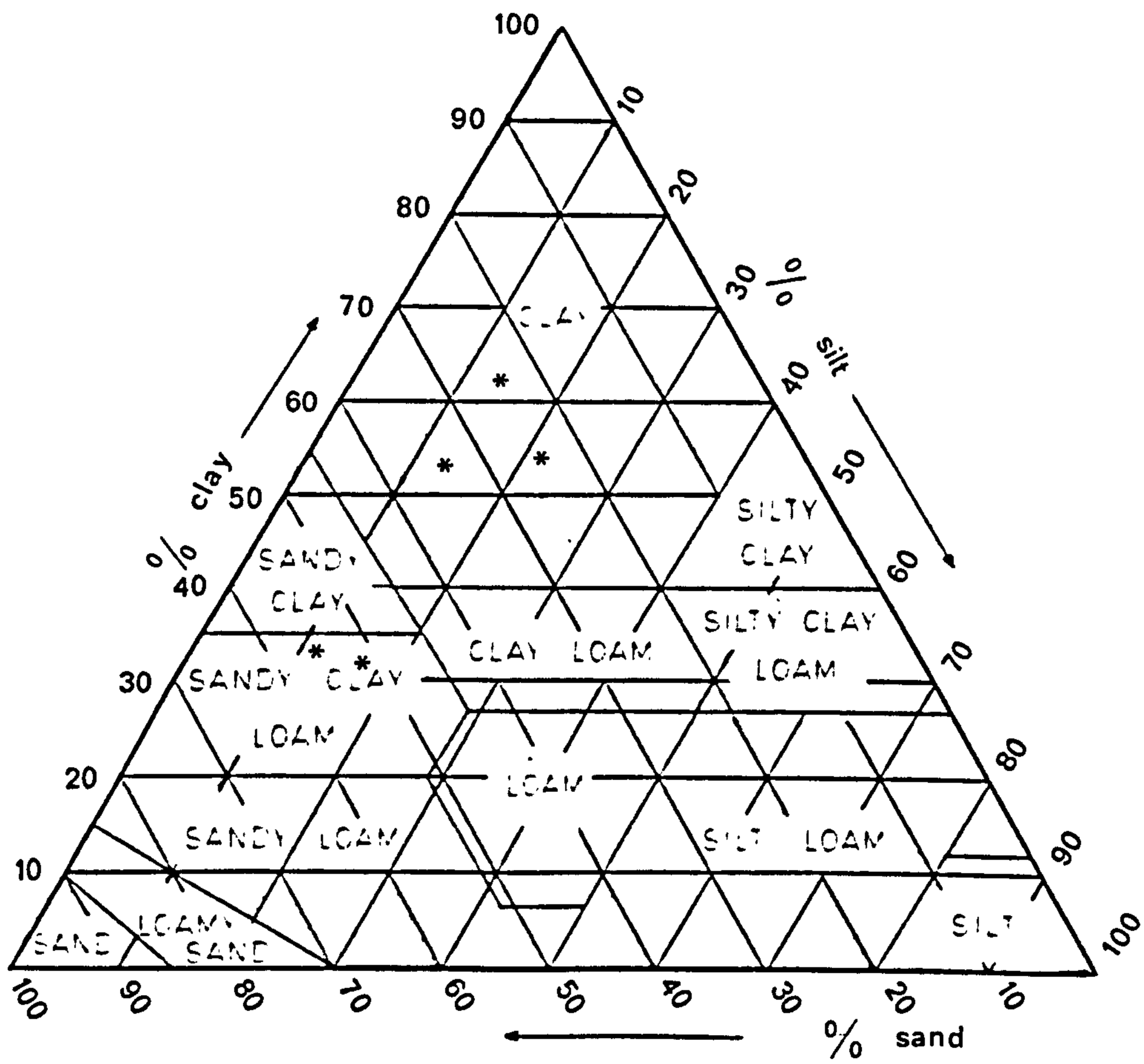
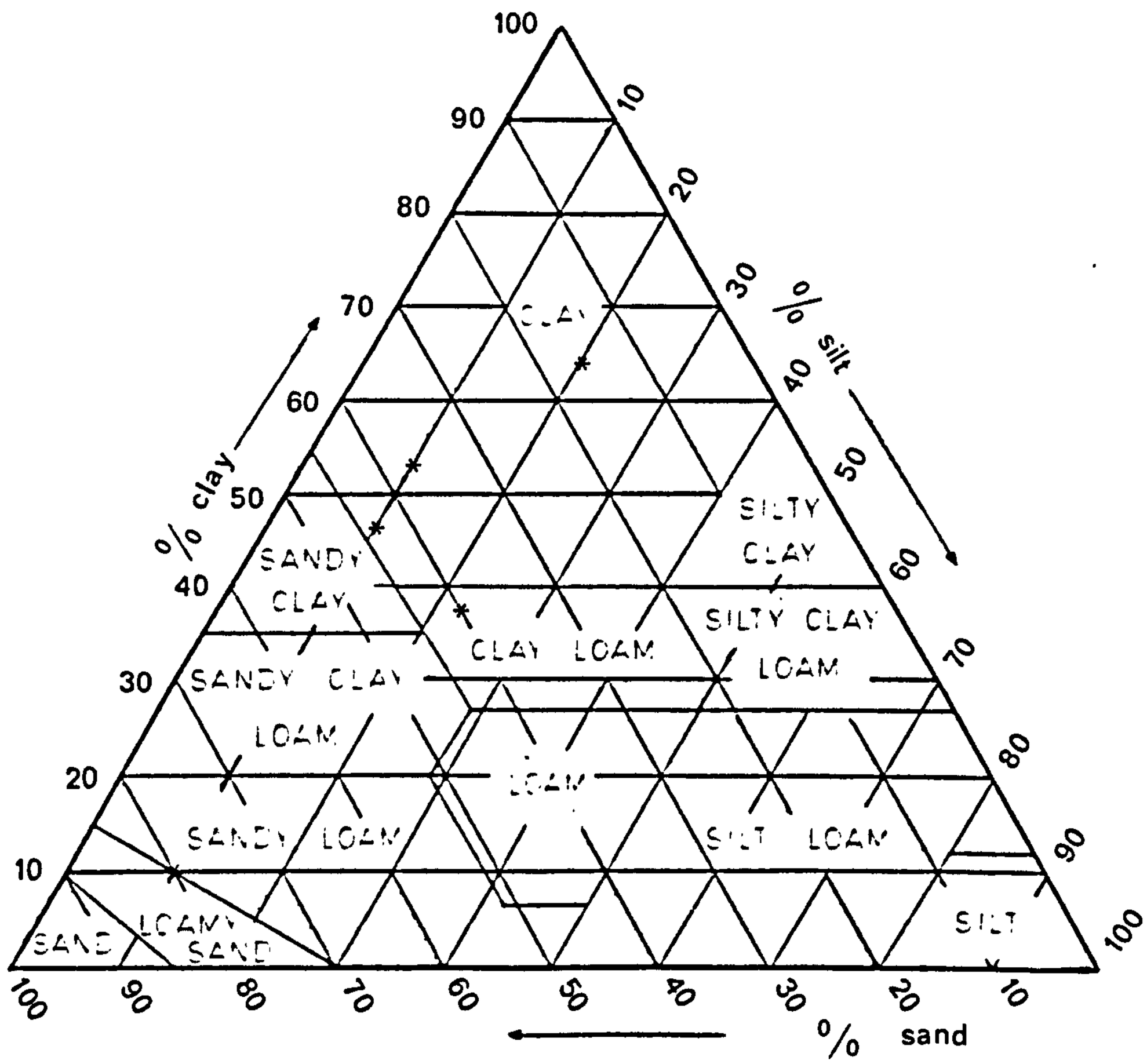


FIGURE B7b. SEDIMENT SIZE ANALYSIS

THE UPPER CLAY (LOTTBRIDGE DROVE)

SAMPLES FROM BH.2.



Bands of shells and the remains of Phragmites are often recovered from this unit. The blue-grey colour of the deposit, which turns brown when exposed to air, indicates a reduced environment of deposition and/or preservation.

Unit 3. The Willingdon Peat.

This unit includes both the peat and the brown organic clay layers that are transitional above and below this deposit. Unit 3 was always found to be thin - never more than 1.17m. - but was encountered in most of the auger holes and in BH.2. However, it was locally absent, in particular close to the Crumbles Shingle. The discontinuity of this unit is shown by figure B4 which illustrates the cross-profile of Willingdon Levels.

The Willingdon Peat contains abundant Phragmites remains, but there is an absence of any larger plant macrofossils. This deposit becomes more compacted on the western edge of the Levels, probably as a result of desiccation especially during dry summer months.

The depth and extent of the peat shows some variation, but the upper surface occurs at around +2m. O.D.. Only rarely is peat found below this level and sometimes it forms thin separated layers with an intervening minerogenic deposit as, for example, at BH.2. This separation into distinct layers suggests the possibility of disturbance to the peat. Additionally, within the Lower Silty Clay small fragments of peat are sometimes recovered, and occasionally a thin very organic layer is found. This suggests either an earlier peat phase which has been largely destroyed, or an originally poorly developed organic layer. Contamination by the auger can be discounted because the occurrence of this organic layer sometimes corresponds to sites where the Willingdon Peat is absent (Fig. B4).

The boundary between the Willingdon Peat and the minerogenic deposits above and below varies between very sharp (1 to 2mm.) to transitions of 5cms.. Also, an exposed face of the peat revealed its upper contact with the transitional brown organic clay to be irregular.

Unit 4. The Upper Clay.

This forms the upper unit and is ubiquitous except where the Lower Silty Clay extends to the surface adjacent to the Crumbles Shingle. It is generally 1m. thick. Sedimentologically the Upper Clay is similar to the Lower Silty Clay, but is distinguished from it by its orange mottling caused by oxidation, its stiffness and by its slightly finer texture. All the samples from Lottbridge Drove tested for their particle size distribution fell within the U.S.D.A. classification for clay.

The surface layer of the Upper Clay is a stiff brown horizon which has a thin friable surface containing roots of the present pastoral vegetation. This surface layer passes down into a stiff orange-mottled brown then blue-grey horizon, which in turn grades into the Willingdon Peat or more rarely into the Lower Silty Clay where the peat is absent.

The Upper Clay is fossiliferous containing Ostracoda, Foraminifera, diatoms, gasteropods and bivalves, the analyses of which are discussed later in this section. The pollen stratigraphy from all four units is examined in Sections C and D.

B 3.3. The bedrock surface underlying Willingdon Levels.

BH.2 encountered weathered bedrock (Gault) at -8.45m. O.D.. Except for the Lottbridge Drove area of Willingdon Levels, knowledge of the depth to bedrock is imprecise. According to investigations carried out by the Joint Site Investigation Unit of

East Sussex County Council the sediments of Lottbridge Drove rest on an inclined surface that dips away in an easterly direction. This surface has a minimum recorded depth of 4m. and a maximum of approximately 15m., close to the location of BH.2 (Fig. B8). However, records of the bedrock for the remainder of the Levels are scarce, but there is a suggestion that the rock surface may show considerable relief. The evidence for this comes from the record of the cross-profile investigation. Hand augers (HA.) 41, 42 and 43 just to the east of BH.2, revealed bedrock at only -0.16m. O.D., -0.33m. O.D. and at -1.63m. O.D. respectively. Depth to bedrock then increases again until close to the eastern margin of the Levels. Indeed, HA.44 only 60m. east of HA.43, showed no trace of bedrock to a depth of 7m. when the augering was terminated. Figure B4 illustrates this and, together with Figure B8, suggests that Willingdon Levels contains a system of buried channels infilled by the four lithologic units ascribed to the Willingdon Levels sediments.

The composition of the bedrock encountered is variable being either a dark grey-black clay or a green glauconitic sand. Analysis of bedrock samples suggests the Gault forms the solid geology at Lottbridge Drove, with Lower Greensand on the eastern margin, while on the western margin it is probably the Chalk as the augering recovered chalk Head, through which it was not possible to penetrate. This area lies close the chalk scarp and boreholes from the nearby hospital (TQ 602010) confirm Lower Chalk. These findings conform to the solid geology shown on sheets 319 (Lewes) and 334 (Eastbourne) of the Geological Survey of England and Wales.

B 4. Data for the study of sea-level change in the Eastbourne area.

The coastal sequencies at Eastbourne have been utilised in this study for two main purposes. First, to examine late-Quaternary

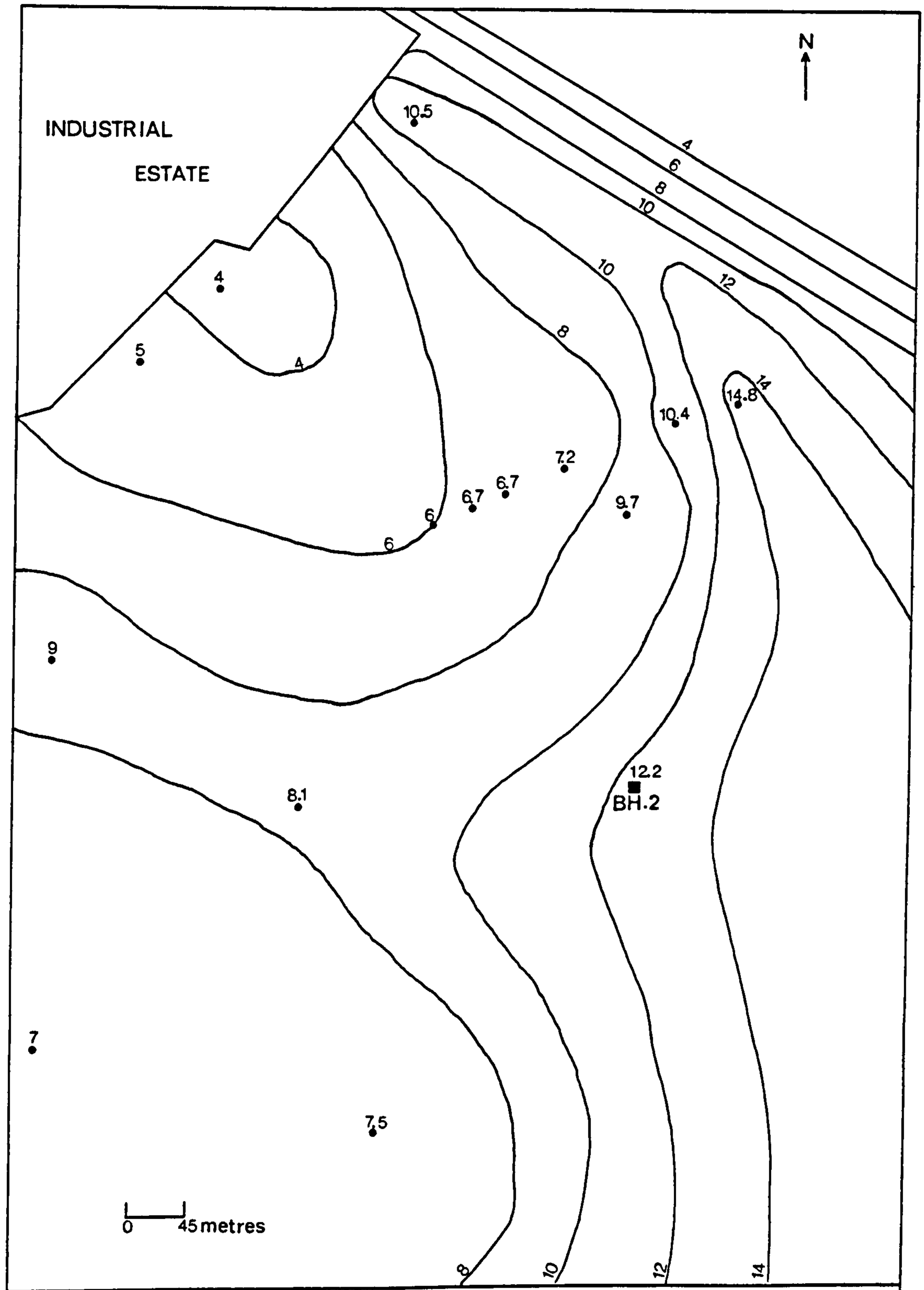


FIGURE B8. DEPTH TO BEDROCK AT LOTTBRIDGE DROVE

KEY

4 commercial borehole with depth to bedrock in metres

4 isopachs in metres

see figure A2 for the location of lottbridge drove

vegetational history by the technique of pollen analysis. The results of this examination are presented in Sections C and D. Second, to investigate whether the sediments contain a record of sea-level changes during the Flandrian. The aim of Section B 4 is to present data on this subject.

From the description of the lithostratigraphic units that compose the Eastbourne sediments, it is clear that large scale coastal accretion has occurred during the Flandrian, most notably at Langney Point where over 33m. of sediment has collected during this period. The picture is less clear for the Lottbridge Drove area because pre-Flandrian deposits may contribute a significant component to the 12m. of unconsolidated material found at this site, as will be discussed in Section D.

In order to understand the nature of this sedimentation, a range of techniques has been employed. The results of the sediment size analysis are presented earlier in this section. The method and results of the pollen analysis are described in Sections C and D. In addition, isolation of gasteropods, bivalves, Ostracoda and Foraminifera was undertaken by wet sieving segments between 160 -260gm. air dry weight from the U.100 cores. The smallest sieve used was 4ø and all the gasteropods and bivalves were collected. Random sampling of the Foraminifera and Ostracoda was carried out by thinly scattering samples onto a black picking tray sub-divided into grid squares. All the specimens on the grid were collected and then stored in a 32 square card-board slide. The object was not to make a frequency diagram but to compile a species list to give an indication whether conditions were freshwater, estuarine or fully marine. The total number of specimens collected varied as some samples were more fossiliferous than others, but the average sample contained between 80 to 100 individuals of Foraminifera and Ostracoda.

Samples for diatom analysis were also taken. Unfortunately, these proved largely unsuccessful, probably as a result of preservation problems (Battarbee, pers. comm.). However, two samples contained a diatom flora, one of which is described in Section C 5.

B 4.1. Langney Point.

The result of these techniques illustrates how, in particular, the Foraminifera, Ostracoda and sediment size analyses indicate a similar pattern of changing environmental conditions.

The Lower Minerogenic Sequence lithostratigraphic unit, which rests upon the Lower Greensand, reveals a transition from freshwater to estuarine conditions. From the base of this unit, at -29.1m. O.D. to -25.94m. O.D. the evidence suggests a freshwater environment. There is no pollen of salt marsh affinities, no Ostracoda and no Foraminifera. Although there are fragments of thin shelled bivalves and gasteropods, it was not possible to identify them.

However, from -25.94m. O.D. to the base of the Crumbles Peat at -24.82m. O.D. conditions are saline. This phase is marked on the pollen diagram by a rise in Chenopodiaceae. At the same time, Ostrea edulis and Scrobicularia plana, two bivalves of brackish/marine environments, are present in the sediments.

It is also suggested from the pollen evidence (Section C 5) that prior to the establishment of this marine episode at Langney Point, a period of dune building occurred. Bio- and lithostratigraphic evidence for this is provided on page 78 of Section C.

The Crumbles Peat represents a return to freshwater conditions with both macrofossil and pollen evidence showing the predominance of Equisetum. The pollen record also reveals the decline of Chenopodiaceae during this phase.

Overlying the Crumbles Peat the Upper Minerogenic Sequence lithostratigraphic unit forms a 'coarsening upwards' pattern, as previously described in this section. These overlying minerogenic sediments culminating in the upper 8m. of shingle represent a progression from estuarine to open marine conditions. This is illustrated by a number of complementary lines of evidence :-

1) The coarsening upwards of the sediments may be related to an increase in the energy of the coastal system.

2) The Foraminifera and Ostracoda exhibit a species change from brackish/estuarine conditions to those of a fully marine environment. Significantly this change coincides with the abrupt coarsening of the sediments between -15.2m. O.D. and -14.2m. O.D.

The Foraminifera and Ostracoda assemblages below -15.2m. O.D. are brackish/salt marsh in their affinities. The Foraminifera are composed of Ammonia beccarii, Protelphidium germanicum and Elphidium spp.. However around -15.2m. O.D. A. beccarii batavus, a more marine variety, co-exists with A. beccarii and then becomes dominant. In the upper substrates Quinqueloculina is also found, which is a sea-weed dweller of the open sea.

This pattern is followed by the Ostracoda. Brackish/salt marsh species, some characteristic of sheltered creeks, dominate at first; Cyprideis torosa, Loxoconcha elliptica, Leptocythere lacertosa and L. castanea. This assemblage is considered to be in situ because of the variation in the size of the instars, and many of the carapaces are too fragile to have withstood reworking. The sample at -18.7m. O.D. also contains a small number of more marine types - Heterocythereis albomaculata, Paradoxostoma, Semicytherura sella, Aurila convexa - but these may have been washed in. However, at -15.2m. O.D. the marine species Heterocythereis albomaculata and Loxoconcha rhomboidea are more strongly represented and there is a mixture of these with the brackishwater species Leptocythere lacertosa.

Above -15.2m. O.D. only marine species are found, in particular Pontocythere elongata which is a sand-dweller. This corresponds very well with the coarsening of the sediments.

In the upper coarser-textured sequence both the Foraminifera and the Ostracoda have more robust shells which is probably the response to higher energy conditions befitting an open marine environment with sand textured sediments.

3) Many of the gasteropods and bivalves identified have a wide environmental tolerance being able to inhabit open bays as well as sheltered estuaries. The types found are Ostrea edulis, Scrobicularia plana, Cerastoderma edule, Hydrobia ulvae, H. ventrosa and Mytilus sp.. However from -15.2m. O.D. the occurrence of both Hydrobia species - true salt marsh/estuarine indicators - and Mytilus sp., a low energy mud environment type, become much less frequent.

4) The Upper Minerogenic Sequence analysed for pollen contains significant frequencies of Chenopodiaceae.

The upper 8m. of shingle forms the Crumbles, the morphology of which has been described by Redman (1851-2), Milner and Bull (1925), Bull (1925) and Steers (1964). Milner and Bull interpret the shingle ridge and trough morphology (see photograph 2) as representing a series of storm beaches that grew eastwards across a bay allowing fine grained sediments to accumulate behind and so produce Willingdon Levels. The morphology of the Crumbles, the coarsening upwards of the sediments and the possible development of the shingle has clear similarities with the formation of Dungeness Foreland, although Steers (1964) has suggested that Langney Point itself may be a recent development according to old map and chart evidence. The pattern of sedimentation along the coast of East Sussex during the Flandrian is further examined in Section E.

B 4.2. Willingdon Levels.*

Except for the basal Valley Gravels which probably belong to the chalk meltwater 'muds' described by Kerney (1963), the sediments of Willingdon Levels are generally of a finer texture than those of Langney Point. In fact the sediment size analysis shows a tendency of fining upwards with the coarsest deposits found in the lower part of the lithostratigraphy.

The Lower Silty Clay unfortunately contains virtually no Flandrian Ostracoda or Foraminifera (except for a few small *Jadammina macrescens*), only some chalk-derived individuals. However, *Hydrobia ulvae* and *H. ventrosa* are present indicating an estuarine nature for these sediments.

More substantial evidence for estuarine conditions can be found in the lower part of the Upper Clay. At +0.97m. O.D. a poorly preserved diatom flora consists of the following species ;

Diploneis gruendleri and *Nitzschia navicularis.*

The sample at +0.97m. O.D. was taken from the Upper Clay that intercalates the Willingdon Peat. Above the Willingdon Peat, a sample at +1.45m. O.D. contains the following Foraminifera and Ostracoda;

> *Foraminifera*; *Trochammina inflata*, *Jadammina macrescens*, *Elphidium* spp. and *Protelphidium germanicum*. Such an assemblage suggests salt marsh subjected to environmental variations.
>
> *Ostracoda*; *Cyprideis torosa*, a species typical of brackish water conditions with widely varying salinities.

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* Note: Samples and sample depths refer to the site of BH.2.

Higher in the Upper Clay, the sample at +1.79m. O.D. again shows estuarine conditions as it contains the following assemblage;

Foraminifera; Elphidium spp., Ammonia beccarii, Protelphidium germanicum.

Ostracoda; Abundant Cyprideis torosa with a small number of Ilyocypris, a freshwater genus.

The sample at +2.35m. O.D. however reveals only small and broken shells of the Foraminifera Protelphidium germanicum and Ammonia beccarii which indicates that either they have been swept in or that salinity is low. At this same depth the only Ostracoda present is Cyclocypris laevis an indicator of freshwater conditions rich in plants.

Therefore the Upper Clay, although appearing to be a single lithological unit on sediment size and colouring (as described earlier), has been deposited under a variety of environmental conditions ranging from salt marsh immediately above the peat to increasingly freshwater conditions. Additional evidence for the initial salt marsh conditions comes from the identification of a layer of abundant Scrobicularia plana in the lower part of the Upper Clay. Also, pollen from the Upper Clay shows a peak of Chenopodiaceae in the lower section, progressively replaced first by Compositae/Liguliflorae and then by Quercus with Cyperaceae.

The Willingdon Peat therefore represents a freshwater phase in an otherwise predominantly estuarine sequence. The freshwater nature of this deposit is illustrated by the two pollen diagrams from Lottbridge Drove discussed in Section C. The diagrams establish the importance of freshwater conditions during this period but they also indicate that saline habitats survived along channels.

The deposition of the sediments forming Willingdon Levels has probably been influenced by the development of coarser sediments that lie below Langney Point and much of the Crumbles. Milner and Bull's (1925) assertion that the growth of the Crumbles produced the accumulation of fine grained sediments landward is therefore supported by the bio- and lithostratigraphies whereby a lagoonal/salt marsh environment was formed behind the coarser coastal sequencies.

However, the history of deposition is more complex than Milner and Bull's hypothesis suggests. Most notably, at Langney Point there is evidence for former estuarine conditions throughout much of the lower sedimentary sequence, and the Willingdon and Crumbles Peats reflect switches to freshwater phases.

This intercalation of peats and freshwater facies in postglacial coastal sediments has been recognised at a number of other sites in Britain (for example Tooley, 1974; Devoy, 1977; Kidson and Heyworth, 1978). Uncertainty has arisen over whether these sedimentary sequencies are the result of eustatic fluctuations or whether they are the product of local factors, such as the growth of spits and bars, obstructing the sea and allowing freshwater deposits to form. In order to make meaningful comparisons of litho- and biostratigraphic investigations between areas that contain this type of sedimentary sequence, accurate field techniques must be adopted and a standardised terminology used to describe these sequencies and the processes that produce them.

The interpretation of such deposits has often been a point of controversy because certain terms have been used with different implied meanings. Also the errors involved in the investigation of these sequencies have not always been appreciated (Kidson, 1982). In the light of these problems, this study must be placed in the context of current understanding concerning sea-level changes. In particular it is important to establish the methodology employed in this type of research.

B 4.3. The problems of terminology and interpretation.

When Tooley published his results from Lancashire (Tooley, 1974) the coastal sequencies were interpreted as deposits that had been laid down as a response to fluctuating sea-levels and a sea-level curve diagram was drawn that followed an oscillating pattern. Ters (1973) constructed such a diagram for the Atlantic coast of France as has Devoy (1977) for the Thames estuary. Each rise on these graphs denoted a 'marine transgression' and each fall a 'marine regression' and thus it was implied that a transgression was synonymous with a eustatic rise of sea-level resulting in a landward migration of marine, brackishwater and freshwater deposits. A regression was the result of a eustatic fall of sea-level so that biogenic, brackishwater and freshwater deposits migrated seawards over the preceding transgressive minerogenic layers. In this way Tooley proposed nine transgressive sequencies (Lytham I-IX) along part of the Lancashire coast and Devoy proposed five such sequencies for the Thames estuary (Thames I-V).

However, Kidson and Heyworth (1973, 1978) interpreted coastal sequencies from the Bristol Channel as being responses to local factors such as storm surges or barrier breaching and, therefore, ascribed a smooth curve to any sea-level diagram because apparent sea-level fluctuations were probably not real eustatic events. For similar reasons Jelgersma (1966) has also proposed a smooth curve for sea-level changes along the Dutch coast. Thus their use of the terms 'transgression' and 'regression' has been different from that of Tooley, Devoy or Ters. A 'transgression' was an incursion of the sea inland but not necessarily due to eustatic changes. Such incursions may have been caused by, for example, an increase in the incidence of storms that altered river mouths or by the breaching of barriers. A 'regression' was an evacuation of an area by the sea probably due to factors unrelated to eustatic changes, for example the blocking of tidal inlets by wind blown sand (Jelgersma *et al.*, 1970).

In addition to this controversy there was disagreement about the existence of higher than present sea-levels in the Flandrian, whether there had been any change since about 5,000 B.P. or whether sea-levels have been continually rising. The only point that received agreement was that sea-levels in the early Flandrian had risen faster than in the latter part. However, it was the ambiguity of the terminology that most hindered comparisons between different areas and therefore made it difficult to recognise any regional trends. One important attempt at definition was that by Vail et al. (1977) who studied changing sea-levels over a long period of geological time and compiled a set of terms which could be applied to sea-level research on recent deposits. Relative changes of sea-level were defined as an apparent rise or fall of sea-level with respect to the land surface. The depositional sequence of related coastal and/or marine deposits they called the 'maritime sequence', the coastal facies of which were controlled by the position of sea-level acting as a base level. By studying the limits of coastal 'onlap' and 'toplap' within maritime sequencies relative changes of sea-level can be identified. Coastal onlap could be used to indicate a relative rise of sea-level by identifying a progressive landward advance (onlap) of littoral and/or non-marine coastal deposits. If a seaward shift of coastal onlap was identified whereby littoral and non-marine coastal deposits extended seaward over the underlying marine deposits, a relative fall of sea-level could be surmised. Where the limits of coastal deposition remained constant, i.e. the position of the shoreline remains the same over a period of time, a relative still-stand of sea-level can be said to have occurred and the term coastal toplap is then employed to show that no onlapping had taken place.

The authors also make the point that the rate of sediment supply from the land could be an important controlling factor. For example, an increase in this supply may produce a seaward migration of littoral and/or non-marine coastal deposits during a

relative rise of sea-level (i.e. to produce a regression in the sense of Jelgersma (1966)).

Within this plethora of terms 'transgression' and 'regression' have become confusing and subject to different meanings. With the establishment of the I.G.C.P. Project 61 in 1974, a standardisation of terminology was essential. It was also apparent that the two schools of thought on sea-level changes (either with an oscillating or a smooth curve) had become too superficial in the light of new studies. Tooley (1982) had modified his views as to the identification of nine 'transgressive' episodes from Lancashire as had Devoy (1982) on the five episodes from the Thames estuary as it was recognised that the construction of a traditional sea-level curve diagram contained inherent errors especially due to the difficulties in establishing an accurate chronology of events.

Tooley (1982) and Shennan (1982, 1983) have, therefore, suggested that the terminology be standardised so that ambiguities can be overcome. The following terms have been put forward following the publication of the I.G.C.P. Project 61 report :-

> 'Transgressive Overlap' :- Applied when littoral and marine facies are deposited where formerly terrestrial sediments had been laid down.
>
> 'Regressive Overlap' :- Applied when marine deposits are replaced by littoral facies which in turn are overlain by terrestrial facies.

Importantly, no processes are implied in the formation of an overlap sequence. They are lithostratigraphic descriptive terms "which can be used to define the boundaries between marine and terrestrial or freshwater formations and the properties of the formations and their constituent parts" (Tooley, 1982 page 45).

By applying a chronology to the transgressive and regressive overlaps, a diagram of overlap tendencies can be constructed which illustrates phases of positive tendencies of relative sea-level movement (an increase in the marine influence) and phases of negative tendencies (a decrease in the marine influence) (Shennan, 1983).

Project 61 also resulted in the application of statistical tests to sea-level data. This highlighted two very important aspects of sea-level research. First, only reliable sea-level indices could be used whereby the exact relationship of the index point (for example a peat or shell layer) to its contemporary sea-level is known. Secondly, only by establishing the synchroneity of events in different areas can any conclusions about regional eustatic changes be made.

The misunderstandings over the use of the terms 'transgression' and 'regression' have partly been the result of uncertainties as to the precise meaning of 'sea-level' and therefore to the exact nature of 'sea-level change'. Whenever the level of the sea is thought to have fluctuated, it should be made clear whether the change in level is considered to have been vertical (either up or down), lateral (across a coastline) or both. In practice this may be very difficult to achieve due to the complex nature of sea-level change. During the Flandrian, vertical and lateral movements of sea-level have taken place both diachronously and synchronously. A vertical change may not necessarily have resulted in a lateral movement, and stratigraphic evidence for lateral changes is not always a reliable indicator of vertical changes. Sea-level change can occur in the lateral plane only due to coastal accretion and erosion. Isostatic movements may result in both types of change.

This important difference between small scale coastal changes and regional sea-level movements has already been referred to

(Jelgersma, 1966; Kidson and Heyworth, 1973; Vail et al., 1977) but should be emphasised. The processes of erosion, transportation and deposition of sediment within the coastal system may result in areas of the coastline becoming flooded by the sea or, through accretion, increase the area of land above sea-level. Thus apparent sea-level tendencies may be interpreted incorrectly because local changes to the coastline may be instigated by processes which are independent of sea-level fluctuations. Also, in areas to which large quantities of sediment are being transported a rise of sea-level may not be recorded in the deposits because the supply of sediment may keep pace with or even outstrip the rate of sea-level rise.

The relationship between local changes in the coastline and actual sea-level fluctuations is central to the understanding of the Holocene sedimentological history of the Eastbourne area.

As referred to above, clarification is also required when using the word 'sea-level'. This could refer to any height of the sea from the lowest astronomical tide to the highest spring tide. Reference is often made to various heights depending upon the context of the work. For example, surveying of sites is related to ordnance datum at Newlyn, whereas coastal peat beds, the position of which is entirely governed by sea-level, may be indicative of Mean High Water Spring Tide (M.H.W.S.T.). This is further complicated by areas which have large tidal ranges especially where it may not be possible to calculate accurately palaeotidal data due to alterations in the configuration of the coastline.

Everard (1979, 1980) discusses the problems of defining and accurately measuring sea-level. He provides a synopsis of work which includes findings that the sea's surface is not flat but contains significant relief even over short distances - a phenomenon that has important implications when correlating

coastal peat beds. Kidson (1982) provides a very useful appraisal of the problems involved in sea-level research.

In this study of the Eastbourne sediments, the term 'sea-level change' is not necessarily used to imply a vertical change (i.e. a genuine eustatic movement), but is used in the broader sense through the recognition of contacts and overlaps. These contacts and overlaps may have been the result of either vertical or lateral movements or both. These may or may not have produced a shift in the coastline. As Shennan states, the investigation of the processes that are responsible for an overlap is the next stage of the research (Shennan, pers. comm.). The terms 'contact' and 'overlap' are purely descriptive, being two types of sea-level index points (Tooley, 1982).

B 4.4. The recognition of sea-level index points in the Eastbourne sediments.

The examination of coastal sediments in the study area is intended to show spatial and temporal patterns of sea-level tendencies. The identification and interpretation of contacts and overlaps in a sedimentary sequence is an important technique in the fulfilment of this aim. Both the Crumbles and Willingdon Peats, and the transition from the Valley Gravels to the Lower Silty Clay at Lottbridge Drove represent overlap sequencies. It is also clear, however, that within the Lower Minerogenic Sequence (clay) from Langney Point and within the Upper Clay from Lottbridge Drove, there is a contact and an overlap respectively, even though these index points occur within what appears to be a uniform lithological unit. Therefore, these should not be called 'contacts' or 'overlaps' because in the meaning of these terms as applied by Tooley (1982) they are lithostratigraphic descriptive terms, but in these Eastbourne sediments only biostratigraphic evidence reveals the changing conditions.

Thus, the terms 'contact' and 'overlap' as defined by Tooley (1982) and by Shennan (1982, 1983) may require refinement because two types can occur, namely :

> Lithostratigraphic contact or overlap - recognised by lithostratigraphic evidence, supported by changes in the biostratigraphy.
>
> Biostratigraphic contact or overlap - identified only by changes in the biostratigraphy. There is no alteration to the lithostratigraphy.

Palaeoenvironmental changes which are recorded in coastal deposits and are revealed only by biostratigraphic evidence, may be described as either positive or negative 'tendencies of sea-level movements' (Shennan, 1983), and thereby avoid the use of the term 'contact' and 'overlaps' in situations where no lithostratigraphic changes are involved. However, the justification for using the term 'biostratigraphic' and 'lithostratigraphic' contact and overlap in this study of the Eastbourne sediments is to standardise the terminology given to litho- and biostratigraphic indicators of palaeoenvironmental change. Both types of contact and overlap are sea-level index points, a contact describing the situation within a single core, while the term overlap is applied when a contact can be traced spatially across an area covered by a series of cores. The identification of contacts and overlaps then allows a measure of the tendency of relative sea-level movements to be made (Shennan, 1983).

Two contacts are recognised on the Langney Point diagram; at -25.94m. O.D. and at -24.82m. O.D.. These are designated contacts as they have been recognised only from the site of BH.1. An overlap is recorded at -24.70m. O.D., as it can be correlated with a contact in a neighbouring borehole.

From Lottbridge Drove (on Willingdon Levels) four overlaps are recognised; at -5.95m. O.D., +1.65m. O.D., +1.92m. O.D. and at +2.25m. O.D.. Because of the possibility of the upper peat layer at Lottbridge Drove encountered by BH.2 being disturbed, the lithostratigraphic contacts between this peat layer and the minerogenic sediments above and below are not considered to be reliable index points. Therefore they are omitted from this analysis. The overlaps at +1.65m. O.D. and at +1.92m. O.D. are taken from the Lottbridge B site which also provided the samples for Carbon-dating (Section C). This site is located approximately 20m. from BH.2. All four overlaps were traced spatially during the hand auger investigation.

B 4.4.1. The Langney Point sea-level index points.

1) At -25.94m. O.D.. This is a biostratigraphic transgressive contact as it occurs within a single lithostratigraphic unit - the Lower Minerogenic Sequence (clay). The pollen record (Section C) shows a transition from fresh to saline conditions. The establishment of an estuarine environment is also evidenced by the molluscan record. The position of the overlap coincides with the boundary of pollen assemblage zones L.P.2. and 3 (Section C) when Chenopodiaceae become consistently present. The first appearance in the sediments of the molluscs *Ostrea edulis* and *Scrobicularia plana* occurs at this time.

2) At -24.82m. O.D.. This is a lithostratigraphic regressive contact at the boundary of the Lower Minerogenic Sequence with the Crumbles Peat. Biostratigraphic evidence consists of a decline in the pollen of Chenopodiaceae. *Ostrea edulis* and *Scrobicularia plana* disappear from the molluscan record well before the lithostratigraphic change indicating that the transition from saline to freshwater conditions was perhaps gradual.

3) At -24.70m O.D.. A lithostratigraphic transgressive overlap dated at 8,770 ± 50 B.P. (SRR-2452) is indicated by the Crumbles Peat being replaced by the Upper Minerogenic Sequence at a sharp boundary. At the same time there is the appearance of Cerastoderma sp. and the return of Scrobicularia plana, Ostrea edulis and, on the pollen diagram, Chenopodiaceae. The biostratigraphic evidence for estuarine and later fully marine conditions during the Upper Minerogenic Sequence is provided by the Foraminifera and Ostracoda assemblages as described in this section.

B 4.4.2. The Lottbridge Drove sea-level index points.

1) At - 5.95m. O.D.. The transition from the Valley Gravels to the overlying Lower Silty Clay is interpreted as being a lithostratigraphic transgressive overlap. The pollen record supports this contention because the freshwater taxa of the Valley Gravels (p.a.z. L.D.2), in particular Alnus and Typha sp., decline while Chenopodiaceae gradually increase during p.a.z. L.D.3. The presence in the Lower Silty Clay of Hystrichospheres and Hydrobia is a further indication of estuarine conditions.

2) At +1.65m. O.D.. A lithostratigraphic regressive overlap is signalled by the transition from the Lower Silty Clay to the Willingdon Peat. This event is dated at 3,750 ± 40 B.P. (SRR-2455). The pollen record indicates the establishment of a freshwater habitat with Filicales, Cyperaceae and Typha sp.. The biostratigraphic data from the Lottbridge A pollen diagram (taken from the site of BH.2) suggest that although freshwater conditions became established, saline habitats persisted locally.

3) At +1.92m. O.D.. This lithostratigraphic transgressive overlap is dated at 3,390 ± 40 B.P. (SRR-2454) and occurs where the Willingdon Peat is replaced by the Upper Clay. On the Lottbridge A pollen diagram, Chenopodiaceae return as the freshwater taxa

decline. Ostracoda and Foraminifera of estuarine affinities are abundant in the lower levels of the Upper Clay and a layer of Scrobicularia plana was identified overlying the peat at the site of the Lottbridge B diagram.

4) At +2.25m. O.D.. A biostratigraphic regressive overlap occurs within the Upper Clay. On the Lottbridge A pollen diagram, Chenopodiaceae decline and freshwater taxa and dry land herbs expand. The estuarine Foraminifera and Ostracoda die out. The only Ostracoda present is the freshwater species Cyclocypris laevis.

B 4.4.3. Summary.

The two Langney Point contacts cannot be used to establish reliably any dominant tendency of relative sea-level movement for this area. However, the transgressive overlap at -24.7m. O.D. and dated to 8,770 ± 50 B.P. indicates a positive dominant tendency of relative sea-level movement in the area at this time. As discussed in Section E, this index point can be traced spatially.

On Willingdon Levels the overlap sequencies reveal four phases of dominant tendencies of relative sea-level movement;

At -5.95m. O.D. - a positive dominant tendency.

At +1.65m. O.D. - a negative dominant tendency dated to 3,750 ± 40 B.P.

At +1.92m. O.D. - a positive dominant tendency dated to 3,390 ± 40 B.P.

At +2.25m. O.D. - a negative dominant tendency.

Following the terminology defined by Shennan (1983), the terms 'positive' and 'negative' dominant tendencies of relative sea-level movement are used to indicate an apparent increase and decrease, respectively, in the marine influence. No specific process is implied.

The interpretation of these index points and tendencies, and their significance for palaeoenvironmental reconstruction in the Eastbourne area, is discussed in Sections E and F.

Postscript.

It is appreciated that the refinement to the terminology of Shennan and Tooley may lead to confusion if correlations are attempted between the sea-level index points described here with those from other areas that adhere to the original terminology. For this reason the table below sets out the sea-level index points using the terminology of Shennan and Tooley. For the remainder of the thesis, the 'refined' terminology will be used for the reasons given above.

Table B2. Sea-level index points.

Langney Point :	-25.94m. O.D. - An index point showing a positive tendency of relative sea-level movement.
	-24.82m. O.D. - A regressive contact.
	-24.70m. O.D. - A transgressive overlap.
Willingdon Levels :	- 5.95m. O.D. - A transgressive overlap.
	+ 1.65m. O.D. - A regressive overlap.
	+ 1.92m. O.D. - A trangressive overlap.
	+ 2.25m. O.D. - An index point showing a negative tendency of relative sea-level movement. This tendency can be traced spatially.

SECTION C. POLLEN ANALYSIS 1.

PREVIOUS WORK, METHODOLOGY, TECHNIQUES AND RESULTS.

C 1. Introduction and previous work.

The extensive deposits at Langney Point and Lottbridge Drove, although mostly minerogenic, were considered to have the potential for studying environmental change using pollen analysis, and so provide much of the information missing from the previous work as outlined later in this section and in Section A. This potential was recognised after an examination of sample pollen slides which revealed a low, but sufficient number of pollen grains to enable the construction of a pollen diagram. It is probably never wise to rely upon only one line of investigation, and therefore the results of the pollen analysis presented in this study must be viewed in association with the other techniques employed, which are described in Sections B and E.

C 1.1 Previous work.

Flandrian vegetational change in coastal areas of East Sussex has received little detailed investigation in the past. Although they are limited in number, previous studies tend to fall into two groups. First, the observations on the submerged forests off Pett Levels, Cooden Beach and Bexhill (Vidler, 1892; Reid, 1913) represent early attempts at realising palaeoenvironmental conditions in coastal areas. These accounts contain useful references to the types of tree that once grew in these locations and provide an invaluable record of discoveries of fossils now lost either due to coastal erosion or to burial under shingle.

Second, investigations using pollen analysis have provided important palaeoecological data. However, within the study area of East Sussex there have been few attempts at applying this

technique. This is probably the result of insufficient knowledge as to the existence of suitable deposits. The paucity of previous work has consequently led to uncertainties regarding the composition of the vegetation of the area throughout the postglacial period. This study is therefore an attempt at providing some much needed information on this topic.

The first major investigation of Flandrian vegetational change in the coastal area of East Sussex using pollen analysis was that made by Thorley (1971, 1981). She analysed the pollen in the peat and peaty-clay of the Vale of the Brooks in the Ouse valley to the south of Lewes (see figure A1). This added biostratigraphic information to the extensive lithostratigraphic investigation carried out by Jones (1971, 1981). Two pollen diagrams were produced which, as indicated by both the pollen spectra and by Carbon-dating, are of mid-Flandrian age. These two diagrams provide a useful insight into the forest composition of this area for the period covered by the pollen diagrams. However, it is difficult to assess the provenance of the pollen and, as a consequence, it is unclear whether the pollen record reflects the vegetation of the neighbouring chalk slopes. Waton (1982), in a discussion of Thorley's diagrams, suggests that local valley bottom vegetational changes are represented on the diagrams. He also questions the influence of pollen deterioration, proposing selective pollen preservation as a possible cause for some of the trends shown on the diagrams.

Further inland along the Ouse Valley, Scaife and Burrin (1983) have constructed a pollen diagram from the alluvium at Sharpsbridge. Although at least one hiatus occurs in the stratigraphy, a picture of early Flandrian to Iron Age vegetational history is inferred from the pollen diagram. The suggestion that at this site man may have effected changes to the vegetation from Mesolithic times is in contrast to Thorley's assertion that at the Vale of the Brooks, forest clearance was

initiated in the Neolithic with no major clearances occurring until the Middle Bronze Age.

Brooks (in Robinson and Williams, 1983a) has analysed pollen from Wellingham Bog, north of Lewes. Six metres of sediment were examined and the resultant pollen diagram reveals interesting changes in the pollen stratigraphy of many of the arboreal pollen types. For example, an early decline in pine frequencies is followed by an elm and lime decline. Unfortunately the absence of radiocarbon analysis has made it impossible to apply a strict chronology to these changes, a limitation that also affects the work of Scaife and Burrin previously described.

On Pevensey Levels, Moffat (1984) and Barnes (1974) have studied the pollen spectra from near-surface peats. Moffat's work concentrates on the provenance of the pollen in relation to vegetational communities growing in the area. He compares documented evidence of changing land use with the pollen record. Although much of his pollen is no older than the 'Historical' period, the lower levels of his diagram are of Sub-Boreal age.

Barnes' site at Gasson's Farm on Pevensey Levels consists of a thin peat below approximately 60cms. of clay, and rests upon a lower estuarine clay. Barnes argues a Medieval age for the peat, a contention based upon pottery sherds and an apparently limited presence of arboreal pollen, other than alder. However, the pottery sherds are confined to the upper part of the peat, and Alnus pollen was not excluded from the pollen sum of 400 arboreal pollen grains, despite reaching a maximum of 80% of the pollen sum. Therefore, Quercus, Tilia, Corylus and Fraxinus are probably under-represented because of this on her diagram. An absolute age determination is required for this peat in order to establish whether, indeed, it is Medieval.

Smyth (1985) has constructed a pollen diagram from the extensive peat and upper minerogenic layers of the Combe Haven valley between Bexhill and Hastings. From the pollen assemblage it appears that the accumulation of peat may have begun over 5,000 years ago just prior to the elm decline. She has identified phases of forest clearance due to edaphic changes and to human interference. Some of these phases correspond to narrow minerogenic horizons within the peat. The upper more extensive clays and silts reveal an opening out of the forest which probably corresponds with the development of the Iron industry and spread of agriculture along the valley. A marine incursion also occurred at this time affecting the lower part of the Combe Haven.

Waller (in prep.) has provided information on vegetational change in the Brede and Tillingham valleys near Winchelsea which, as with Smyth's work, has traced the composition of the forest and the understory vegetation as well as the recent changes due to agriculture. The neighbouring Pett Level forest beds have also been analysed for their pollen content (Sutherland, in prep.).

C 2. Methodology.

Pollen analysis is usually undertaken on biogenic deposits where the anaerobic conditions encourage good preservation and the absence of reworking results in stratigraphically undisturbed pollen and spores. However, as explained in Section B, the extensive sediments in the Eastbourne area are mostly of a minerogenic nature and this has allowed an appraisal to be made of the use of pollen analysis on clay, silt and sand textured lithologies.

This aspect of the research has provided additional information on grain reworking and deterioration. As a consequence, pollen analysis, as applied to these coastal sequencies, is used to investigate other processes, not just vegetational change. This is illustrated by the extensive minerogenic deposits at Lottbridge

Drove. These were found to contain secondary (or derived) pollen in significant numbers that do not reflect the contemporary vegetation at the time of their incorporation into the sediments. Although such sediments are of limited use for investigating Flandrian changes to the vegetation, secondary pollen dispersal can provide important information on the nature of sedimentation that occurred during the development of postglacial palaeoenvironments. Secondary pollen indicate that sediments were deposited under conditions whereby many pollen and spores were being reworked from older sequencies. It will be demonstrated that this situation applies to the Lower Silty Clay unit of Lottbridge Drove, and it will be argued that the large amounts of secondary grains found in this unit indicate the reworking of pre-Flandrian sediments within Willingdon Levels during the postglacial period.

This emphasises the important consideration when using pollen analysis that because pollen is sampled from sediments, it is never plausible to divorce the processes that deposit pollen from the processes that deposit the sediment in which the pollen is preserved. This is often illustrated by changes on the pollen diagram occurring at the same depth as changes in the lithostratigraphy. As will be explained, this is a noticeable feature of the main Lottbridge Drove diagram and it is important to identify the reasons for such a correlation.

This close association between the pollen spectra and the types of sediment, in particular minerogenic sediments, is an important consideration in the palynological interpretation of the biostratigraphies investigated in this study and is discussed at length in Section D.

Therefore the technique of pollen analysis is used in this study to identify a number of different palaeoenvironments through the recognition of both primary and secondary assemblages. The application of pollen analysis as a technique for investigating

more general geomorphological processes as well as vegetational change has often been used in other studies. For example, forest clearance either by man or by natural processes has often been inferred from reductions in the percentage of arboreal pollen, while successions to and from pollen assemblages of salt marsh species in coastal peat beds has provided information on sea-level tendencies. A number of studies have also shown that within organic deposits, changes on the pollen diagram, usually a decline in the arboreal pollen, correlate with narrow more minerogenic horizons (Godwin and Vishnu-Mittre, 1975; Smyth, 1985) and thereby illustrate the association between changes in a pollen profile and changes in sedimentation. However, these studies base their conclusions on changes to the primary pollen record. For the Langney Point and Lottbridge Drove sites evidence from primary pollen assemblages is used to investigate Flandrian vegetational changes, while evidence from secondary pollen is used to elucidate the process of sedimentation that has taken place in the Flandrian, so that together they help to reconstruct the pattern of environmental change and development. A record of the type and extent of deterioration to the pollen and spores contributes to this objective.

C 3. Techniques.

C 3.1 Pollen analysis.

The isolation of pollen and spores followed the standard procedure outlined by Faegri and Iversen (1975). This included treatment of the samples in Hydrochloric and Hydrofluoric acid to remove carbonates and silica. Although most of the sediments from both sites are minerogenic, sample slides revealed pollen and spores but in low frequencies. However, because of the possibility of obtaining a Lateglacial and early Flandrian record, it was considered worthwhile undertaking a pollen count.

Samples for pollen analysis were taken from the centre of the extruded U.100 cores at an interval of 6cms. from the Langney Point sediments. In the minerogenic layers of the Lottbridge Drove site the interval was 15cms. but this was reduced to 2cms. in the Willingdon Peat. These samples were taken within two weeks from the time of drilling to minimise any risk of them drying out. Samples were also taken from an exposed section of the Willingdon Peat, again at intervals of 2cms.

The pollen slides were mounted in Glycerine Jelly and stained in safranine 'O' solution. The identification of grains followed the classification used by Moore and Webb (1978). The work was undertaken on a Zeiss microscope using oil emersion at X1000 magnification when identification was difficult.

Three pollen diagrams have been constructed; one from the extensive lower deposits at Langney Point and the other two from Lottbridge Drove. One of these - Lottbridge A - illustrates the pollen spectra of the entire sequence from ground level to bedrock. The other - Lottbridge B - is from the Willingdon Peat only. The Langney Point diagram contains 153 levels, Lottbridge A 82 levels and Lottbridge B has 21. On all three diagrams the frequency of taxa is expressed as a percentage of all dry land and marsh pollen. This method is preferred to using a percentage of arboreal pollen because of the small quantities of tree pollen contained in many of the samples, a problem compounded by the low pollen concentration. A count of between 250 to 300 pollen including Cyperaceae and marsh taxa but excluding obligate aquatics and spores was achieved for most levels.

The concentration of pollen and spores was observed to be low throughout the Langney Point and for most of the Lottbridge A diagrams. Only within the peats were concentrations higher, this being particularly true for the Willingdon Peat at Lottbridge Drove.

No accurate method of calculating pollen influx was viable because only the Willingdon Peat and the Crumbles Peat could be reliably radiocarbon-dated. Therefore it was not possible to determine sedimentation rates.

A crude measure of concentration can be made by counting the number of traverses across each slide in order to reach the pollen sum. This figure has been recorded down the right hand side of the pollen diagrams. This method has been used by others (e.g. Sparks and West, 1959) to give at least a general indication of relative concentration rates.

When this method is applied to the Lottbridge A diagram, there appears to be a tendency for pollen concentration to increase towards the surface which is commensurate with the location of the organic layers (the Willingdon Peat) in which pollen concentration is highest. However, this positive correlation between pollen concentration and organic content does not exist for the Langney Point diagram. At neither site is there any relationship between pollen preservation and concentration which suggests that no significant amount of pollen has been totally lost through deterioration. This is further discussed in Section D.

In addition to the low pollen concentrations observed at both sites many grains were found to be deteriorated. In particular Pinus grains were often broken. This genus, as with Picea, has saccate grains so that individual detached sacci and 'bladder-less' bodies were counted and their combined value divided by three. The number of deteriorated grains is shown on the three diagrams. A record was taken of the quantity and nature of the deterioration as Cushing (1967), Birks (1970) and Lowe (1982) have suggested this may provide useful information on the environment of depositon. The frequency of morphologically distinct pre-Quaternary pollen and spores and of Hystrichospheres was also recorded and shown on the diagrams. The significance of

this type of information is considered in Section D. For each pollen level a composite diagram has been constructed showing the percentage of arboreal pollen (A.P.) - including Picea but excluding pre-Quaternary types -, the percentage of shrubs and herbs, the percentage of Gramineae and Cyperaceae, the percentage of aquatics and the percentage of spores which excludes small Bryophyte spores that were often found in great abundance and also excludes pre-Quaternary and unknown types. The intention of this diagram is to portray an overall picture of general pollen types and spore representations. Thus the percentage A.P. quoted in the text refers to these figures.

Although it is usual to exclude the aquatics and spores in this calculation, this will over-represent tree and herb taxa in a predominantly open environment. As will be argued in this and the following sections, the study area, especially at Lottbridge Drove, contained a variety of habitats throughout the period covered by the pollen diagrams, so that open and damp environs were often at least as important as forest communities. For this reason the aquatics and spores are included when calculating the percentage of A.P.

Support for adopting this method can be found in Dimbleby (1957) who argues that for pollen analysis from soils that have experienced open environments, even the original pollen sum should include Pteridophyte spores. Dimbleby believes:

> "There is no doubt that in the past there have been ecological phases in which ferns have been very important.....and it seems reasonable to include their spores in the count."

He also points out that Erdtman used the same technique on soils in Lapland and also included Sphagnum in the sum.

However both the aquatics and the spores are omitted from the pollen sum used in the construction of the pollen diagrams in order to facilitate comparison with previous work. On the main part of the diagrams, the aquatics and the spores are represented as a percentage of the pollen sum (i.e. as a percentage of all dry land and marsh pollen). The same calculation is applied to the pre-Quaternary pollen and spores, and to the Hystrichospheres.

C 3.2 Plant macrofossil extraction.

In addition to samples taken for pollen, plant macrofossils were also extracted as they can be used to recognise local plant communities and thus aid the interpretation of pollen diagrams.

After the samples for pollen analysis had been taken, segments 4cms. long were removed throughout the U.100 cores from Langney Point and from most of the Lottbridge Drove cores. These segments were saturated in water and then gently vibrated or washed through a nest of sieves in order to deflocculate the sediment and isolate the macrofossils which were then stored in vials.

The results and discussion of the plant macrofossil analysis is given in this and the following sections.

C 4. ^{14}C determinations.

The lack of sediments containing organic material limits the potential of Carbon-dating in the study area. However, 4 samples were submitted to N.E.R.C. Radiocarbon Laboratory for analysis, two from Langney Point and two from Lottbridge Drove. A Libby half-life of 5,570 was used in the calculaton of the age values given in years B.P. with the $\pm$ 1σ level for analytical confidence. Laboratory numbers are given in brackets.

C 4.1. Langney Point.

The two samples from this site submitted for ^{14}C analysis were taken from the U.100 cores. These are sufficiently large to allow adequate quantities to be taken for dating. No contamination by algae or fungi was observed on the cores. As a precaution, the removal of the surface of the U.100 samples was standard practice in case 'smearing' or any other possible contamination had occurred.

Sample 1:- This was taken from the upper surface of the Crumbles Peat at approximately -24.70m. O.D. The sample consists of very compact plant macrofossils. This is probably part of the same organic horizon that has been previously Carbon-dated to between 8,760 ± 75 B.P. and 9,510 ± 75 B.P. (Shephard-Thorn, 1975). However, the latter samples were taken from an organic layer that is more extensive than the Crumbles Peat encountered in BH.1, even though the two respective boreholes were located only twenty metres apart. Therefore it was considered important to corroborate the belief that they are both representatives of the same organic deposit.

Result:- 8,770 ± 50 B.P. (SRR-2452)

Sample 2:- This corresponds to the onset of sedimentation at Langney Point and was taken close to the base of the borehole at approximately -29.08m. O.D. just above the Lower Greensand bedrock. The sample is therefore composed of sandy clay (U.S.D.A. system) of the Lower Minerogenic Sequence (sandy clay) unit. Nevertheless, there is some organic material present. After pre-treatment in Hydrochloric acid there was a 16% organic component present, calculated by loss on ignition.

Result:- 11,390 ± 170 B.P. (SRR-2453).

This date is likely to be an overestimate of the true age. The sediment contained an appreciable carbonate content which was removed using acid hydrolysis prior to ^{14}C assay. However, in this hard-water environment aquatic vegetation, through photosynthesis, can result in erroneous dating in the order of up to approximately 1000 years too old (Harkness, in Keatinge and Dickson, 1979). Aquatics are present on the pollen diagram at this stage and therefore the true date for the onset of sedimentation at this site is likely to be circa 10,500 B.P., i.e. the end of the Lateglacial and the opening of the Flandrian.

C 4.2. Lottbridge Drove

The two samples were taken from the Willingdon Peat unit at this site. As discussed in this and Section B, some of the peat recovered from BH.2 may have been disturbed and reworked. Although two distinct layers of Willingdon Peat were occasionally encountered at other sites on Willingdon Levels by the hand augering, it was usual to find just one peat. Because of this possibility of reworking, a pit was excavated, close to the site of BH.2, where a single peat unit was found and considered therefore to be *in situ*. This supposition was later supported by the pollen record. Samples for ^{14}C determination and pollen analysis were taken from the exposed face.

Sample 1:- This sample is from close to the upper surface of the peat at approximately +1.92m. O.D. No roots were observed growing into the peat from the overlying Upper Clay unit. The sample itself contained a small amount of clay and abundant *Phragmites* remains.

Result:- 3,390 $\pm$ 40 B.P. (SRR-2454).

Sample 2:- In order to ascertain the period of peat formation at this site, a sample from the lower surface of the peat was taken

at a depth of approximately +1.65m. O.D. Again, Phragmites were abundant and although some small roots were found, these appeared to be from the peat itself and not from the overlying sediment.

Result:- 3,750 ± 40 B.P. (SRR-2455)

As well as establishing a chronostratigraphy, the two Willingdon Peat samples and the Crumbles Peat sample specifically date overlap sequencies. This is considered to be an important objective of the Carbon-dating as this can help to establish sea-level index points.

C 5. Results and discussion of the pollen data.

The three diagrams are shown on figures C1, C2 and C3 which can be found in the jacket on the back cover. The Langney Point diagram and the main diagram from Lottbridge Drove (Lottbridge A) have been constructed from the sediments obtained by the commercial drilling rig. It is considered that the pollen spectra has not been affected by the drilling because, when extruded, there did not appear to be any disturbance to the sediments in the centre of the U.100 cores from where the sub-samples for pollen analysis were taken.

As discussed in Section B, no alternative method of sampling the deeper deposits was available and every care was taken to ensure an accurate logging of the depths. Gaps in the biostratigraphy occur because during the drilling there was a loss of unsampled sediment, as outlined in Section B. However, this has not significantly diminished the value of either diagram.

In addition to the main diagram from Lottbridge Drove, a second diagram (Lottbridge B) has been constructed from the Willingdon Peat. The samples for pollen analysis were taken from the exposed face that had been excavated in order to collect the samples for

^{14}C determinations. As indicated in the previous sub-section, this was considered necessary because part of the Willingdon Peat encountered by BH.2 may have been disturbed and was therefore considered to be unreliable for both pollen investigation and for absolute dating purposes.

The diagrams are sub-divided into pollen assemblage zones (p.a.z.'s). These are considered to be local zones which are not intended to have any regional significance or to necessarily coincide with the general scheme adopted by Godwin (1975), although, where possible, a correlation is attempted. Significant changes on the pollen diagram are the criteria used to determine the boundary of each major p.a.z.

The rest of this section is concerned with an analysis of the p.a.z.'s and an interpretation of any unusual characteristics of the pollen record. A division of the pollen spectra into distinct plant communities is attempted in Section E. The recognition of such communities aids the reconstruction of palaeoenvironments, but the identification of associations or communities of plants requires the recognition of secondary grains belonging to taxa that were therefore not part of the contemporary flora. This is dealt with in Section D. Only then is it possible to recognise plant communities from the pollen record.

C 5.1 Langney Point. (Fig. C1).

C 5.1.1 The pollen assemblage zones.

Three pollen assemblage zones are recognised based on major changes in the pollen record:-

L.P.1. -29.08m. O.D. to -27.58m. O.D.
Corylus, *Pinus*, Cyperaceae, Filicales.

L.P.2. -27.58m. O.D. to -25.94m. O.D.
Juniperus, Corylus, Pinus.

L.P.3. -25.94m. O.D. to -17.46m. O.D.
Corylus, Quercus, Gramineae, Chenopodiaceae.

There is no correlation between these major divisions on the pollen diagram and lithostratigraphic changes. This is considered to be significant as it suggests that the pollen assemblages have not been materially influenced by redeposition and therefore truely reflect vegetational change. Moreover, the ability to apply a zonation scheme is further evidence that the action of the drilling rig did not destroy the biostratigraphy.

L.P.1. -29.08m. O.D. to -27.58m. O.D.(Corylus, Pinus, Cyperaceae, Filicales zone).
This is the oldest of the three zones, with the onset of sedimentation occurring around 10,500 B.P., as discussed on page 66 . Both Corylus and Pinus were already established in high percentages at the opening of the zone attaining maxima of 46% and 49% respectively. Juniperus undergoes an early but short-lived expansion to 28% but otherwise reaches values of around 10% or less. Other arboreal taxa (Quercus, Ulmus, Alnus, Salix, Acer and Tilia) are present but in very low frequencies. The interesting occurrence of Tilia pollen at this early date may not necessarily be attributable to reworking but may indicate the growth of this genus locally. Scaife (1980) and Godwin (1943) found Tilia in early Flandrian (Zone IV) deposits on the Isle of Wight* and at Southampton respectively. Similarly the Quercus frequencies, which attain a maximum of 5% during this zone, may also attest to the local growth of this genus in the early Flandrian, as Godwin (1945) found at Gosport.

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* Note: Only a single grain was recorded.

Other well represented taxa are Cyperaceae which attains values of between 10% and 41%, and Filicales (24%).

These pollen spectra suggest a landscape that is mostly forested by Pinus with Corylus either forming an understory or even growing in pure stands. The low frequencies of herbaceous pollen, reaching only a 10% maximum of the total pollen and spore sum, indicate a closed canopy. Indeed the A.P. is consistently around 50%. However, the phase in which Juniperus replaces Pinus for a short period from -28.9m. O.D. to -28.84m. O.D. suggests an opening of the canopy at this time, a contention supported by an increase in Pteridium. In addition, damp habitats with pools of freshwater are indicated by the presence of Filicales, Cyperaceae, Equisetum and Potamogeton sp.

The outstanding characteristic of this p.a.z. is the probable Pre-Boreal establishment of a pine/hazel forest. Significantly this has also been observed by Haskins (1978) in Dorset. On the Isle of Wight (Scaife, 1980, 1982), in the New Forest (Seagrief, 1960), and at Elstead in Surrey (Seagrief and Godwin, 1960), pine and hazel had also become established by the early Flandrian. The presence of hazel at Langney Point is further discussed on page 75.

L.P.2. -27.58m O.D. to -25.94m. O.D. (Juniperus, Corylus, Pinus zone)

This zone is characterised by a major expansion of Juniperus which reached a peak of 49%. Except for Acer, all the other abroreal genera decline so that at the height of the juniper peak Corylus falls to 7% while Quercus, Ulmus, Tilia and Alnus, along with all of the herbaceous pollen are not represented at all. This is well shown on the composite diagram where the high A.P. percentage is a reflection of the Juniperus values. The suppression of the herbaceous taxa at a time of juniper expansion has also been found by Scaife (1980) at sites on the Isle of Wight where the juniper increase marks the climatic amelioration at the Lateglacial/early Flandrian boundary.

Within this zone, Cyperaceae, Filicales and Sphagnum are continuously present but in reduced numbers, while Gramineae, Potamogeton sp., Equisetum and Pteridium become sporadic in their representation. Thus much of L.P.2 has a poor floristic variety.

After the juniper peak most of the genera recover immediately, notably Corylus in reaching a value of 44% and Gramineae expanding rapidly to 18%. Chrysosplenium increases to 5% at this time. However, Pinus steadily declines throughout this zone to a minumum of 5%.

L.P.3. -25.94m O.D. to -17.46m. O.D. (Corylus, Quercus, Gramineae, Chenopodiaceae zone).

L.P.3 is the most extensive of the three assemblage zones. It is within this zone that breaks in the biostratigraphy occur resulting from the failure of the U. 100 sampler to obtain a perfect core. These 'breaks' are shown on the pollen diagram where it is noticeable that on either side of a break the frequencies for each taxa do not show sudden alterations. This suggests that the imperfect sampling has not devalued the continuity of the pollen diagram.

By the L.P.2/3 boundary, Pinus has declined to values of between 5% and 10% while Quercus, Ulmus, Chenopodiaceae and, to a lesser extent, Betula undergo expansion. The establishment of Quercus in values of between 10% and 20% by the early stages of this p.a.z. represents a Boreal or even Pre-Boreal age for this event because this genus becomes established prior to the formation of the Crumbles Peat. This organic horizon gave a ^{14}C assay of 8,770 $\pm$ 50 B.P.. The growth of Quercus during the Boreal has also been found on the Isle of Wight (Scaife, 1980) and in the Poole Basin (Haskins, 1978).

Corylus maintains its high values during this zone but Juniperus declines and fluctuates widely, never attaining the representation

it achieved in L.P.2. Many other genera also fluctuate considerably even though the sampling interval is only 6cms. For example, although Cyperaceae has declined by the opening of this zone, in one level it suddenly attains a value of 42%.

Chenopodiaceae appear at the opening of this zone and are present throughout, reaching a peak of 23%. This, together with the high Gramineae frequencies, is indicative of a salt marsh community, a conclusion supported by the presence of the fauna described in Section B. Other taxa of a littoral affinity present on the pollen diagram are Linum catharticum, Frankenia, Parnassia and Glaux.

It is clear that L.P.3 has a greater floristic variety than either of the other two zones with a number of herbaceous taxa consistently present, in particular Urtica type and Ranunculus. However, the frequencies of Filicales, Pteridium and Sphagnum all decline at the beginning of the zone and remain low throughout.

Three sub-zones are recognised and annotated on the diagram. One sub-zone (3b) corresponds with the thin Crumbles Peat unit, but no widespread change occurs on the pollen diagram at this time. The main characteristic of L.P.3b is the further decline of Pinus - at one level it is less that 1% - and the corresponding sharp rise in Equisetum to 65%. The Crumbles Peat contains many macrofossil remains of this genus which suggests it formed a local community growing in the swampy conditions that produced the peat. Although there is a small increase in Filicales during this sub-zone, there is no accompanying rise in the Potamogeton and Typha curves while Sphagnum completely disappears from the diagram. Therefore, although there can be no doubt that the water-table was high during its formation, the Crumbles Peat cannot have been formed in open water, neither does it represent a peat bog built up by the accumulation of moss with hydroseral succession to a fen carr. It seems more likely that the Crumbles Peat represents a phase in

which the deposition of estuarine sediments was interrupted (see section E) allowing terrestrial species, capable of colonising fresh sediments, to expand their range. Equisetum is ideally suited to this type of environment being able to rapidly spread onto new sediments in areas influenced by a high water-table. The decline of Chenopodiaceae during this sub-zone lends further support to the contention that estuarine conditions were replaced by a freshwater phase.

The continuing presence of Pinus throughout L.P.3c is interesting. Scaife (1980) found consistent pine values of up to 6% on the Isle of Wight during the mid-Flandrian and postulated small stands of pine on the poorer soils. Haskins (1978) reached similar conclusions for the Poole Basin area of Dorset. However, at Langney Point, the decrease and virtual elimination of Pinus in sub-zone 3b implies that during the remainder of L.P.3 the grains of this genus were brought in either by marine transportation or by reworking from older sediments. The reason for this lies in the behaviour of pine in the other two assemblage zones. The high Pinus frequencies in L.P.1 and gradual decline in L.P.2 indicates that as the water-table rose and estuarine conditions developed so this genus may have retreated to the drier slopes surrounding Willingdon Levels. But if the range of pine had simply continued to retreat with the changing conditions of L.P.3, then it would be expected to find pine grains within the Crumbles Peat due to wind transportation from its refugia. It is worth noting that its absence is not statistical because pollen concentration is still low in the peat unit.

Thus the low values of Pinus pollen in sub-zone 3b cannot be used as reliable indicators of pine growing in the area by then, i.e. by 8,770 $\pm$ 50 B.P.. Marine transportation or reworking are therefore considered to be the best explanations for the presence of pine during L.P.3. In support of this, Godwin (1975) reports that relatively high pine pollen frequencies were found in the

estuarine 'Fen-Clay' of the Fenlands which "greatly over-emphasises" the importance of pine in the near-by forest. Devoy (1979) also found an increase in pine pollen in estuarine clays and silts in the Thames estuary which he attributed to marine transportation.

In the upper levels of L.P.3c, Tilia becomes consistently present but in low numbers. At the same time Fraxinus expands. This, with the Tilia presence and a single grain of Hedera, suggests the onset of the Atlantic period, Godwin's Zone VIIa.

C 5.1.2. Discussion of the Langney Point diagram.

The Langney Point diagram is of an early Flandrian age and therefore helps to elucidate patterns of vegetational change during a period about which little is known from East Sussex.

From the results of the pollen analysis, L.P.'s 1 and 2 appear to conform to Godwin's Pollen Zones V and VI (the Boreal) on the basis of the pine/hazel frequencies, while L.P.3, with the establishment of Quercus and Ulmus and later the consistent appearance of Tilia and Fraxinus, shows the transition from Zone VI to Zone VIIa (the Boreal to the Atlantic). However, although the sequence of vegetational change is generally similar to that proposed by Godwin, the timing is different. The high Pinus and Corylus frequencies at the opening of L.P.1 are considered to be of Zone IV (Pre-Boreal) age, while Quercus and Ulmus became established before 8,770 $\pm$ 50 B.P.. Neither of these characteristics are synchronous with Godwin's scheme. This is not unexpected considering the general nature of his scheme and, as Moore and Webb (1978) warn, it can be misleading to rigidly apply Godwin's scheme due to "regional variations in pollen diagrams".

Besides the lack of synchronism, the pollen assemblages from Langney Point do not adhere strictly to Godwin's zones on a number of other points:-

1) The presence of Corylus in high frequencies as early as Zone IV.

2) The expansion of Juniperus in L.P.2.

3) The small quantity of Betula on the diagram.

4) The early appearance of Alnus.

5) The occurrence of Acer pollen.

1) The high frequencies of Corylus.

According to Godwin's general scheme of vegetational development in the Flandrian, Corylus expands rapidly during Pollen Zone V (the early Boreal). However, at Langney Point this genus was already well established by the Pre-Boreal, as evidenced by the remains of hazelnuts as well as the high pollen frequencies. It appears that this genus favoured proximity to the sea in the early Flandrian (Moore, 1972) as the resultant oceanic climate would have moderated winter and spring temperatures allowing successful flowering and germination.

Deacon (1974) has analysed all available Carbon-dates (published by 1973) that correspond with the expansion of Corylus. From this study she concludes that a refugia of Corylus probably existed off the west coast of Britain during the Devensian and that migration out of this area was aided by an absence of competition from other trees. Of interest to the Eastbourne area, Deacon also notes that hazel favours calcareous conditions, a characteristic suggested by

Kerney et al. (1980) to explain the higher values of Corylus in the early Flandrian of Kent compared to those found in the New Forest and at Elstead.

Moore (1972) observed that the expansion of Corylus at a lowland site in Wales began before the Zone III/IV boundary peak of juniper and provides strong support for a western refugia. Godwin (1975) maintains that the presence of Corylus pollen, particularly in north west Britain, during Pollen Zones I to III indicates the close proximity of the genus to Britain even in the Lateglacial. However, he further argues that only in north west Britain does Corylus expand in Zone IV. In southern England at this time, for example around the Solent area, Corylus pollen attains values of only 5% A.P. (excluding Corylus). In this region Godwin maintains that the expansion of hazel occurs in Zone V. However, Scaife (1980) records high Corylus frequencies within Zone IV on the Isle of Wight. Here, as at Langney Point, it is usually found in association with Pinus in the early Flandrian. Scaife further suggests that the activity of Mesolithic man may have encouraged the growth of hazel. On Willingdon Levels no archaeological or palynological evidence has been found of man in the early Flandrian, although a Mesolithic settlement at Belle Tout, west of Beachy Head, has been identified (Bradley, 1972).

Therefore it appears that Corylus was able to expand very early in the Flandrian (Zone IV) in areas of oceanic climate and to survive as an understorey plant first below Pinus and then under Quercus and Ulmus. The high pollen frequencies recorded at Langney Point also suggest that hazel may have formed pure stands.

The early record of Corylus at Eastbourne and on the Isle of Wight attests to the migration of thermophilous trees into areas of southern England during Zones IV and V. This is further shown by the establishment of Quercus in the Boreal at Langney Point, the

Isle of Wight (Scaife, 1980) and in Dorset (Haskins, 1978), the early occurrence of Alnus at Langney Point and Lottbridge Drove (as discussed later) and on the Isle of Wight (Scaife, 1980) and the probability that Tilia was growing in the Eastbourne area and at Southampton (Godwin, 1943) by Zone IV.

2) The expansion of Juniperus in L.P.2.

The high values of the fragile pollen of this genus and the occurrence of juniper fruits in the sediments indicate it was growing locally. The expansion during L.P.2 cannot be a response to an amelioration of the climate consequent upon the opening of the Flandrian circa 10,500 B.P. because the juniper peak occurs after the opening phases of the postglacial period by which time a pine/hazel wood had already become well established in the area. Therefore on both chronostratigraphic and biostratigraphic evidence the major expansion of Juniperus does not mark the Zone III/IV boundary and an alternative explanation has to be sought.

Today juniper grows on the Chalk provided it is not shaded out by taller trees. However, the nearest Chalk is 5 kilometres away from the site and therefore cannot be the provenance for the large juniper frequencies. It is unlikely that juniper would have flourished if it was in direct competition with Pinus and Corylus and it is interesting that juniper begins to rapidly expand while pine and hazel are still well established. Therefore to explain the high frequencies of Juniper in L.P.2 a local source area must have existed separate from the pine/hazel wood. This source area would have been well drained as juniper will fail in swampy conditions and it may be significant that at the height of the juniper peak Potamogeton sp, Typha sp., and Equisetum decline to very low values or they are absent altogether. Conversely, the formation of the Crumbles Peat, although occurring within a phase of lower juniper values within L.P.3b, does not produce any

further significant depletion in juniperus' representation. Therefore this genus was probably not growing on low-lying areas but had become established on higher ground. St. Anthony's Hill is approximately 1.5 kilometres from Langney Point and so it is not sufficiently local to account for the juniper peak.

The boundary between L.P.2 and L.P.3 occurs as juniper is declining and Chenopodiaceae increase. The latter group of plants together with the fauna described in Section B, is taken as evidence for the establishment of a salt marsh. The proximity of the sea during the juniper peak of L.P.2 can therefore be postulated but, as discussed above, juniper would not have been growing in areas with a high water-table prone to flooding. The ephemeral nature of the juniper peak suggests that the higher ground which it inhabited was not stable. Significantly, Godwin (1975) believes that open and disturbed soil conditions encouraged the spread of juniper in the Lateglacial and early Flandrian. The continuing though declining presence of juniper in L.P.3 suggests that this higher ground must have been gradually overrun by the sea. This would result in continued instability and disturbed conditions which is suggested by the continuous representation of Urtica type pollen.

The establishment of sheltered saline conditions and transient higher ground can be explained by the formation of coastal sand dunes, in the lee of which a salt marsh could develop. Ultimately the dunes were inundated as the Flandrian transgression continued. This hypothesis, discussed in Secton E, is supported by both biostratigraphic and lithostratigraphic evidence.

i) Biostratigraphic evidence:-

(a) As described in Section B, the fauna isolated from the sediments obtained by the U.100 cores indicate

predominantly sheltered saline conditions during L.P.3, i.e. soon after the juniper peak of L.P.2.

(b) The occurrence of Frankenia, Parnassia and, to a lesser extent, Linum catharticum during the secondary juniper peaks of L.P.3 are indicative of sand dunes. The presence of Chenopodiaceae and Glaux indicate nearby salt marsh.

(c) In Holland juniper often forms the climax vegetation on coastal dunes today and pollen records indicate that this genus has long been associated with this type of environment (Jelgersma et al., 1970). From these Dutch sites, it appears that juniper prefers calcareous conditions. Sediment samples taken from the U.100 cores at Langney Point reacted with dilute Hydrochloric acid. Indeed, the local Greensands are calcareous.

(ii) Lithostratigraphic evidence:-

(a) Overlying the Crumbles Peat is a narrow layer of sandy-clay-loam (U.S.D.A. classification). This horizon is coarser than the overlying sediments and so runs counter to the general trend of coarsening upwards of the sediments (see Secton B 3). This may be explained by overwashing of neighbouring sand dunes and significantly contains the following fractured marine diatoms;

Nitzschia punctata, Paralia sulcata, Raphoneis sp..

(b) The sudden transition from clay to sand textured sediments in the Upper Minerogenic Sequence of the lithostratigraphy at -14.2m. O.D. and the accompanying faunal change from salt marsh to open coastal types may mark the complete overrunning of a dune system.

The hypothesised dunes themselves are not preserved in the Lower Minerogenic Sequence of the Langney Point lithostratigraphy. The juniper peak occurs in a freshwater clay with only a 34% sand content. This is taken to indicate that during the p.a.z.'s L.P.1, 2 and 3, the sand dunes were seaward of the site but close by, allowing, in their protection, a salt marsh to become established following a freshwater phase.

The development of the Eastbourne coastline throughout the Flandrian is discussed in Sections E and F. The establishment of dunes and associated offshore bars is an important facet of this reconstruction. The occurrence of juniper, sometimes in abundance, may be intimately linked to coastal processes in that its presence, together with the other lines of evidence referred to, may indicate dune formation.

3) The low frequencies of Betula.

The low frequencies of this pioneer genus in the early Flandrian can be most readily explained by competition from Pinus which was well established in the area during this period. It is therefore possible that the pollen record does not begin until after an earlier Betula peak. During the height of the Pinus frequencies in L.P.1 and during L.P.2 Betula is virtually absent, although there is a small peak in the early stages of L.P.1 when pine has lower values. This elimination of Betula by Pinus and Corylus in the early Flandrian has been recognised at other sites in southern England. For example, during Zones IV/V on the Isle of Wight (Scaife, 1980) Betula is replaced by Pinus, while at Wareham and Nursling (Seagrief, 1959), Cranes Moor (Seagrief, 1960) and at Elstead (Seagrief and Godwin, 1960) a similar pattern was found. Furthermore, at Brook in Kent, Kerney et al. (1964) have suggested that Pinus was a component of the flora even in the Lateglacial.

Throughout L.P.3 at Langney Point, Betula only manages phases of minor expansion which suggests that conditions in and around Langney Point were never suitable for this genus. As oak and elm replaced pine, so birch faced new competition against which it could not succeed.

Although the persistently high values of Corylus indicate a relatively light canopy or even pure stands of this genus, Betula does not survive as an understorey plant and was never able to form the canopy layer itself. Therefore, competition from other trees was probably the cause of the unusually low early Flandrian representation of Betula at Langney Point.

4. The early appearance of Alnus

Alnus is present, but in low values, in L.P.1 and L.P.3. As with most other arboreal taxa, alder is virtually absent during the expansion of Juniperus in L.P.2. However, the appearance of alder in L.P.1 represents an early arrival for this genus as Godwin (1975) shows alder not expanding until the Atlantic period (Zone VIIa). The explanation may be that Aluns, similar to Corylus, thrived in the humid temperate climates of coastal districts in the early Flandrian.

In southern England during Zone IV, Godwin (1975) reports low frequencies of Alnus, while Scaife (1980) found alder values of 5% on the Isle of Wight at this time. Significantly, Devoy (1979), in the Thames estuary, found Alnus to be well established before 8,000 B.P. and he attributed this to locally favourable conditions. In north west France, Huntley and Birks (1983) report that Alnus obtained relatively high frequencies by 10,000 B.P., reaching a maximum of 23%. They also record low frequencies of Alnus in Scotland, northern England and north west France even during the Lateglacial, but question whether these findings may be due to reworking or to long distance transportation.

Therefore, the low alder values in L.P.1 at Langney Point are not incompatible with this picture of limited Alnus development during the early Flandrian in north west Europe. As will be argued later, at Lottbridge Drove this genus was probably present in the Lateglacial when a local maritime climate allowed a relatively thermophilous vegetation community to grow.

It is perhaps surprising that Alnus does not undergo some expansion during the Crumbles Peat phase (L.P.3b). This is further evidence that the Crumbles Peat was not developing as a fen carr.

5) The occurrence of Acer pollen.

Acer is not considered to have migrated into Britain until relatively late in the Flandrian. Godwin (1975) records no trace of this genus until Zone V11b when macro- and micro-fossil remains of Acer campestre are identified. Being a low pollen producer and not wind-pollinated, it never attains high values on pollen diagrams and as a consequence is often under-represented. Even today in areas where Acer is locally co-dominant in the forest, it rarely exceeds 5% of the pollen sum (Huntley and Birks, 1983).

Acer pollen is found in all three pollen assemblage zones of the Langney Point diagram, although its frequency is never more than a single grain. It is present during the juniper peak of L.P.2. The problem is to determine whether the Acer pollen is primary or secondary. There is only a very small representation of morphologically distinct secondary pollen and spores on the Langney Point diagram and Acer shows no correlation with these. For example, the behaviour of Picea, arguably a secondary grain (see Section D), shows no similarity to that of Acer on the diagram. Thus there is no evidence from the pollen diagram that Acer is secondary and therefore this genus may have been growing locally at Eastbourne in the early Flandrian. In support of this

contention, there are two characteristics of the local environment in the early Flandrian that may have been conducive to the growth of Acer:-

(i) The open nature of the woodland is shown by the high frequencies of Corylus. This absence of strong competition would allow Acer to flourish.

(ii) Acer requires well-drained base-rich soils which the weathered Chalk, Greensands and Clays would have provided. It is perhaps significant that Acer is present at the time of the juniper expansion. As argued earlier, juniper probably expanded on dunes which provided local well-drained habitats. Therefore it is conceivable that these dunes supported a woodland dominated by Juniperus with limited growth of pine, maple and hazel.

At both Langney Point and Lottbridge Drove, known secondary grains were found, although at Langney Point there were very few. Besides these derived pollen and spores, there are a number of other 'anomalous' pollen types, especially at Lottbridge Drove, which are believed to be primary. Unfortunately, it is not clear into which category to place Acer. Although, as outlined above, it can be argued that the conditions at Langney Point (and at Lottbridge Drove) would have allowed this genus to flourish, southern England lies a great distance from the suggested glacial refugia of Acer (Huntley and Birks, 1983), a problem for interpretation that does not exist for Corylus and Alnus.

Therefore the presence of Acer pollen at Langney Point is equivocal. If the grains are primary then the Eastbourne area must have acted as a refugia for maple, an idea which finds no support in any other work, although the occurrence of Acer in early Flandrian deposits of southern Scandinavia is also anomalous (Huntley and Birks, 1983). On the other hand, there is little evidence for the grains being of secondary origin.

C 5.1.3. Summary

The Langney Point diagram appears to be largely unaffected by secondary pollen redeposition and therefore does reflect early Flandrian vegetational change. There are some close similarities between the pollen assemblages of Langney Point and those from sites on the Isle of Wight analysed by Scaife (1980). The main similarities have already been referred to, namely the widespread occurrence of Pinus and Corylus, and the small representation of Alnus (and Tilia) at the opening of the Flandrian and the early establishment of Quercus during the Boreal. Although on the Isle of Wight there is a delay before Pinus becomes a dominant member of the woodland in the early Flandrian, in Dorset it is important at this time (Haskins, 1978) which suggests a similarity in the vegetational histories of the Eastbourne and Dorset areas during the opening stages of the postglacial period. However, the expansion of Juniperus in the early Flandrian at Langney Point cannot be found in either the Dorset or the Isle of Wight sites referred to above. This may be cited as further evidence that at Langney Point there were special local conditions that allowed juniper to flourish.

The decline of pine, the expansion of Quercus and Ulmus and the later low but consistent presence of Tilia during L.P.3 is typical of the transition from Godwin's Pollen Zones VI to VIIa, but, as indicated above, the initial rise of oak and elm occurred during the Boreal (Zone V) reflecting the early development of thermophilous woods in southern England. Unfortunately the record ends at this point as the upper silts and sands of the Upper Minerogenic Sequence of the Langney Point lithostratigraphy could not be sampled by the drilling rig to the required reliability and no alternative method of extraction was feasible. It should also be emphasised that the discussion on the 'early Flandrian' vegetation at Langney Point assumes that the Carbon-date of 11,390 $\pm$ 170 B.P. is erroneous. Therefore the early assemblage zones

are considered not to be Lateglacial but are more likely to represent the end of Godwin's Zone III and all of Zone IV.

C 5.2. Willingdon Levels.

Two pollen diagrams have been constructed from this area. One covers the entire lithostratigraphic sequence (Lottbridge A) with the samples being taken from the sediments obtained by the commercial drilling rig at Lottbridge Drove. The second diagram (Lottbridge B) has been constructed from samples taken from the exposed face of Willingdon Peat that also provided the material for Carbon-dating.

C 5.2.1. Lottbridge A. (Fig. C2).

Similar to the Langney Point diagram, the quantity of pollen and spores was found to be low and they were also in a poor state of preservation. The exception was in the Willingdon Peat unit where pollen concentration was found to be greater and the grains usually less deteriorated.

The pollen assemblage is unusual as many levels contain a considerable proportion of reworked pollen. In addition the A.P. content never attains values greater than 59% of the total pollen and spore sum and is usually less than 30%.

C 5.2.2 The pollen assemblage zones.

In contrast to the Langney Point diagram, the pollen zones show a close association with the lithostratigraphy. Therefore the p.a.z.'s mostly correspond to the lithostratigraphic units outlined in Section B 3.2. However, the boundaries between the zones are not based upon lithostratigraphic changes but have been selected where there is a clear change in the pollen assemblage followed by a period of relative palynological consistency.

Five major pollen assemblage zones are recognised:-

L.D.1. -8.75m. O.D. to -8.10m. O.D. Cyperaceae, Equisetum.

L.D.2. -8.10m. O.D. to -6.10m. O.D. Alnus, Cyperaceae, Gramineae.

L.D.3. -6.10m. O.D. to +0.18m. O.D. Pinus, Gramineae, Cyperaceae, (Picea.)

L.D.4. +0.18m O.D. to +1.40m. O.D. Quercus, Gramineae, Chenopodiaceae, Filicales.

L.D.5. +1.40m. O.D. to +2.55m. O.D. Chenopodiaceae, Gramineae, Cyperaceae.

L.D.1. -8.75m. O.D. to -8.10m. O.D. (Cyperaceae, Equisetum zone).

This is the narrow basal zone that corresponds with the weathered horizon of the Gault bedrock. Pollen is sparse and dominated by Cyperaceae which attains values of 84%. Equisetum and, to a lesser extent, Sphagnum are also significant in this zone, while Pinus and Gramineae are present but in small amounts.

L.D.1 is poor in species with an absence of arboreal pollen. The small amounts of Pinus and even smaller quantities of Picea may be due either to long distance transport by wind or to reworking of older sediments. This absence of trees with a landscape dominated by Cyperaceae, with Equisetum and Sphagnum, suggests cold conditions with swampy ground. Since L.D.1 lies below the Valley Gravels it may therefore be ascribed to a glacial episode.

L.D.2. -8.10m. O.D. to -6.10m. O.D. (Alnus, Cyperaceae, Gramineae zone)

This zone corresponds with the Valley Gravels of the lithostratigraphy and, as might be expected in coarse textured

minerogenic sediments, the pollen concentration is very low. The sudden changes on the pollen diagram at the opening of this zone coincide with the boundary between the weathered Gault horizon and the Valley Gravels. This may indicate an hiatus in the sedimentation at this point. The presence of Alnus in values of up to 25%, Cyperaceae (to 64%) and, in one level, Typha angustifolia suggest that water was present during L.D.2, a contention supported by the stratified nature of this lithologic unit. There is also a marked increase in the number of herbaceous taxa. In particular Urtica type is consistently present indicating disturbed conditions.

The occurrence of arboreal pollen, especially Alnus but also the smaller amounts of Betula, Corylus, Quercus, Ulmus, Fraxinus, and even Acer and Tilia, supported by the presence of Filipendula and Typha sp. suggest warmer conditions than those of L.D.1. With the exception of Betula, all of these tree genera are normally associated exclusively with an interglacial climate and would therefore imply a Flandrian age for this zone. Significantly, the thermophilous element on the pollen diagram is found throughout the Valley Gravels. This is taken to indicate that these genera colonised the sediments as they were being laid down. Eluviation of the pollen grains is thought unlikely because of their relatively good state of preservation. Contamination is also considered to be unlikely because the U.100 samples are encased in metal which protects the cores from both air and water-borne contamination. Although water was used to aid drilling, there is no opportunity for any 'fresh' pollen to settle out and no likelihood that water could penetrate through to the centre of a core.

This problem of contamination of samples is very important in sequences that contain low pollen concentrations where even low numbers of contaminants can distort the diagram. However, it is difficult to explain the number of Alnus pollen and grains of other thermophilous taxa, isolated from these sediments, as being

the result of contamination. The possibility that Alnus and these other taxa may have been reworked from older sediments may also be discounted because of the absence of morphologically distinct secondary grains, except at the top of L.D.2 where reworking from the overlying sediments is the likely cause. Significantly, Picea which, as will be argued later, is considered to be secondary, is not found in this zone. Thus the absence of known secondary grains from L.D.2 infers the assemblage is likely to be primary.

The taxa present in this zone suggest an interglacial climate but, as has been explained, the early Flandrian vegetation at Langney Point is characterised by a well established pine/hazel forest. The low frequency of Corylus and the virtual absence of Pinus from L.D.2 therefore mitigate against an early Flandrian age for this p.a.z.. The very low pine values are particularly difficult to explain if L.D.2 is of this age. The grains of Pinus are easily transported by the wind so that even if pine was not growing at Lottbridge Drove this genus should be represented in higher values due to wind transportation of the pollen from the Langney Point area.

It appears that this p.a.z. must either pre-date or post-date the pine/hazel zone of Langney Point. The low levels of Quercus, Ulmus and of other arboreal representatives of the 'Mixed-Oak Forest' indicate that a later Flandrian age for this zone is not a viable explanation. Thus L.D.2 probably does not post-date the pine/hazel period.

Kerney (1963) described a series of 'stratified Chalk muds and fine rubbles' from a number of sites in Kent, Surrey and Sussex. Because they were considered to be deposited by water, he called these sediments 'Chalk meltwater muds' and, as outlined in Section B, the Valley Gravels of Lottbridge Drove may also be ascribed to this type of sedimentary sequence. One of Kerney's sites is Cow Gap near Beachy Head. The age of the Chalk meltwater muds here, as at the other sites, is considered, from their molluscan

content, to be Lateglacial. If the Valley Gravels of Lottbridge Drove were also of this age, it would explain both the absence of the pine/hazel zone and the low values of the 'Mixed-Oak Forest' pollen types. This, however, is only circumstantial evidence and does not properly explain the thermophilous element present. Nevertheless, there are other factors which support a Lateglacial age for this pollen zone. These are:

1). It is unlikely that the Valley Gravels represent a solifluction flow reworked in the early Flandrian by river action and then deposited at Lottbridge Drove. There are two reasons for suggesting this:-

i) The pollen assemblage does not support such an age for this deposit, as explained above.

ii) The hand auger investigation found the Valley Gravels on the buried slopes of the bedrock surface and not just in the buried channel (see figure B4). It is difficult to envisage a situation whereby active mass movement of this nature occurred on slopes in the early Flandrian because the rapid colonisation of the area by herbaceous and arboreal taxa would have stabilised the slopes. The pine/hazel forest at Langney Point had become established by the Pre-Boreal and therefore large scale mass movement had probably ceased in the area by then.

2). The Valley Gravels therefore appear to be Lateglacial sediments. At Cow Gap, the Zone III facies of the Chalk meltwater muds were found to be thick compared to the Zones I and II facies, and were usually better stratified (Kerney, 1963). This suggests that much of the Valley Gravels at Lottbridge Drove may also be of Zone III age, in which case the occurrence of thermophilous taxa requires explanation.

Bell (1969) concluded that it was quite reasonable to have had vegetation typical of a Southern and Steppe distribution present in the Weichselian flora of southern Britain. The appearance of

thermophilous species at that time can be explained by factors such as the existence of large areas of open habitat, free from competition by trees, outweighing climatic restrictions. The variety of habitats available during glacial conditions would have resulted in the co-existence of Southern, Steppe and Halophytic species in such a way that no present day analogues can be found (Bell, 1969).

Smith (1965) has drawn attention to the variations in the quantity of tree pollen present on Lateglacial diagrams from northern England. He suggests that when the climate is in a state of flux, as, for example, during the Lateglacial, local factors such as microclimate and soil characteristics are likely to produce a variety of habitats which in turn would result in variations in the extent of woodland development.

The sharp rise in Alnus and the smaller increase in Betula, Corylus and Tilia at the base of the Valley Gravels at Lottbridge Drove indicate a rapid amelioration of the climate. These genera are either absent or in very low frequencies in the previous p.a.z.. The absence of a well established 'Mixed-Oak Forest' element suggests that L.D.2 is not interglacial (as discussed above) and, considering Bell's arguments and Smith's observations, may better be explained as a Lateglacial response to climatic amelioration.

3). Kerney (1963) found the molluscan content of his Chalk meltwater muds at Cow Gap indicated relatively mild conditions even in Zones I and III. He explained this by advocating, based on a study of the sub-marine contours, an inlet of the sea extending close to Beachy Head during the Lateglacial. The resultant maritime influence allowed more thermophilous types of mollusc to flourish locally. If this assertion is true, this could also explain the presence of thermophilous vegetation at Lottbridge Drove in the Lateglacial. An oceanic climate, fresh,

base-rich moist sediments and an absence of competition may have been factors conducive to the establishment of copses or sparse woodland comprising Alnus and other arboreal taxa. The drilling rig did not recover any branches or trunks and the hand auger was unable to penetrate the Valley Gravels. Therefore it is impossible to assess the extent of Alnus by macrofossil analysis. However, the palynological evidence of high frequencies for Cyperaceae and Gramineae suggest an open/sparse woodland.

The above factors infer L.D.2 to be of lateglacial age. However, as no organic remains within the Valley Gravels have been found it is not possible to apply ^{14}C dating to this sequence. In addition, it has not been possible to identify an Alleröd soil. Furthermore, the Zone III/IV boundary is missing as there is no characteristic Juniperus expansion in the upper part of this p.a.z., only a small increase to 4%. It is also unclear whether the band of large angular flint cobbles encountered within the Valley Gravels represents a climatic deterioration, or a change in the load carried by the stream as a response to a very short term event such as a flood. For these reasons it is difficult to divide this p.a.z. into the Lateglacial Zones I, II and III (Godwin, 1975).

Significant local variations in the Lateglacial climate and response by the vegetation (Watts, 1980) questions the applicability of Godwin's scheme for the purpose of regional correlation. The problem of zonation of the Lateglacial in north west Europe has been recognised by a number of authors (e.g. Watts, 1980; Lowe and Gray, 1980). Although in detail the Lateglacial appears to be a climatically complex episode (Watts, 1980), in general terms it may be summarised as exhibiting an amelioration from approximately 14,000 B.P. followed by a deterioration between 11,000 and 10,000 B.P. (Lowe and Gray, 1980).

Lowe and Gray (1980) have suggested the Lateglacial be divided into two climatostratigraphic units; the 'Lateglacial

Interstadial', to mark the phase of climatic amelioration, and the 'Younger Dryas Stadial', to represent the episode of climatic deterioration.

The Lateglacial pollen record from Lottbridge Drove may be applied to this scheme in the following manner. It is a feature of L.D.2 that all the thermophilous taxa decline just below the band of large flints and this may indicate a climatic cooling. Tilia completely disappears from the diagram at this point and does not return until L.D.3. The herbaceous taxa also decline in the upper part of the diagram. On this tentative evidence, the lower section of L.D.2, which contains the maximum frequencies of the thermophilous and herbaceous taxa, may be ascribed to the Lateglacial Interstadial. The absence of organic material often encountered in sediments of this age may be explained by the site being on the side of a channel and thereby susceptible to erosion. The upper portion of L.D.2, from the large flints to the L.D.2/3 boundary, may be referable to the Younger Dryas Stadial, the thermophilous taxa persisting in reduced numbers by benefiting from the local oceanic climate. However, at the very top of this p.a.z., Pinus replaces the thermophilous genera and this may herald more typical Younger Dryas Stadial conditions.

The uppermost levels of L.D.2 may have been eroded prior to the deposition of the Lower Silty Clay as evidenced by the sudden change on the pollen diagram at the L.D.2/3 boundary. This may explain the absence of the juniper expansion, although an alternative explanation is competition from Pinus. At Langney Point, pine was well established by the early Flandrian while in Kent, Kerney et al. (1964) have demonstrated that pine may have been present during 'Zone III', that is the Younger Dryas Stadial. Therefore, considering the possibility of local maritime conditions at Eastbourne during the Lateglacial, it is likely that pine was able to respond quickly to any amelioration of climate at the opening of the Flandrian and thereby prevent juniper undergoing its characteristic expansion at this time.

It is therefore possible that Alnus along with other thermophilous taxa were able to survive locally during the Lateglacial at this coastal site where conditions of moist base-rich sediments and an oceanic climate were sufficient to allow such a community to grow. In Smith's terms, the threshold for vegetational change that would allow alder at this site had been crossed (Smith, 1965). Furthermore, the establishment of alder at Lottridge Drove during the Lateglacial helps to explain the early Flandrian occurrence of this genus at Langney Point.

The contention that Alnus may have been present locally within southern England during the Lateglacial is supported by the investigations of Haskins (1978) into the vegetational history of the Poole Basin. She found a low but consistent presence of Alnus pollen at a Lateglacial site and attributed this to a local stand of alder. Also of note, Haskins was unable to recognise any clearly defined 'Zone II and Zone III' of the Lateglacial and suggested reworking during 'Zone III' as a reason for this.

L.D.3. -6.10m. O.D. to + 0.18m. O.D. (Pinus, Gramineae, Cyperaceae, (Picea) zone).

This zone is equivalent to the Lower Silty Clay unit of the lithostratigraphy and represents a distinct change in the environment of Willingdon Levels. The sudden change on the pollen diagram at the Zone 2/3 boundary, although reflecting a different type of sedimentation, may also indicate an hiatus at this junction resulting in the erosion of the uppermost levels of the under-lying Valley Gravels.

The aboreal pollen is dominated by Pinus with smaller amounts of Picea. Other tree pollen are present but usually in low percentages. However, in sub-zones 3b and 3d, Pinus and Picea decline and are replaced on the diagram by increases in Corylus, Quercus, Ulmus, Alnus, Fraxinus and, in 3b only, Tilia. This expansion of Tilia to 14% may be a reflection of its pollen's resistance to deterioration. Godwin (1975) has indicated that

Tilia may sometimes be over-represented because of this despite being a low pollen producer. However, the very low frequencies of Tilia during the remainder of L.D.3 suggests that in sub-zone 3b a genuine increase in the quantity of Tilia pollen present in the sediment occurred.

Throughout L.D.3 Gramineae and Cyperaceae fluctuate, mostly alternately, between values of over 50% to less than 5%. In sub-zone 3b Cyperaceae attains values of up to 72% just prior to the increase in the pollen of the deciduous trees. Its association at this time with an increase in Typha angustifolia, Equisetum and Filicales and low A.P. suggest an open swampy environment. Indeed, freshwater taxa are almost continuously present throughout L.D.3 but in low frequencies, although they undergo minor expansions in 3b and 3d. The occurrence of Filipendula, Chrysosplenium and the spores of Polypodium, Equisetum, Sphagnum and Filicales is further evidence for the proximity of moist freshwater habitats during L.D.3.

Chenopodiaceae are sporadic in their representation but become continually present in the later stages of this p.a.z.. This pollen type tends to show a positive correlation with Gramineae and, together with the fine grained texture of the Lower Silty Clay, points to salt marsh development. This contention is supported by other lines of evidence, namely the presence of estuarine molluscs (see Section B) and Hystrichospheres.

Thus L.D.3 contains evidence for saline and freshwater habitats co-existing close to the pollen site at Lottbridge Drove. The faunal record indicates a salt marsh environment at the site, the pollen diagram supporting this through the Chenopodiaceae frequencies.

A characteristic of L.D.3 is the quantity of exotic grains namely pre-Quaternary pollen of the Classopollis type, Cretaceous spores and Picea. Such a co-existence of exotic grains indicates

extensive reworking whereby pollen and spores of different ages have been redeposited under the estuarine conditions revealed by the pollen and fauna record. A discussion on this subject follows in Section D where it is argued that much of the Pinus pollen is also derived, either from older sediments and/or has been transported by ocean currents. This latter possibility has been proposed for some of the pine at Langney Point. Reworking of pine pollen in estuarine environments has been noted by other authors (Godwin, 1975; Devoy, 1979; Brooks, 1972) and therefore an increase of this genus on pollen diagrams taken from estuarine sediments must be treated with caution as this may not reflect changes to the near-by contemporary vegetation.

Therefore L.D.3 consists of a complex assemblage of derived grains and representatives of terrestrial, freshwater and salt marsh taxa. Sub-zones 3b and 3d show an increase in the pollen of the 'Mixed-Oak Forest' genera as the exotic types decline. However, such a pattern probably does not indicate a major change in the comtemporary vegetation of the area. Instead it may mark a change in the provenance of the pollen with a switch from secondary to primary or penecontemporaneous sources.*

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*Note: Cushing (1964) has suggested a set of terms to differentiate between derived and contemporary grains:-
Primary pollen:- Pollen from plants living at the time of deposition of their pollen which has not undergone any reworking.
Penecontemporaneous pollen:- Redeposited pollen from living plants, i.e. redeposited primary pollen. Cushing uses the example of redeposition from the litter layer to illustrate this.
Secondary pollen:- Redeposited pollen from older layers that may be pre-Quaternary or pre-Flandrian in age.
The age of secondary pollen may therefore differ greatly but should not be confused with penecontemporaneous pollen whose age should be no more than single years and which, for the purposes of pollen analysis, is not significantly older than primary pollen. Secondary pollen may be thousands or millions of years old and may have undergone several cycles of redeposition. This terminology has been used in this work to describe the various derivations of pollen and spores.

This view finds support in Cushing (1964) who believes that a sharp rise in arboreal pollen may be due to an influx of grains washed in from the surrounding slopes. This penecontemporaneous pollen, although not a reflection of the atmospheric pollen rain, is however a good indicator of the vegetation close to the site. Further support for this comes from West et al. (1974) who concluded that the pollen spectra of Devensian deposits at Wretton in Norfolk exhibited "variable pollen sources" due to changes in the type of sedimentation. For example, during phases of coarser sedimentation there was an accompanying rise in some herbaceous species that are indicative of mineral soils. This was interpreted as representing a greater influx of primary pollen from local sources.

It must be emphasised that the percentage of A.P. in L.D.3 is, to a great extent, artificial because it usually reflects the Pinus and Picea frequencies both of which, as will be argued in the next section, are derived. Therefore, the 59% A.P. recorded in sub-zone 3d is of interest as this is due to a sudden rise in Quercus and Corylus. However, because this increase is not sustained, this further questions whether it reflects a genuine expansion of the 'Mixed-Oak Forest' and may instead by attributable to a change in the source of the pollen. Thus the increase in the pollen of the 'Mixed-Oak Forest' taxa during 3b and 3d is not a reliable indicator of the relative abundance of each individual genus, but it is considered that they represent the Flandrian vegetation of the area. This, of course, assumes that their pollen is primary or penecontemporeaneous and are not themselves of secondary origin. This may be a safe assumption because there appears to be no positive correlation between them and the frequency of known secondary pollen and spores.

The abundance of secondary grains makes it difficult to correlate L.D.3 with Godwin's scheme, or to find similarities with the Langney Point diagram. However, it may be significant that taxa

normally associated with the mid- to late-Flandrian (i.e. from the Atlantic stage or Zone VIIa onwards) either first appear or expand almost contiguously in the upper part of sub-zone 3b. The Tilia peak, followed by a small increase in Fraxinus, the arrival of Hedera and Carpinus and later Fagus and Ilex are referable to Zones VIIa (The Atlantic) and VIIb (The Sub-Boreal).
Unfortunately, Ulmus is too inconsistent to allow any recognition of an elm decline during L.D.3, but an Atlantic to Sub-Boreal date for much of this p.a.z. is supported by the ^{14}C assay of 3,750 $\pm$ 40 B.P. for the base of the overlying Willingdon Peat.

L.D.4. +0.18m. O.D. to +1.4m. O.D. (Quercus, Gramineae, Chenopodiaceae, Filicales zone).
The opening of this p.a.z. does not coincide with a lithostratigraphic boundary, but occurs below the transition of the Lower Silty Clay with the Willingdon Peat. This suggests that no unconformity exists between the two lithostratigraphic units (Hall, 1981). Taxa that had been in low frequencies during L.D.3 increase prior to the peat layer. However, within L.D.4 the subdivisions correlate with lithostratigraphic changes.

L.D.4a, the lower of the three sub-zones, is marked by a rise in Quercus, to a peak of 36%, and an increase in Ulmus and Alnus. Pinus virtually disappears from the diagram. At the same time, Chenopodiaceae show a sudden increase and this is soon followed by a rise in the freshwater taxa of Typha angustifolia, T. latifolia, Potamogeton sp. and Filicales. The derived grains - Classopollis type, Cretaceous spores and Picea - are absent.

This sub-zone incorporates the top of the Lower Silty Clay deposit and the two lower Willingdon Peat horizons. Thus, as the nature of sedimentation changes from minerogenic to organic, and thereby forming a lithostratigraphic overlap, the pollen assemblage alters from one dominated by derived grains to one characterised by Quercus, Chenopodiaceae and freshwater types. The replacement of

Chenopodiaceae by the freshwater taxa marks a concurrent ecological change whereby salt marsh is succeeded by freshwater conditions.

In L.D.4b Quercus and Gramineae maintain high frequencies but derived grains return. Chenopodiaceae increase to 22% while the freshwater taxa (except Potamogeton) decline. This shows a return to saline conditions, a contention supported by the diatom flora described in Section B 4.2, and coincides with a return to minerogenic deposition. At the lithostratigraphic boundary, Pinus immediately reappears at a value of 13%, Quercus expands from 5% to 12% and Typha angustifolia declines from 15% to 2%. These sudden changes on the pollen diagram reflect the change in sedimentation with the onset of different environmental conditions, but also suggest that the top of the Willingdon Peat layer has either been eroded or the drilling rig failed to sample the transition between the peat and the minerogenic horizon.

The Pinus values, by correlating so well with the minerogenic sediments, may again be due to reworking and marine transportation. Its near absence in the peat and its reappearance in minerogenic deposits has also been observed at Langney Point where it is argued that this characteristic cannot be used to infer local growth of this genus.

L.D.4c sees an expansion in Menyanthes, Typha angustifolia (to 15%), Filicales (to 130%) and a further increase in Gramineae. Chenopodiaceae decline to very low values and the derived grains are once again virtually absent. This sub-zone corresponds with the upper of the Willingdon Peat horizons and marks a further return to freshwater conditions.

However, as has been referred to in Section B, the Willingdon Peat may have been disturbed by the intercalation of the minerogenic horizon so that the upper component of this peat unit is possibly

reworked. Its present stratigraphical positon may be attributable to displacement by current or wave activity (see Shennan, 1984). It is possible for peat to be detached and float to a new location, and therefore there is some doubt as to whether this peat horizon is in situ.

L.D.5. +1.40m. O.D. to +2.55m. O.D. (Chenopodiaceae, Gramineae, Cyperaceae zone).
With the transition from the Willingdon Peat to the Upper Clay the pollen assemblage undergoes a further change. Chenopodiaceae return in high frequencies to a peak of 27%. This occurs while the A.P. are still well represented indicating the establishment of littoral salt marsh species rather than dry land types. This return to saline conditions is supported by the faunal evidence described in Section B.

As the Chenopodiaceae decline, Compositae/Liguliflorae expand to 20% before quickly disappearing. This heralds a transition from saline to freshwater conditions. This biostratigraphic overlap is also shown by the fauna (see Section B).

Except for Ulmus, the A.P. show a decline throughout L.D.5 to very low values. This corresponds with the rise in Compositae/Liguliflorae, Pteridium and a smaller increase in Bidens type. However, in the top level Pinus, Corylus and Quercus expand while most of the herbaceous pollen declines. The cause of the A.P. decline is discussed in Secton E.

With the return to minerogenic sedimentation, the derived grains also return but in reduced values. Picea, for example, is absent except in the top level which is probably due to afforestation by man, although the increase in pre-Quaternary pollen and spores, Hystrichospheres and Chenopodiaceae at this level may represent a partial return to saline conditions resulting in renewed reworking.

C 5.2.3. Lottbridge B. (Figure C3).

The possibility of disturbance to the Willingdon Peat unit in the original borehole questions the accuracy of the pollen record in p.a.z. L.D.4. Therefore an exposed face of Willingdon Peat, close to B.H.2, was used to obtain samples for both pollen analysis and Carbon-dating. These samples were obtained by constructing a pit through the peat. This revealed a single and apparently undisturbed organic sequence extending for 37 cms. from +1.63m. O.D. to +2.0m. O.D. (see figure C3). This peat unit contains more clayey horizons towards the top of the sequence. However, this does not resemble the blue-grey clay layer, recovered in BH.2, which intercalated the peat. At this second site, the entire sequence is organic.

The samples for pollen were taken at 2cms. intervals throughout the deposit.

This diagram does not possess the distinctive sub-zones of the Lottbridge A diagram. For this reason the Lottbridge B diagram has not been zoned. Instead the whole of this diagram is ascribed to p.a.z. L.D.4.

Nevertheless, the pollen assemblage does show certain trends. Most noticeable of these is the decline of Filicales towards the middle section of the diagram. This is to some extent matched by a similar characteristic in the frequencies of Typha angustifolia and by the A.P.. Quercus, for example, attains a value of 23% at the +1.72m. O.D. level and 16% at the +2.0m. O.D. level. In between this genus declines to a value of 2%. Alnus and Corylus follow a similar pattern.

Chenopodiaceae remain low throughout, although this pollen type undergoes a minor expansion at the time of lower A.P. and lower Filicales. Whether this increase of Chenopodiaceae reflects the

growth of salt marsh or of terrestrial taxa is not clear. Its association with a single grain of Glaux maritima at +1.86m. O.D. and its expansion coinciding with the decline of Filicales suggests these grains probably represent a nearby salt marsh community.

Thus the Lottbridge B pollen diagram reveals an environment in which arboreal taxa played a secondary role to herbaceous types in the vegetation of the area at least close to the site. In detail, there are two phases of higher A.P. values separated by a period of very low A.P. frequencies. Wetland herbaceous taxa dominate the flora with Filicales and Cyperaceae being particularly important. On occasions, Gramineae and Typha angustifolia also form an important component of the vegetation.

C 5.2.4. Comparison of the Lottbridge A and B diagrams.

In general terms the similarities between the two diagrams allow a degree of correlation. In particular the two peaks of Quercus, Filicales and Typha angustifolia can be readily identified on both.

However, there are also some very noticeable differences between the two diagrams. These differences appear to be associated with the intercalation of the minerogenic horizon on the Lottbridge A diagram. Although the second diagram does contain an increase in minerogenic content towards the top of the lithostratigraphy, there is no corresponding change in the biostratigraphy.

There are two major differences between the two diagrams and importantly these contrasts probably mirror variations in the environment during the period of Willingdon Peat formation.

The first difference is the presence on the Lottbridge A diagram of relatively high frequencies of Pinus accompanied by Picea and pre-Quaternary pollen and spores in the minerogenic layer. This is attributed to reworking under estuarine conditions, as explained earlier.

The second difference is the values attained by Chenopodiaceae. On Lottbridge B, which has a largely biogenic lithostratigraphy, they usually only attain very low frequencies. However, on the Lottbridge A diagram, Chenopodiaceae reach a maximum of 22% in the minerogenic layer, from which an estuarine diatom flora was recovered (Section B 4).

These differences are particularly significant occurring as they do between two pollen diagrams constructed from sites only 20m. apart. The general similarities between the two diagrams, remarked upon earlier, suggest that the organic layer at each site is of the same age, a contention supported by the uniformity of the Willingdon Peat unit in terms of its depth and extent.

It therefore appears that the intercalation of the minerogenic horizon on the Lottbridge A diagram (corresponding to p.a.z. L.D. 4b) may reflect a local channel along which estuarine conditions prevailed during the formation of the Willingdon Peat. It may be significant that the site from which the Lottbridge A diagram was constructed lies close to a small stream (the Lottbridge Sewer) and therefore it is likely that the major drainage channels on Willingdon Levels today mark the courses of channels cut into the peat during its formation.

No trunks or branches of trees were encountered either during the drilling or the hand augering at any site on the Levels. This suggests the A.P. found in the peat on both diagrams originated from woodland that became established on the drier slopes surrounding Willingdon Levels. The Levels themselves supported an open, wet-habitat community dominated by Cyperaceae, Filicales and *Typha* sp.. However, along the channels a salt marsh community of Chenopodiaceae developed. Thus, throughout the formation of the Willingdon Peat, the continuously high water-table resulted in a predominantly freshwater environment, but localised intrusions of saline conditions were also a characteristic feature of this period.

This picture of freshwater and saline conditions existing in close proximity to each other indicates very local and restricted dispersal of some of the pollen. The site of Lottbridge A is only 20m. from the site of Lottbridge B and yet the frequency of Chenopodiaceae pollen and of secondary grains is much greater especially in the minerogenic horizon of Lottbridge A. It therefore appears that the primary pollen associated with the saline component of the environment was dispersed very locally while the secondary pollen was literally 'channelled' to areas of salt marsh.

The formation of the Willingdon Peat was terminated by a return to estuarine conditions. This is attested to by a layer of Scrobicularia plana that was found in the lower levels of the Upper Clay during the construction of the pit at the second site. This is further supported by the high Chenopodiaceae values of the Lottbridge A diagram and by the Ostracoda and Foraminifera assemblage described in Section B.

Thus for a brief period from 3,750 ± 40 B.P. to 3,390 ± 40 B.P. a freshwater phase replaced an estuarine environment, although even during this phase saline conditions were still locally important. The transition to the Willingdon Peat therefore represents a regressive overlap, and its replacement by a return to estuarine conditions marks a transgressive overlap. The cause of this environmental change is considered in Section E.

C 5.3. Comparison of the Langney Point and Lottbridge Drove diagrams.

One objective of analysing pollen from two sites located within the same area is to construct a detailed picture of vegetational change for that area. Clearly, however, the two sites in this study contain significantly different pollen records. This is mostly the result of the reworking of pollen at Lottbridge Drove.

It may also reflect diachronous sedimentation at both sites in the early Flandrian. Nevertheless, within these contrasting records, a number of comparisons exist which shed light upon the general characteristics of the vegetational history of the area.

Although a dominant pollen type in L.D.2, Alnus never attains high values in any other p.a.z. of the Lottridge A diagram. Low values are also a characteristic of alder at Langney Point. It is perhaps surprising that Alnus does not undergo any marked expansion in the Willingdon Peat where it reaches a maxima of 13% on the Lottbridge B diagram. This genus is often over-represented on pollen diagrams constructed from peat and peaty-clay from mid- to late-Flandrian sites in East Sussex, for example the Vale of the Brooks (Thorley, 1971), the Combe Haven (Smyth, 1985), Pevensey Levels (Moffat, 1984), the Brede Valley (Waller, in prep.) and Pett Levels (Sutherland, in prep.). The Lottbridge Drove site is the only one of these pollen studies from East Sussex that contain mid- to late-Flandrian peat in which Alnus does not reach high values.

The low representation of Betula is another comparable feature of the diagrams. At Langney Point this can be explained by competition from other trees, but at Lottbridge Drove the low amounts of primary arboreal pollen suggests that competition from other taxa is not the cause, especially during the Lateglacial. Betula is also found in relatively low frequencies in the Vale of the Brooks (Thorley, 1971), the Combe Haven (Smyth, 1985) and on the Pett Levels (Sutherland, in prep.). This pattern suggests that in certain coastal areas of East Sussex conditions have not been favourable for this genus during the Flandrian.

At both sites Pteridium and Sphagnum spores are found in higher values in the minerogenic sediments than in the peats. This may be explained by these two types being easily transported by water as observed by Peck (1973) in a study of pollen transport in a

small catchment basin. However, an additional consideration are periods of hill slope instability, caused either by man or by other processes, which could have resulted in minerogenic sedimentation on Willingdon Levels. Such phases may have encouraged the spread of Pteridium.

Acer pollen is present at both Langney Point and Lottbridge Drove. At Langney Point the pollen is likely to be primary, but at Lottbridge Drove the status of this pollen type is equivocal because, as discussed in Section D 2, the occurrence of Acer follows a similar pattern to that of Picea suggesting a common derived origin. Phillips (1974), from an analysis of Ipswichian sites in Britain, concluded that Acer was locally abundant during that interglacial. Thus some of the Acer pollen may have been derived from a pre-Flandrian source along with Picea. This is further discussed in Section D.

However, the pollen of this genus is also found in p.a.z. L.D.2 (in the Valley Gravels) and in L.D.4c (the Willingdon Peat) which probably demonstrates a primary source.

Therefore it is possible that Acer was a component of the Flandrian vegetation of the study area, but some of the grains may be of secondary origin.

The main feature of the Lottbridge A diagram is the significant frequencies of secondary grains, especially in p.a.z. L.D.3. As a consequence, much of this diagram cannot be used to study in detail vegetational change in the Flandrian as successfully as the Langney Point diagram. P.a.z.'s L.D.1, 2, 4a, 4c and 5 probably do reflect vegetational change contemporary with each zone because secondary pollen does not distort the assemblages. Thus Lateglacial, early and late-Flandrian vegetational changes can be analysed. However, such analysis is difficult in the extensive L.D.3 due to the secondary pollen. A discussion on the provenance

of both primary and secondary grains is the subject of Section D 2 which deals at length with the Lottbridge A diagram.

The significant quantities of secondary grains in L.D.3 makes it difficult to correlate the Lottbridge A and Langney Point diagrams. This problem is compounded by the nature of the sediments which makes it impossible to obtain reliable absolute age determinations for either the lower part of the Lottbridge A diagram or the upper part of the Langney Point diagram. Therefore the p.a.z.'s are specific to each site as it is difficult to amalgamate them into a single scheme of assemblage zones.

This difficulty of correlation considerably restricts any attempt to reconstruct the mid-Flandrian vegetational history of the area. It is during this period that, because of the limitations of the drilling procedure, the record at Langney Point ends, while on the equivalent section of the Lottbridge A diagram, secondary pollen distort the assemblage.

However, Table C1 illustrates the periods of the Lateglacial and Flandrian considered to be represented at each site.

It is therefore believed that the Lottbridge A diagram covers all the period from the Lateglacial Interstadial to the present day. However, the early to mid-Flandrian record has been concealed mostly due to the abundance of secondary pollen. To a great extent this phase is well covered by the Langney Point diagram. Unfortunately, due to the limitations of the drilling at Langney Point and to the preponderance of secondary grains at Lottbridge Drove, Zone VIIa remains poorly represented. However, the corrected diagram for Lottbridge Drove, discussed in Section D 2 and illustrated by figure D1, gives some indication of the vegetation of the study area at this time.

Table C1.

	Godwin's pollen zones	Blytt and Sernander periods	Langney Point	Lottbridge A	Lottbridge B
FLANDRIAN	VIII	SUB-ATLANTIC	^{14}C B.P.		^{14}C B.P.
	VIIb	SUB-BOREAL			3390±40 3750±40
	VIIa	ATLANTIC			
	VI	BOREAL			
	V				
	IV	PRE-BOREAL	8770±50 (11390±170)	?	
LATEGLACIAL	III	*YOUNGER DRYAS STADIAL			
	II	*LATE GLACIAL			
	I	INTERSTADIAL			
FULL GLACIAL				? ?	

Key:- ------- Record heavily influenced by secondary pollen.
? Uncertain record either due to natural hiatus or to the limitations of the drilling.
( ) ^{14}C assay considered to be unreliable.
* Terminology after Lowe and Gray (1980).

SECTION D. POLLEN ANALYSIS 2.

PROVENANCE, REDEPOSITION AND DETERIORATION OF POLLEN AND SPORES.

D 1. Introduction.

Two important aspects of the information taken from pollen diagrams are first, ascertaining the extent to which the pollen and spore assemblage truly reflects vegetational change and composition and is not the product of pollen deterioration, selective pollen deposition or reworking from older sequences. These considerations are examined in this section. Second, the investigation of the relative proportions of the regional and the local component in the assemblage in order to reconstruct palaeovegetation communities. This is further discussed in Sections D 3 and E 1.

The influence of sedimentation on the pollen spectra can be fundamental with respect to both these aspects. This is particularly true for minerogenic sediments laid down by fluvial processes or under estuarine conditions. These circumstances can often lead, on a pollen diagram, to the occurrence of variations in the pollen record which are independent of contemporary pollen production in the local and regional vegetation. This may happen for two reasons. First, fluvial and estuarine processes can result in the transport of pollen and spores into an area by agencies other than wind. Many of these grains may be penecontemporaneous, in which case they are a reliable indication of the regional vegetation. However, other grains may be secondary and are therefore no reflection of the surrounding vegetation. Second, the type of sedimentation can determine the quantity of pollen and spores present.

The precise relationship between the sediments and their pollen content is complex. For example, there is disagreement over the

cause of variations in pollen concentration. Florer (1973) maintains that an increase in pollen concentration within a deposit reflects an increase in the contemporary vegetation cover. However, other authors, for example Heusser and Balsam (1977) and Peck (1973) argue that the quantity of pollen in minerogenic sediments will be determined by the sediment load of rivers and not by the extent of the surrounding vegetation. Peck (1973), in a study of a small drainage basin in Yorkshire, found the pollen concentration of most taxa increased as stream discharge increased. Hall (1981) believes it is the type of sediment that determines pollen frequencies, with a maxima in fine grained textures. Such a correlation has been noted in marine sediments where the greatest concentration of pollen is found in clay to silt textured deposits (Muller, 1959; Stanley, 1969). Peck (1973) also found this pattern in river and lake sediments, but warned that variations in pollen production may disturb this relationship.

Besides pollen concentration, the state of preservation and variations in the pollen assemblage can also be influenced by the sediments. This can be illustrated by the pollen diagrams from the Eastbourne sites. For example, at Lottbridge Drove abrupt changes in the pollen record occur at lithostratigraphic boundaries. This effect is strong enough to result in each lithostratigraphic unit having its own characteristic pollen assemblage. Also at Lottbridge Drove, the trend is for better preservation and increased concentration of pollen to correlate with organic deposition, while poor preservation and low concentration occurs in minerogenic sediments. West et al. (1974) maintain that these characteristics point to secondary pollen deposition in the latter type of sediment. This is shown well by the Lottbridge A diagram on which pre-Quaternary pollen and spores and other derived grains are common in the silt and clay deposits. However, as discussed later in this section, deterioration of pollen is an unreliable measure of secondary pollen content.

The pattern of pollen deterioration, the presence of pre-Quaternary microfossils in the minerogenic sediments and sudden changes in the pollen record at lithostratigraphic boundaries, particularly at Lottbridge Drove, show close similarities with the results of Birks (1970). He studied the pollen assemblage at Loch Fada, Isle of Skye, and although his site consisted of Late Weichselian silts with bands of Bryophyte remains, the conclusions reached by Birks concerning redeposition and deterioration of pollen and spores are pertinent to this study. Birks found;

> "The close correspondence between the boundaries of the pollen zones and the major lithological changes in the stratigraphy suggests that the pollen and spore content, the kind and extent of pollen deterioration and the content of pre-Quaternary microfossils .... are closely related to the sediment lithology." (Page 831).

The establishment of such correlations are of fundamental importance to the interpretation of pollen diagrams. Therefore, consideration must be given to the nature of sedimentation because it is likely to affect the pollen spectra and therefore the use and ultimately the value of a pollen diagram.

In Section D 3 of this work, a model is presented which is an attempt to illustrate the various origins and pathways of pollen and spores before they become incorporated into (estuarine) minerogenic sediments. Data and discussion on the deterioration of grains is given in Section D 4. The pollen diagrams from Lottbridge Drove and Langney Point present a good opportunity to look at these aspects and to gauge the value of pollen analysis as a technique for investigating palaeobotanical changes in predominantly minerogenic sediments. Although this was not an original aim of this thesis, some interesting and hopefully useful observations came to light during work on these coastal sediments which illustrate the important relationship between minerogenic sedimentation and pollen deposition.

D 2. Provenance and redeposition of pollen and spores.

At both Langney Point and Lottbridge Drove, minerogenic sedimentation, mostly occurring under estuarine conditions, is more extensive than biogenic deposition. Only thin peats were recovered by the drilling rig and hand auger. Despite this similarity in the type of deposits, only the Lottbridge Drove site has a pollen record that appears to be seriously affected by secondary pollen and spores. Therefore, it is principally through a study of the Lottbridge A pollen diagram that a better understanding of the provenance and redeposition of pollen and spores may be achieved.

D 2.1. The Lottbridge Drove diagram.

The incorporation of exotic pollen and spores, especially in p.a.z. L.D.3 and to a lesser extent in L.D.4b and L.D.5 of the Lottbridge A diagram, can be used to illustrate the problem imposed by the different provenances of pollen and spores, and in particular by redeposition. Thus the following sub-section is concerned just with this diagram which has been constructed largely from minerogenic estuarine sediments. Consideration of the provenance of the pollen and spores found in estuarine sediments will be dealt with first. From this, the problems of identification of secondary grains will be examined and special reference will be made to the presence of *Picea* pollen at Lottbridge Drove. This is followed by an attempt to identify the provenance of the secondary pollen examined in this study and to date the sediments from which some of the secondary grains may have been reworked.

D 2.1.1. The provenance of pollen in estuarine sediments.

It has been established from the pollen and fauna record that for much of the postglacial history of Willingdon Levels, an estuarine

environment prevailed with intermittent freshwater phases. Estuaries receive pollen and spores from four possible sources;

1). Transportation by wind. This can occur locally or over great distances.

2). Transportation by rivers and by slope wash.

3). Transportation by coastal sea currents - marine palynology.

4). Redeposition from older sediments and strata.

The importance of each of these must be assessed because they can have a great influence upon the interpretation of pollen diagrams constructed from this type of sediment.

1). Transportation by wind.

The aerial component in offshore marine deposits is small according to Muller (1959), but Mudie (1982) believes that the transportation of grains with sacs (*Pinus* and *Picea*) by wind will be important in explaining the concentration of these types in marine sediments. In estuaries, due to the proximity of the land, primary pollen and spores of species growing locally are likely to be easily carried onto the sediments directly by wind at low tide when the mudflats are exposed. Reworking of this pollen by current action when the flats are covered by the sea will result in penecontemporaneous pollen deposition. This is further discussed in 4) below.

2). Transportation by rivers and by slope wash.

It has been established by Bonny (1976, 1978), working in the Lake District, that rivers act as important transport agents of pollen and spores. Peck (1973) calculated that nearly all the pollen deposited in the sediments of a Yorkshire reservoir were transported there by streams. Through studies such as these, it has been demonstrated that river channels serve as main arteries

for pollen dispersal. In the case of estuaries, Groot (1966) found, in a study of the Delaware River, that the pollen in suspended sediments reflected the regional vegetation of the Delaware River Basin with the coastal marshes especially well represented. Zagwijn and Veenstra (1966) in their study of sediments, found around the Dogger Bank, maintained that the pollen assemblage was a true representation of the vegetation found on the nearest land, that being eastern England. They suggested that transportation by rivers, carrying the pollen out to sea, is an important means by which pollen is transferred from the land and into marine sediments. Balsam and Heusser (1976) came to the same conclusion for the transport of pollen into sediments off Chesapeake Bay. Also, Florer (1973), Heusser and Florer (1973) and Heusser and Balsam (1977) found a good match between the pollen record found in marine sediments off the north east Pacific coast and vegetational change on land. Again, river transport of pollen was acknowledged as being important in establishing this pattern.

These studies suggest that rivers are a major source of pollen input to estuaries and to the sea, a conclusion supported by a number of other studies in marine palynology which are discussed in 3). Importantly, Stanley (1969) and Dyer (1972) found that some fine grained sediments (and therefore pollen and spores) become trapped in estuaries due to turbidity currents and are not released into offshore waters.

The above considerations demonstrate that river transport is an important means by which pollen is transferred to estuaries. Willingdon Levels today contain only small streams that are embanked and have their flow regulated by sluice-gates. This has limited their importance as agents of pollen dispersal. But, before the streams were regulated, flooding would have been more common. Thus, throughout much of the Flandrian the streams may have been able to deposit pollen, carried within fine grained

alluvial and estuarine sediments, over the developing Levels. Additionally, whenever the streams eroded the Cretaceous bedrock, microfossils of this age could have been released. This is one likely source of the pre-Quaternary pollen and spores present in p.a.z.'s L.D.3, 4b and 5.

Slope wash, by bringing down primary pollen and redepositing it as penecontemporaneous pollen, may explain the increase in A.P. in sub-zones 3b and 3d. Although Lottbridge Drove contains virtually no relief today, the lithostratigraphic investigation revealed considerable relief on the buried bedrock surface. Therefore, before the complete infilling of Willingdon Levels, mass movement on slopes may have brought down sediment and pollen. However, the extent of mass movement during the Flandrian is difficult to estimate. It has been previously suggested in Section C 5.2 that widespread mass movement had ceased by the early Flandrian due to slope stabilisation by vegetation.

3). Transportation by coastal sea-currents - marine palynology.

The majority of the work on marine palynology has been concerned with sediments offshore on the continental shelf or in ocean trenches, and is not directly applicable to this study of deposits found around Eastbourne. However, this area has been on the 'coastal margins' for most of the Flandrian and therefore many of the observations concerning the transportation and behaviour of pollen and spores in coastal areas, before being subsequently carried offshore, are of great value to the understanding of the pollen diagrams from this area.

Much work has been carried out on marine palynology, for example, Dyakowska (1948), Muller (1959), Rossignol (1961), Groot (1963, 1966), Cross and Shaefer (1965), Stanley (1966, 1969), Cross *et al.* (1966), Zagwijn and Veenstra (1966), Bottema and van Straaten (1966), Koreneva (1966), Groot and Groot (1966), Traverse and

Ginsburg (1966), Heusser and Florer (1973), Florer (1973), Balsam and Heusser (1976), Heusser and Balsam (1977) and Mudie (1982).

These studies indicate that pollen and spores are mainly transported to marine environments by wind or by rivers, as discussed above. In addition, wind-blown grains may attain greater distances, as much as 80km. (Mudie, 1982) by virtue of ocean currents. Grains with air sacs (Pinus and Picea) are able to be transported over the greatest distance. These genera, especially Pinus, are often over-represented in offshore sediments (Dyakowska, 1948; Groot, 1963; Cross et al., 1966; Stanley, 1969; Mudie, 1982).

Many authors have observed that when transported in water, pollen and spores behave in the same way as fine grained mineral particles and, as a consequence, are deposited in the same areas as clastic material. Muller (1959) observed that pollen and spores act in a similar way to fine silt (0.004mm. to 0.008mm. diameter) and that they are scarcely found in coarse sand. This is a characteristic also recognised by Rossignol (1961), Koreneva (1966), Groot and Groot (1966), Groot (1966), Traverse and Ginsburg (1966), Stanley (1969), Heusser and Balsam (1977) and Mudie (1982).

In the Eastbourne area, the fauna and pollen record clearly show that marine and estuarine environments have existed for much of the postglacial. The surface currents of the English Channel flow in a west - east direction, up-Channel during the flood and down-Channel in the ebb. Within the Strait of Dover, North Sea surface currents meet the Channel currents and are effectively prevented from entering the Channel for most of each tide (Admiralty Tide Tables). If this was the situation throughout the Flandrian subsequent to Britain becoming an island, then this precludes Scandinavia, the Low Countries and eastern England, as a source area for any marine transported pollen, either primary, penecontemporaneous or secondary, that might be found on Willingdon Levels.

However, Kidson (1982) has emphasised the difficulty in obtaining palaeotidal data. Indeed, the present day system of currents within the English Channel are complex and it is difficult to identify the routes by which these currents transport pollen and spores. This is illustrated by Groot (1963) who analysed the pollen assemblage in a core from the Bay of Biscay. He found difficulty in explaining how the grains could have been transported to the area of his site because the surface currents in this part of the North Atlantic do not flow from the probable source area of his grains. He identified the English Channel as the provenance, but the surface currents from there do not transport material to the location of his core. Groot suggested that bottom currents may flow in a different direction and offered these as an explanation for the transportation of pollen.

Because of the complexity of tidal currents in the Channel today and the difficulty of ascertaining the nature of these currents throughout the Flandrian, it is almost impossible to assess accurately the importance of transportation by sea currents of pollen and spores into the study area. Nevertheless, sea currents are probably not an important source of the pollen and spores found in the Eastbourne sediments. Although derived grains are often found in estuarine silts and clays (for example, Devoy, 1979), they usually only account for a small percentage of the pollen sum. Godwin (1975) has drawn attention to the peaks of Pinus pollen in this type of sediment concluding that the peaks do not reflect vegetational change but are due either to reworking or to marine transportation. It is noticeable at Lottbridge Drove and Langney Point that Pinus pollen is often associated with the deposition of estuarine silts and clays, and is either absent or in very low frequencies in the peat horizons that intercalate these minerogenic sequencies. It should therefore be acknowledged that some of the Pinus representation at Lottbridge Drove and Langney Point may be explained by this process. This was discussed in Section C 5.

4). Redeposition (penecontemporaneous and secondary pollen and spores).

Reworking of pollen grains is an important consideration in palynology. Birks and Birks (1980) discuss this problem with reference to glacial deposits, but this can also occur in marine sequencies as observed by Muller (1959), Groot (1963), Stanley (1966, 1969), Zagwijn and Veenstra (1966), Groot and Groot (1966) and Mudie (1982).

There are four types of redeposition that may occur in an estuary:-

4a). By tidal action on surface layers.

4b). Bioturbation.

4c). Migration of channels and changes in channel morphology.

4d). Reworking of older deposits including bedrock.

4a). The first type is the redeposition of surface layers at each tide. This results in penecontemporaneous pollen deposition. Studies of salt marsh sediments show that material can be disturbed by wave and current action. Ranwell (1972) considers that disturbance by tides over intertidal flats will, however, be small because the tide will quickly rise and fall over this zone, thereby restricting the scope for disturbance. Evans (1965) observed in the Wash that wave action is particularly important only on sandflats and is not effective on the salt marsh and mudflats where the absence of wave disturbance allows fine grained material to be deposited. This suggests that since the sediments on Willingdon Levels are fine grained, the amount of redeposition by wave and current action would have been minimal.

Rapid sedimentation would also reduce disturbance and preserve a chronology within the silts and clays. Unfortunately, the rate of sedimentation on Willingdon Levels is difficult to assess because of the lack of reliably datable material.

4b). The second type of redeposition is due to bioturbation. Evans (1965) found that disturbance to sediments in the Wash attributable to this varied depending upon sediment type. In sand-textured deposits reworking by organisms was abundant to the extent of destroying any stratification. However, in 'mud'-textured deposits bioturbation was less and sometimes nonexistent, although it was found locally in marshpools and muddy creeks.

The absence of Foraminifera and Ostracoda, the presence of only a few species of gasteropod (mostly Hydrobia sp.), no finds of any oxidised invertebrate burrows and the low frequencies of Chenopodiaceae suggest an inhospitable liquid-mud habitat during the deposition of much of the Lower Silty Clay. Therefore, there is some justification for suggesting that bioturbation was minimal while the Lower Silty Clay was deposited. However, the environment associated with the Upper Clay may have been more conducive to bioturbation as evidenced by the abundance of Foraminifera and Ostracoda and the high frequencies of Chenopodiaceae.

4c). The migration of channels within estuaries and salt marshes is the third way that redeposition can take place. The increased scouring associated with a channel migrating across an area would produce a truncation of the deposits with a mixing of younger and older sediments and fossils. Such a palaeochannel should be detectable in the lithostratigraphy by a layer of coarser material deposited by the stronger currents of the channel. No such material was found in either the Lower Silty Clay or Upper Clay units of the lithostratigraphy of BH.2 from which the samples were taken.

4d). The fourth type of redeposition involves the reworking of grains from older (pre-Flandrian or pre-Quaternary) deposits and bedrock by the action of waves and tidal currents or by rivers

that flow into the estuary through unresistant fossil-rich sequences. By these processes secondary pollen are released and it is this type of redeposition that is commonly encountered in marine palynology (Stanley, 1966). It may also have been important during the deposition of the minerogenic estuarine sediments found on Willingdon Levels.

D 2.1.2. The identification of secondary grains.

The identification of secondary grains presents a serious problem because on morphological grounds they are often inseparable from primary grains. Some authors believe that the amount of stain taken up and the general state of preservation is a method of recognising secondary grains. For example, Stanley (1966, 1969) believes that yellowish grains in a Holocene sample stained pink by safranine 'O' could be derived from older sediments or rocks. He also observed that some late Mesozoic or Early Tertiary grains can become darkly stained.

Stanley (1966) maintains that variations in stain acceptance may form the basis by which secondary grains can be recognised, but he also cautions that the main reason for variable stain acceptance is changes in the exine chemistry during reworking, although heat caused by burial or metamorphism may also have the same effect. This, as a consequence, questions the value of stain acceptance as a method of recognising secondary grains because if secondary grains have been subjected to only limited reworking or have escaped from the effects of heating, they are likely to take up stain in a similar way to primary grains. This has two important implications for the recognition of secondary grains. First, grain deterioration cannot be used as an indication of secondary pollen. This contention is supported by the observation of Hall (1981) that damage can occur to primary grains by corrasion and corrosion in silts and clays, or even during the preparation of samples. As a result, secondary pollen may be equally or better

preserved than primary grains (Cushing, 1964). This is further discussed in Section D 4.

The second implication is, as Stanley (1966) has warned, that age may not directly affect stain acceptance.

These two implications have resulted in great difficulty in the recognition of secondary grains that are morphologically similar to primary pollen and spores. For example, in studies involving marine palynology, Muller (1959) found it "next to impossible" to separate reworked older Holocene pollen from primary pollen. Groot (1963) commented that it was very difficult to differentiate between modern and Tertiary grains. In addition, personal observation of the pollen and spores analysed in the Eastbourne sediments, suggests that a diversity of staining may be due to factors other than reworking but which are also independent of the age of the grain. For example, factors such as variations in the ratio of the volume of stain to the volume of sampled sediment, inadequate mixing of stain and sample, and different staining characteristics in pollen sampled from peat compared to those taken from clay and silt may also serve as explanations. Many of these factors resulting in variable stain acceptance occurred despite careful preparation of the samples.

Differentiating primary and secondary grains by their colour was not pursued in this study because of the problems inherent in stain acceptance. However, the presence of secondary grains was recognised by the identification of Cretaceous and early Tertiary pollen of Classopollis type and of Cretaceous spores, in particular Appendicisporites. This was possible because they are morphologically distinct from primary grains.

D 2.1.3. Secondary pollen at Lottbridge Drove.

Finding these older secondary grains in the minerogenic sediments of Lottbridge Drove was not unexpected. The underlying and

surrounding geology of the Lower Greensand, Weald Clay, Gault and Chalk is likely to contain fossils that would be released as these strata are weathered and eroded. In addition, Cretaceous and Tertiary grains have been recognised in Flandrian marine clays from the Thames estuary (Devoy, 1979), Scotland (Brooks, 1972), Sweden (Fries and Ross, 1950), in buried channel deposits in the Strait of Dover (Destombes et al., 1975) and in offshore sediments of Flandrian age (Muller, 1959; Groot, 1963; Groot and Groot, 1966; Zagwijn and Veenstra, 1966; Mudie, 1982).

As discussed above, morphologically distinct secondary grains present no problem to identification, but some secondary grains are identical to primary ones, and unless it is possible to have some measure of their presence the value of a pollen diagram containing these grains is diminished.

One statistical method used to calculate the percentage of all secondary grains, including those which are indistinguishable from primary ones, is to work out, for each pollen level, the percentage of grains that are known to be secondary (i.e. morphologically distinct). This figure can then be subtracted from the totals of the pollen types that are suspected of containing secondary grains. This was successfully achieved by Iversen (1936) working on Lateglacial deposits in Jutland. However, the problem is deciding which pollen types to 'correct' in this way. As Birks and Birks (1980) point out, 'correcting' for secondary pollen must involve a careful consideration of why a particular pollen type might be redeposited. Just because the pollen assemblage 'looks odd' is not an objective reason. Plant associations probably existed in the past which were different from any found today. This is particularly true of the Lateglacial and early Flandrian in areas such as southern England, for which there may be no present day analogues. With respect to this, Bell (1969) explained the occurrence of fossils belonging to apparently thermophilous taxa in Weichselian sediments in southern

Britain as being due to the variety of environments available under those conditions. Bell argued that factors other than climate, for example the existence of open habitats, may have been responsible for the appearance of species not normally associated with glacial conditions. This led Bell to remark that "a species should not be dismissed (from the fossil record) as derived on the grounds of its present distribution".

Another factor to consider before 'correcting' a diagram by the above method is that the most successful attempts at distinguishing the secondary pollen component (for example Iversen, 1936), have only been possible "because the exotic types were in sufficiently large quantity to be evaluated" (Birks and Birks, 1980).

The quantity of known secondary grains (Classopollis type and Cretaceous spores) is very small on the Lottbridge A diagram, but were found in every p.a.z. except sub-zones L.D.4a and 4c which correspond to the Willingdon Peat lithostratigraphic unit. The frequencies of morphologically distinct secondary grains, expressed as a percentage of the pollen sum, reach a maximum of less than 1% in L.D.1, 1% in the top level of L.D.2, 3% in L.D.3 and 1% in both L.D.4 and 5.

This small proportion of known secondary grains suggests that redeposition of this type of pre-Quaternary pollen and spore is not an important consideration when interpreting the Lottbridge A diagram. Also, they are not in sufficient numbers to be used for correction purposes.

A more complex problem is the redeposition of microfossils indistinguishable from primary ones. These are likely to be derived from bedrock or from unconsolidated pre-Flandrian deposits. As has been explained, the bedrock of the study area could provide pre-Quaternary pollen and spores, but the existence

of older Quaternary sediments that contain secondary pollen is more difficult to demonstrate. It could be suggested that since at Lottbridge Drove the Valley Gravels, which contain virtually no distinct secondary grains, lay almost directly upon the bedrock, any older sediments must have first been removed from the Levels, at least at this site. As a result, the amount of redeposition of indistinguishable grains from pre-Flandrian unconsolidated sequences might also be small. Unfortunately, this contention cannot be very well supported for the following reasons :-

1). It assumes the Valley Gravels unit is either of Lateglacial age or younger. Due to the amount of chalk and the lack of biogenic remains in this unit, it is not possible to obtain an accurate absolute date. By its composition, stratigraphical position and pollen content, the Valley Gravels have, however, been ascribed to the Lateglacial for the reasons provided in Section C 5.2.2.

2). It cannot be assumed that because underlying older unconsolidated deposits appear to be absent from the Lottbridge Drove area today they have always been missing or indeed have been absent from the remainder of Willingdon Levels during the Flandrian.

D 2.1.4. The presence of Picea pollen at Lottbridge Drove.

It should be recognised that due to the low pollen concentration in the minerogenic sediments of Lottbridge Drove, the assemblages would be influenced by even small numbers of secondary grains. As a consequence, the reworking of pre-Flandrian Quaternary sediments that contain microfossils may produce a significant component of grains on the pollen diagram. This is illustrated by the presence of Picea in L.D.3. This genus last occurred as a native in the British Isles during the Chelford Interstadial (Simpson and West, 1958) and its occurrence on the Lottbridge A diagram may therefore be indicative of reworking of older unconsolidated sediments.

This contention that Picea represents a secondary pollen type redeposited from unconsolidated sediments within Willingdon Levels under estuarine conditions, is supported by a number of arguments:-

(1) Picea is the only well represented arboreal pollen type that does not transcend the Lower Silty Clay - Willingdon Peat boundary. The occurrence of Picea on the diagram is a characteristic of the fine grained minerogenic estuarine sediments. Except for a small representation in the basal lithostratigraphic level, coincident with p.a.z. L.D.2, and an appearance at the very top of the diagram, Picea is mostly confined to the Lower Silty Clay and to p.a.z. L.D.3.

(2). If Picea was growing locally or its grains wind-blown over great distances, then this pollen type should have been identified in greater numbers on other Flandrian pollen diagrams, especially from south-east and eastern Britain. These regions have a more continental climate which Picea prefers (Godwin, 1975), and they are closer to the part of mainland Europe where this genus is a native. However, but for an occasional Lateglacial appearance and an even rarer Flandrian occurrence, this pollen type is absent.

(3). Long distance marine transportation is considered to be an unlikely explanation for the following reasons :-

(a). Tidal currents from northern Europe where Picea is found today and throughout most of the Flandrian are restricted from entering the Channel (see page 115).

(b). Picea is either absent or in very low frequencies (up to 1%) in Flandrian estuarine sediments analysed on the north coast of France (Clet-Pellerin et al. 1977; INQUA Guide, 1979), the east coast of England, for example the Thames estuary (Devoy, 1979) and East Anglia (Godwin and Vishnu-Mittre, 1975), and in deposits from

within the Channel (Huault and Auffret, 1975). This genus is also absent from the Carse clay of Scotland (Newey, 1966; Brooks, 1972) and is present in Flandrian sediments in the North Sea in only very small quantities, up to 1 to 2% (Zagwijn and Veenstra, 1966).

(c). There are fewer Picea grains on the Langney Point diagram (never more than 1%) even though the estuarine sediments are of the same texture and the site is more seaward.

(4). The preservation of pre-Flandrian Quaternary deposits in southern England, from which pollen could be reworked, has been demonstrated by the recognition of early Ipswichian sediments at Stone in Hampshire and Selsey in West Sussex (West and Sparks, 1960). Destombes et al. (1975) have ascribed an Ipswichian to Chelford age range to deposits found in depressions in the Strait of Dover. The pollen assemblage analysed by Morzadec-Kerfourn includes Picea. To these sites should be added the deposits of marine sands and gravels of Ipswichian age on the West Sussex coastal plain and at Black Rock, Brighton (Hodgson, 1964, 1967).

Therefore, it appears that the presence of Picea in values of up to 13% on the Lottbridge A diagram can best be explained by redeposition from older unconsolidated sediments with probably some additions being derived from the bedrock. The same may also apply to much of the Pinus representation as the behaviour of this genus on the pollen diagram follows a similar pattern to Picea.

There is some suggestion that a proportion of the Picea and Pinus grains may share a common source with the Cretaceous grains. For example, the peak of Picea and Pinus from -6.10m. O.D. to -5.45m. O.D. is coincident with some of the highest frequencies for Classopollis and the Cretaceous spores. The low representation of Picea and Pinus between -5.32m. O.D. and -5.25m. O.D. and between -4.60m. O.D. to -4.25m. O.D. corresponds to an absence of the known secondary grains. However, such a correlation cannot be

found as convincingly again on the pollen diagram, and indeed there are levels, particularly in L.D.5, where known secondary grains are present but Picea is absent and Pinus occurs in much reduced values.

This absence of Picea and reduction of Pinus in L.D.5, except for the top level, may be explained by the Willingdon Peat 'sealing off' the deposits from which Picea and some of the Pinus grains were being reworked. In this context, although Picea is mostly absent during L.D.5, Classopollis and the Cretaceous spores are present suggesting that the provenance of Picea is different from that of the other two types during this phase.

Thus, although the possibility is recognised that some of the Picea and Pinus grains may themselves be of Cretaceous age, eroded from the bedrock, there is no reliable method of determining the proportion. As discussed previously, variations in staining and grain preservation are not reliable indicators. A particular difficulty is the accurate assessment of the proportion of Cretaceous grains, including Pinus and Picea, that had been redeposited into pre-Flandrian Quaternary sediments and then redeposited again during the postglacial. Birks (1970), working on the Isle of Skye, found this process had probably occurred in Late-Weichselian sediments. To compound this problem, the age of secondary grains and the age of sediments in which they are found may not always follow the same pattern. It is usual for secondary grains to be a great deal older than the surrounding sediment. The Cretaceous spores and the Classopollis pollen in the Flandrian sediments at Lottbridge Drove are examples of this type. However, reworking of interglacial sediments can result in the redeposition of older, interglacial pollen into younger sediments of the same interglacial. For example, Sparks and West (1959) found evidence for large scale reworking of pollen in the upper sections of an Ipswichian sequence at Histon Road, Cambridge, caused by processes operating during the last glaciation. In this way, older

Ipswichian secondary grains became incorporated into younger Ipswichian sediments.

The identification of this type of reworking involving only interglacial pollen and spores depends upon an ability to distinguish on a pollen diagram, climatic or edaphic change from redeposition. This requires careful palaeoecological analysis of the pollen diagram, sometimes aided by comparisons with other diagrams which have a pollen assemblage of the same age. Thus Sparks and West (1959) were able to present palaeoecological evidence for redeposition and to contrast their pollen diagram with others. In so doing, they concluded that anomalous pollen present in late Ipswichian sediments was due to redeposition from earlier Ipswichian deposits and was not indicative of an ameliorating climate.

It is also feasible for secondary pollen to be younger than the surrounding sediments. For example, in a sedimentary sequence that contains an erosion surface, primary pollen may be reworked into the upper horizons of the sediment immediately below the erosion surface at the onset of renewed sedimentation. This type of redeposition is most likely to occur in floodplain and estuarine deposits, and therefore must be considered in the interpretation of the Lottbridge A diagram.

The probable multi-origin and polycyclic redeposition of secondary grains has precluded any reliable attempt to correct the Lottbridge A diagram following the method used by Iversen (1936), who was able to demonstrate a single origin for his derived grains. Nevertheless, a corrected pollen diagram for selected taxa in L.D.3 has been constructed (Fig. D1.). It is this assemblage zone which has the greatest proportion of secondary pollen and spores. The object of this corrected diagram is to demonstrate the effect the secondary grains have on this local assemblage zone. By excluding these grains a more accurate

picture is formed of the surrounding vegetation, thereby assisting the recognition of the local and regional primary pollen components.

D 2.1.5. The corrected pollen diagram (Fig. D1).

The following criteria were used to construct the corrected diagram:-

1). Omitting all the Picea.

2). Reducing Pinus, first by the ratio Pinus : Picea to produce a corrected Pinus sum. As discussed above, the behaviour of Pinus and Picea on the diagram is similar, which suggests a common provenance for much of this assemblage zone. Pinus and Picea frequencies show a close positive correlation throughout most of L.D.3 in a ratio of between 2:1 and 6:1. Only in the upper levels of this zone does the ratio break down when it becomes as great as 20:1*.

3). Reducing Pinus, second by the corrected Pinus: Hystrichosphere ratio. Although this is not comparing like-with-like, it can be demonstrated that throughout most of L.D.3 this ratio is almost constant at 1:1 with occasional fluctuations to 3:1, one level at 4:1 and one at 7:1. Therefore Pinus and Hystrichospheres may share the same provenance, either from ocean currents or from older sediments. One of the most important criterion that Iversen (1936) used was a constant ratio between taxa considered to be derived. Significantly, Hystrichospheres are commonly found in estuarine sediments because most are marine organisms, but they are also liable to be reworked from older deposits. Therefore, all corrected Pinus frequencies in the ratio of up to 3:1 with Hystrichospheres have been omitted. Above 3:1 corrected Pinus have been proportionately reduced by this ratio.

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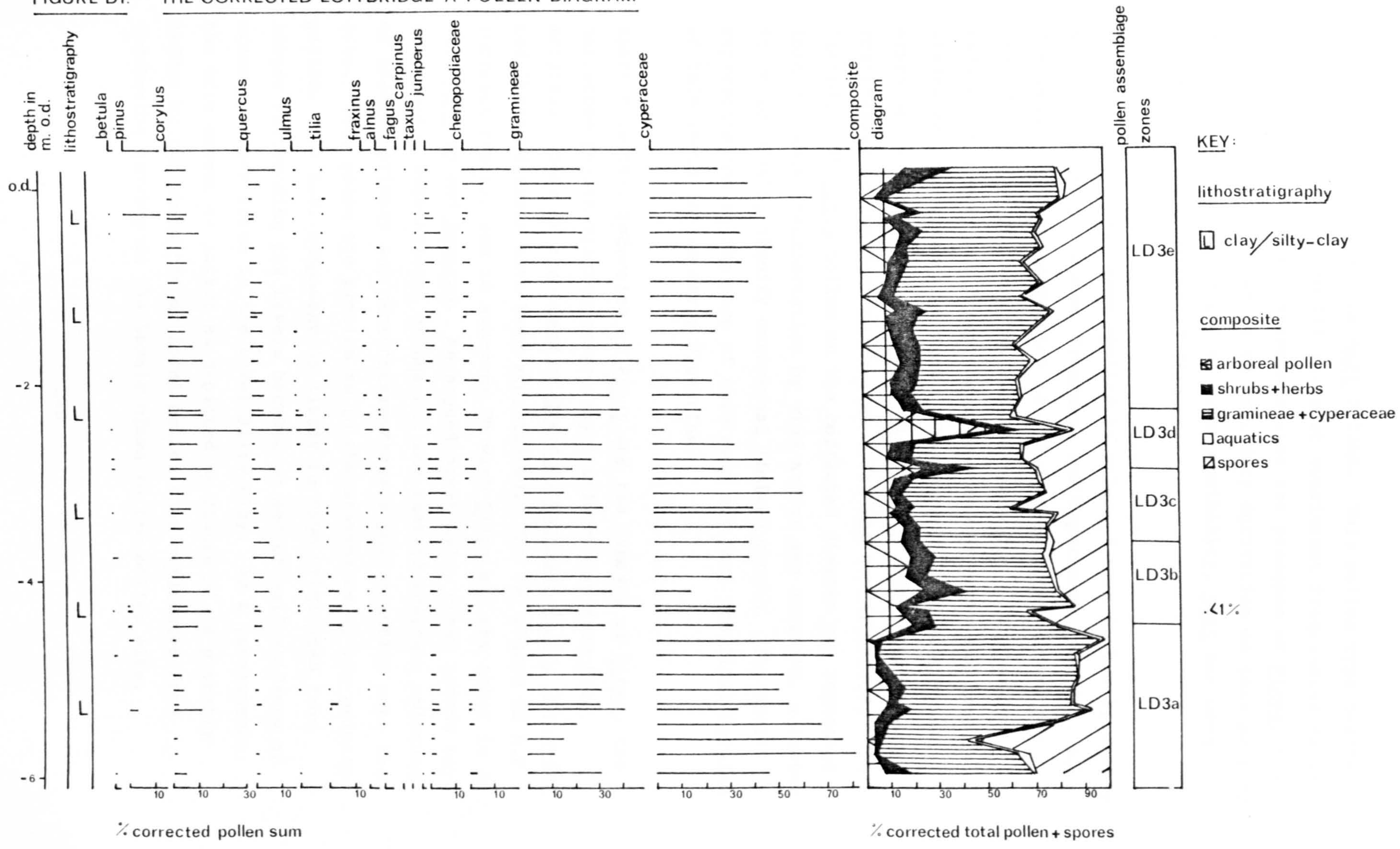
*Note : Ratios are calculated from the total number of grains counted, not from percentage figures.

FIGURE D1. THE CORRECTED LOTTBRIDGE A POLLEN DIAGRAM



4). Omitting all the Acer pollen. This pollen type reaches its maximum (less than 1%) and most consistent frequencies during L.D.3. Because this corresponds with the presence of Picea, the pollen of Acer may also be of secondary derivation on this part of the diagram. In the light of this possibility, Acer has been removed from the corrected diagram.

Factors 1 to 4 have been applied to selected taxa in L.D.3, namely the A.P., Chenopodiaceae, Gramineae and Cyperaceae (see Fig. D1). The result of this correction is, of course, to eliminate the secondary Picea pollen type. In addition, Pinus is greatly reduced to a very small representation in the early and later stages of this assemblage zone. This supports the contention, expressed in Section C 5.1, that Pinus was probably not growing continually in the Eastbourne area after the Boreal period. The 'residue' of Pinus pollen on the corrected diagram may represent long distance transportation by wind and/or sea currents, although it could equally signify occasional limited growth. The small representation at the base of this zone may mark the final decline of this genus in the early Flandrian.

Apart from this reduction of Pinus and the removal of Picea, the corrected pollen diagram shows very little change from the original. Some of the peaks of Quercus, Corylus, Tilia, Juniperus and Chenopodiaceae have been accentuated. The two phases of A.P. increase remain, one in sub-zone 3b with Tilia and the other in 3d with Corylus and Quercus. As argued previously, these trends may not reflect vegetational change but may instead indicate episodes of greater primary and penecontemporaneous pollen influx onto the site. This poses the problem as to the provenance of the primary pollen. The A.P. component is likely to have originated from slopes surrounding the Levels because no macrofossil evidence of trees has been found in the Lower Silty Clay. As a consequence, the true extent of forest as depicted by figure D1 is probably hidden by the abundance of local pollen that originated from vegetation growing on the Levels close to the pollen site.

However, the occurrence of Corylus and Juniperus indicates that only a light woodland covered some parts of these slopes. It is not possible to determine the location of either the lighter or more densely forested areas, but nevertheless the corrected pollen diagram suggests that the surrounding slopes probably contained a patchwork of woodland and shrub communities. On the Levels, Gramineae, Cyperaceae and Chenopodiaceae formed the main constituents of the vegetation.

Throughout the corrected pollen diagram Gramineae and Cyperaceae are abundant. It would be tempting to exclude these two taxa from the pollen sum, but this has been resisted because neither are in continuously high frequencies. In some levels they drop to 15% or less and therefore cannot be excluded on the grounds of over-representation. A correction factor as used by Andersen (1970) for over- and under-representation of A.P. types was not used because such corrections are only applicable to forested areas (Andersen 1973). The above account portrays an open landscape on Willingdon Levels with a discontinuous forest on the neighbouring slopes.

Although the relatively low A.P. values are probably not a reliable guide to the extent of woodland surrounding the Levels, they do add support to the contention that Willingdon Levels was an estuary. The steep Chalk scarp to the west together with lower hills of Upper Greensand and Gault, and the Weald Clay hill to the east that separates Willingdon Levels from Pevensey Levels, represent the only areas where trees could have become established in such an environment. Although the A.P. component is likely to be under-represented for the reasons given above, this picture of the Levels is supported by the corrected composite diagram which illustrates the proportion of A.P. as a percentage of the total corrected pollen and spore sum.

The corrected pollen diagram provides a more realistic assessment of the primary pollen assemblage and therefore of the vegetation

surrounding Willingdon Levels, both local and regional. This will be returned to in Section E in order to reconstruct the vegetational history of the study area. But first, the occurrence of the secondary grains, in particular Picea, can also aid environmental reconstruction especially if the provenance of these grains can be identified. In this way, the existence and perhaps the age of unconsolidated pre-Flandrian deposits may be analysed.

D 2.1.6. The provenance of secondary pollen at Lottbridge Drove.

Although the existence of derived pollen can be demonstrated at Lottbridge Drove, it is more difficult to identify the nature of the sediments from which these grains originated. This is made all the more problematic by the possibility of the sediments undergoing a number of phases of redeposition. The following represent possible types of sediments and their provenance applicable to Willingdon Levels. However, this must remain speculative in the absence of firm evidence.

1). Sediments from the English Channel. Steers (1939) from Tremadoc Bay, Wales and Evans (1965) from the Wash suggest that the major source of sediments to many estuaries is the sea. With respect to Willingdon Levels, a number of sources within the Channel and along its coast may exist. Solifluction deposits and other sediments transported by rivers onto the floor of the Channel during the low sea-levels of the Devensian could have contained interglacial, glacial and pre-Quaternary pollen. As the sea-level rose during the Flandrian, these sediments and their pollen could then have been transported onto Willingdon Levels.

2). Till. The types of redeposited pre-Quaternary palynomorphs found in L.D.3 have also been reported in postglacial marine clays and silts that probably have been derived from till (Fries and Ross, 1950; Zagwijn and Veenstra, 1966). Therefore the Lower Silty Clay unit of Lottbridge Drove may conceivably contain sediments of glacial origin. Exponents of a Channel glaciation

(Kellaway et al., 1975) believe the Anglian Stage to have been the most likely age for this event. However, till deposited at this time in the Channel and along its present coast, including Willingdon Levels, would have had to withstand subsequent reworking by interglacial marine processes and periglacial solifluction in order to have survived into the Flandrian. Also, the absence of Abies from the pollen record makes it unlikely that the age of any pre-Flandrian Quaternary sediment is older than the Ipswichian.

3). By river action. Willingdon Levels is an infilled basin within Cretaceous strata. Therefore rivers, by eroding the bedrock, could release pre-Quaternary pollen and spores. They could also rework unconsolidated sediments of Quaternary age, as has been previously discussed in this section.

4). From interglacial and/or interstadial sediments preserved within Willingdon Levels. This is considered to be the most likely source because the secondary Picea pollen is thought not to have been transported as a primary or secondary grain by wind or by sea for the reasons already given. Such sediments must first have survived Devensian solifluction and fluvial processes before being reworked either by river action or by the rising sea-levels of the Flandrian. Evidence for the existence of interglacial sediments in coastal areas of south east England has already been referred to on page 125.

From an analysis of the pollen assemblage of L.D.3, it is possible to suggest a more precise age range for the sediments from which the Picea have been derived. Simpson and West (1958) consider the Chelford Interstadial to have been the last time that Picea grew naturally in Britain. The absence of Abies from the pollen record at Lottbridge Drove may be used to infer that the sediments are not older than the Ipswichian. Thus an Ipswichian to early Devensian interstadial age seems the most likely. From published work on the pollen zones of the Ipswichian, the latter part of this interglacial is often characterised by high Picea

frequencies. Jessen and Milthers (1928) analysed several sites in Jutland and north west Germany which they considered to be of Ipswichian age. Their pollen zones 'h' and 'i' are characterised by the establishment of a coniferous forest of pine and spruce.

In East Anglia at Histon Road, Cambridge, Walker (1953) found Picea pollen in values of up to 6% in the upper section of an Ipswichian pollen diagram. The low A.P., the dominance of Pinus, the absence of Carpinus and the Picea values referred to above allowed Walker to suggest that this section correlated with Zone 'i' of Jessen and Milthers' subdivision of the Ipswichian.

These concluding phases of the last interglacial are also ascribed to pollen zone Ip iv of West's (1968) scheme for this interglacial. Although Picea is present in the previous zone, Ip iii, the high Carpinus frequencies characteristic of this zone, for example at Aveley, Essex (West, 1969) and in zone 'g' of the Histon Road diagram (Sparks and West, 1959), precludes a Zone Ip iii date for the Picea pollen at Lottbridge Drove where Carpinus is virtually absent. Many authors, as summarised by Phillips (1974), suspect that a true Picea zone may be missing from the Ipswichian of Britain. Even at Wing in Leicestershire where a complete Ipswichian sequence has been identified, Picea is almost totally absent (Hall, 1980). However, Phillips (1974) argues that the apparent lack of Picea in this interglacial may be due to a combination of the relatively low pollen production of this genus and to erosion of later Ipswichian sediments that contained Picea pollen. Woillard (1978) discusses problems associated with the division of the Eemian (Ipswichian) interglacial, and her long record of vegetational history (the Grande Pile sequence) from the Southern Vosges in north eastern France reveals several climatic fluctuations over the last 140,000 years. Picea is well represented in her diagrams at the levels designated to be of Eemian and later, interstadial age.

From this summary of previous work, it appears that maximum Picea frequencies are characteristic of pollen zones 'h' and 'i' of Jessen and Milthers and of Zone Ip iv of West. These zones are representative of the later stages of the interglacial. Therefore it is proposed that the unconsolidated sediments of Lottbridge Drove from which Picea originated were most likely to have been of late Ipswichian to early Devensian interstadial age. Van der Heide (1957) from sites in the Netherlands and Sparks and West (1963) from Stutton, Suffolk, have recognised that the Ipswichian may consist of two major marine transgressive episodes which were probably separated by an erosion phase. Furthermore, an appraisal of post-Hoxnian Interglacial deposits in Britain by the I.G.C.P. Project 24 (Shotton et al., 1983) suggests that two interglacials rather than the one Ipswichian are now favoured. In the light of this revision of the Ipswichian, it is possible that the later pollen zones of Jessen and Milthers and of West designated to be of Ipswichian age, may represent a cool temperate climatic phase distinct from the earlier, warmer Ipswichian. During this cool phase Picea and Pinus became established, the former indicative of more continental weather conditions than those prevailing today in south eastern England. This contention is supported by the belief, discussed in Sparks and West (1959), that many of the thermophilous indicators shown on some late Ipswichian pollen diagrams are considered to be derived from earlier Ipswichian sequences.

The consistent values of between approximately 5% and 10% attained by Picea throughout most of L.D.3 is a strong argument in favour of the sediments containing this pollen type being in situ. As Phillips (1974) has indicated, the Picea zone of the Ipswichian is rare in Britain. Even when present, Picea is found in only low frequencies, reflecting the relatively small pollen production of this genus. Thus the frequencies of Picea pollen at Lottbridge Drove would be expected of an in situ site. Indeed, the mechanism of redeposition would tend to 'water down' the representation of

any derived pollen type, so that the original values that the pollen attained before reworking can only be guessed.

However, an appraisal of all the data from Lottbridge Drove suggest that these late Ipswichian/early interstadial deposits are probably not preserved today having been reworked under Flandrian estuarine conditions. More detailed stratigraphic investigation is required before this can be confirmed, but several lines of evidence indicate that at Lottbridge Drove at least, these sediments are no longer in situ :-

1). The pollen spectra of L.D.3 is characterised by Pinus and Picea but brief increases in Corylus, Quercus, Ulmus, Fraxinus and Tilia form the sub-zones 3b and 3d. These probably do not reflect short lived changes in the forest community from coniferous to deciduous, but may instead be explained as representing an influx of primary or penecontemporaneous pollen, independent from contemporary vegetational change.

2). There is no evidence for any palaeosol preserved within the Lower Silty Clay in either the litho- or biostratigraphies. No erosion surface is apparent within this lithostratigraphic unit, and there is a gradual transition from the Lower Silty Clay to the Willingdon Peat in both the pollen and lithostratigraphic records. This suggests continuous sedimentation occurred over this boundary which is dated to 3,750 $\pm$ 40 B.P. Therefore the Lower Silty Clay appears to be a single lithostratigraphic unit of Flandrian age.

3). The underlying Valley Gravels are considered from pollen evidence to be of Lateglacial age. No exotic pollen indicative of the Ipswichian was found in this deposit. In fact the p.a.z. from this deposit proved to be virtually free of any recognisable secondary pollen.

4). If the pollen record within the Lower Silty Clay represents an in situ assemblage, then the Acer expansion at the same time as the rise in Pinus and Picea is in conflict with

published views on the Ipswichian flora (Phillips, 1974). Acer reaches an Ipswichian peak in Zone Ip iib (West, 1968; Godwin, 1975), while Pinus and Picea are not usually well represented together until Zone Ip iv. As explained earlier, some of the Acer pollen is likely to be of Flandrian age although it is recognised that the proportions of primary, penecontemporaneous and secondary grains is equivocal.

5). The molluscan assemblage described in Section B indicates estuarine conditions during the formation of the Lower Silty Clay. This is also supported by the Chenopodiaceae pollen found in L.D.3. Taking into account factors 1) to 4) above, these conditions are considered to represent Flandrian environments, not Ipswichian.

The relatively high Picea values of between approximately 5% and 10% at Lottbridge Drove suggest that the grains have not travelled far from their source. It therefore appears that reworking was occurring locally, close to the pollen site.

The presence of 'anomalous' pollen in a biostratigraphy must always be treated with caution unless their origin can be ascertained. The Picea pollen at Lottbridge Drove is believed to be a consequence of local reworking and is not due to long distance transportation or to contamination. The latter cause may be dismissed because as argued earlier in the discussion on the Alnus pollen in the Valley Gravels, contamination is very restricted to non-existent in samples collected by U.100 chambers. Long distance transport either by wind or by sea, although considered a possibility, cannot adequately explain the pollen assemblage of L.D.3. In this respect, the work by Cundill and Whittingdon (1983) is pertinent. They proposed three explanations for the occurrence of thermophilous tree taxa, including Picea and Acer, in Late Devensian sediments at Creich in east Scotland. These explanations were; contamination, long distance wind transport and reworking from interglacial

(Ipswichian) sediments and from till. Although long distance transportation could not be discounted, reworking from older sediments was considered to be the most likely source of the 'anomalous arboreal pollen'.

The implication of the secondary pollen for the sediments at Lottbridge Drove is the existence of unconsolidated deposits within Willingdon Levels at the opening of the Flandrian. The suggestion is that pockets of Ipswichian/early interstadial sediments were gradually reworked during the Flandrian, releasing secondary pollen and spores into the developing estuarine sediments. Some of these pre-Flandrian deposits were probably dissected or totally removed by fluvial or by mass movement processes in the areas where the Valley Gravels were deposited. Loessic material may also have been incorporated into the sediments, which would have enhanced the silty-clay texture. Catt (1978) and Burrin (1981) have claimed that considerable aeolian deposits may have formed in East Sussex during the Devensian but have subsequently been transported from the hills down into the valley bottoms. Gallois (1982) however has shown that weathering and erosion of many of the Cretaceous rocks of the region can produce a very similar grain size to that of loessic material.

This complex picture of sedimentation within Willingdon Levels during the Flandrian is purused in Section F in which a model of coastal evolution is presented. The significance of this complex picture for palynology is the way in which the pollen record, through the examination of secondary grains, can provide information on the age and the formation of sediments even if the assemblage is of limited use in the study of vegetational change. Indeed, it has been principally through pollen analysis that evidence has been obtained for the possible existence of pre-Flandrian sediments in the study area.

D 2.2. The Langney Point diagram.

In contrast to the Lottbridge Drove diagram, the three major p.a.z's. of Langney Point are considered to reflect Flandrian vegetational change and are not significantly affected by secondary grains. However, as discussed in Section C 5.1, the occurrence of Pinus pollen in L.P.3 may only be explicable in terms of marine transportation or redeposition. The very low frequencies of Picea pollen and Cretaceous spores also indicate a limited presence of secondary grains. The reworking of Picea in the upper levels of L.P.3 may be due to redeposition from the sediments and bedrock of Willingdon Levels.

The fluctuating values of many of the taxa shown on the pollen diagram may be explained by a number of possibilities.

1). The rising sea-levels of the Flandrian were likely to have created an unstable environment at this site. This would have resulted in periods of stress affecting different species at different times depending upon the location and the tolerance of individual plants and communities. Variations in pollen production, and therefore dispersal, caused by stress would only significantly affect the pollen diagram if the vegetation concerned was local. Janssen (1973) has demonstrated that local pollen values often fluctuate. Therefore the variable representations on the Langney Point diagram may simply be a reflection of variations in the local pollen rain. These variations may have been accentuated by environmental factors, although the link is not clear. Of all the major pollen types present on the diagram, Pinus exhibits least variation from one level to the next. It may be significant that this pollen type in L.P.3 is considered to represent reworking or marine transportation and is not a local pollen type.

2). The fluctuations may also be the product of penecontemporaneous pollen influx from the surrounding hills.

3). The absence of any apparent pattern to the fluctuations precludes erosion or variations in the rate of sedimentation as an explanation. However, the silts and clays of the Langney Point formation contain fossils of many different types of fauna, as described in Section B. This suggests that bioturbation may have destroyed some detailed palynological changes resulting in apparently random fluctuations, so that only major long term trends in the pollen record have survived. Evidence for bioturbation comes from the identification of oxidised invertebrate burrows within both the Lower and Upper Minerogenic Sequencies. Analysis by a Scanning Electron Microscope indicates the burrows to be made of Silica, Iron and Aluminium with smaller amounts of Calcium.

Davis (in Birks and Birks, 1980) has shown that burrowing animals in freshwater lake sediments can redistribute pollen vertically over 15cms., although most disturbance occurs over only 3 to 4cms.. In estuarine clays, silts and sands Evans (1965) maintains that most species of fauna burrow to a depth of only 3 to 5cms. although Arenicola marina can burrow as deep as 26cms. Evans also observed that maximum disturbance occurs in sand textured sediments, a point which suggests that bioturbation is likely to have been restricted in the fine grained deposits of Langney Point.

Thus bioturbation would tend to remove some of the detail from the pollen record. However, if bioturbation had been prevalent at Langney Point then it is difficult to explain the preservation of the laminae and thin lenses of finer textured material observed in some of the cores. The most notable laminae occur between -17.9m. O.D. to -17.46m. O.D.. This corresponds to the top section of L.P.3. No reduction in the extent of the fluctuations occurs at this time, indeed the curve for Quercus becomes more erratic. Therefore bioturbation cannot be an important cause of the inconsistent curves on the pollen diagram, and where laminae are present then disturbance by burrowing animals must have been negligible.

D 2.3. Redeposition - conclusion.

The Lottbridge A diagram, particularly in L.D.3, probably contains primary, penecontemporaneous and secondary pollen. The principal source of the primary grains is considered to be the local vegetation growing on and around the Levels. Penecontemporaneous pollen transported to the pollen site by river, wave or current action is considered to have been limited, although inwash from nearby slopes may account for the rise in deciduous A.P. in sub-zones 3b and 3d. Bioturbation was probably limited in the Lower Silty Clay, but the fossil record suggests that it may have been more prevalent in the Upper Clay. Within most of the Valley Gravels and the Willingdon Peat only primary pollen is present.

The provenance of the secondary pollen and spores is complex. Many, especially the Cretaceous grains, may have undergone several cycles of redeposition, but one important source may have been unconsolidated Quaternary sediments deposited before the Flandrian. From the pollen record it is argued that these sediments are of late Ipswichian to early Devensian interstadial age, and were reworked during periods of estuarine conditions in the Flandrian. In this way secondary pollen became incorporated into the Lower Silty Clay unit of the Willingdon Levels lithostratigraphy.

The importance of long distance marine transport is hard to assess at both sites. This process may account for some of the *Pinus* representation at Lottbridge Drove. Also the low pine frequencies of p.a.z. L.P.3 at Langney Point are thought likely to have been transported to this site by the sea. The considerable and persistent amounts of Hystrichospheres found in the minerogenic sequences of Lottbridge Drove and Langney Point support the possibility of marine transportation, but it is unclear what proportion of the Hystrichospheres are Flandrian or have themselves been reworked.

Most of the local assemblage zones constructed from both pollen sites contain little or no reworked pollen, allowing observations of Lateglacial and Flandrian vegetational change to be made. However, inwash and bioturbation may have affected the pollen record from Langney Point. Within L.D.3 of the Lottbridge A diagram, secondary pollen constitutes a significant proportion of the pollen assemblage. As a consequence this p.a.z. cannot be used to investigate detailed Flandrian vegetational change, but can help to elucidate sedimentation processes.

D 3. A model for pollen transfer in minerogenic sediments.

The interpretation of a pollen diagram should take into account the provenance of the grains represented. The foregoing has suggested that pollen and spores may originate from a variety of sources, and from this analysis it is possible to suggest a model of pollen transfer that is applicable to the sediments at Eastbourne.

The pathways followed by primary wind-blown pollen before it becomes incorporated into sediments have been examined by Tauber (1965). He identified three routes by which pollen can travel before being deposited, namely :-

1). The Trunk Space Component.

2). The Canopy Component.

3). The Rainout Component.

The relative importance of each will normally determine the primary pollen spectra. However, river transport of primary pollen will also be influential.

Davis (1968, 1973), Davis and Brubaker (1973), Hopkins (1950) and Bonny (1976) have studied the deposition of pollen within lakes. These studies demonstrate two important considerations in the analysis of pollen from lake sediments.

1). Different areas of lake sediments may have different pollen spectra due to differential floatation of pollen.

2). Natural processes occurring within the lake can result in redeposition of the upper surface of lake sediments and therefore of pollen.

In addition Peck (1973), Bonny (1976) and Edwards (1982) have drawn attention to the importance of pollen input to lakes from rivers. Bonny (1976) for example, from a study of pollen input into lakes of the Lake District, calculated that up to 89% of pollen entering a lake may be supplied by streams. Although this was considered to be a maximum figure due to problems of trapping pollen, Bonny nevertheless stresses the importance of river transport to lakes. This has also been shown by Peck (1973) who suggests that as much as 97% of pollen deposited in a reservoir in Yorkshire was probably transported by streams.

These methods of pollen dispersal can result in pollen being transported over variable distances. For example, vegetation growing along the course of a river will deposit pollen directly into the water. This may settle out immediately or be transported great distances depending upon the strength of current and the length of the river. Also, the mode of transport may favour the removal of certain types of pollen. For example, Pinus pollen is particularly buoyant (Hopkins, 1950) and is therefore often over-represented where transportation by water, particularly ocean currents, is involved.

This feature of variable distances over which pollen is transported applies particularly to wind-blown pollen. In a study of the pollen spectra recovered over a small lake (circa 200m x 100m.) surrounded by forest, Tauber (1977) found that as much as 60% of all airborne pollen trapped above the lake surface had been transported through the trunk space of the neighbouring forest. About 35% had been transported above the canopy and only about 5% was attributable to rainout. The provenance of the pollen trapped above the lake surface was considered to lie only 200m. to 400m. from the lake.

However, as Jacobson and Bradshaw (1981) and Moore (1984) have stressed, the size of the receptor site and the extent of forest cover will have a major influence upon the proportion of local and regional pollen present in the sediments. The sites at Langney Point and Lottbridge Drove are located, respectively, by the sea and on Willingdon Levels. They are also not far from slopes of Chalk, Upper and Lower Greensand, Gault and Weald Clay. It is therefore important to try to ascertain the proportion of the primary pollen identified at these sites which records the vegetation of the Levels, and the proportion which represents the vegetation of the surrounding slopes, including the Chalk.

The problems involved with this are shown by the discussion of the corrected pollen diagram for p.a.z. L.D.3 (this Section) and are also well illustrated by Thorley's work in the Vale of the Brooks (Thorley, 1971, 1981). She argues that the pollen recovered from her two sites reflect the vegetation of the surrounding Chalk slopes. However, Waton (1982) has argued for a more local, valley bottom source for much of Thorley's pollen. It must also be remembered that Thorley's sites are also close to valley gravels as well as chalk. Because of these uncertainties, the provenance of Thorley's pollen is, unfortunately, equivocal. Nonetheless, her work represents an important step towards reconstructing the history of a chalk landscape, provided the above problems are borne in mind.

The significance of this controversy for the Eastbourne area lies in the possible similarity of the provenance of the pollen at the Vale of the Brooks with that at Lottbridge Drove and Langney Point. Thorley's sites in the Ouse valley are situated ½km. from the nearest chalk slopes. Lottbridge Drove is 2km. east of the chalk scarp of the South Downs, while Langney Point is located 5km. east of the chalk and 1½km. south of the Weald Clay hill at Langney. Therefore the problem of identifying the source areas for the primary pollen at Lottbridge Drove and Langney Point is

similar to that faced by Thorley for her sites in the Ouse valley. However, the provenance of the pollen at Lottbridge Drove and Langney Point may be inferred by a careful examination of the pollen record supported by macrofossil evidence. In this way a picture of Late-Quaternary vegetation communities and change can be constructed. This is examined in Section E 1.

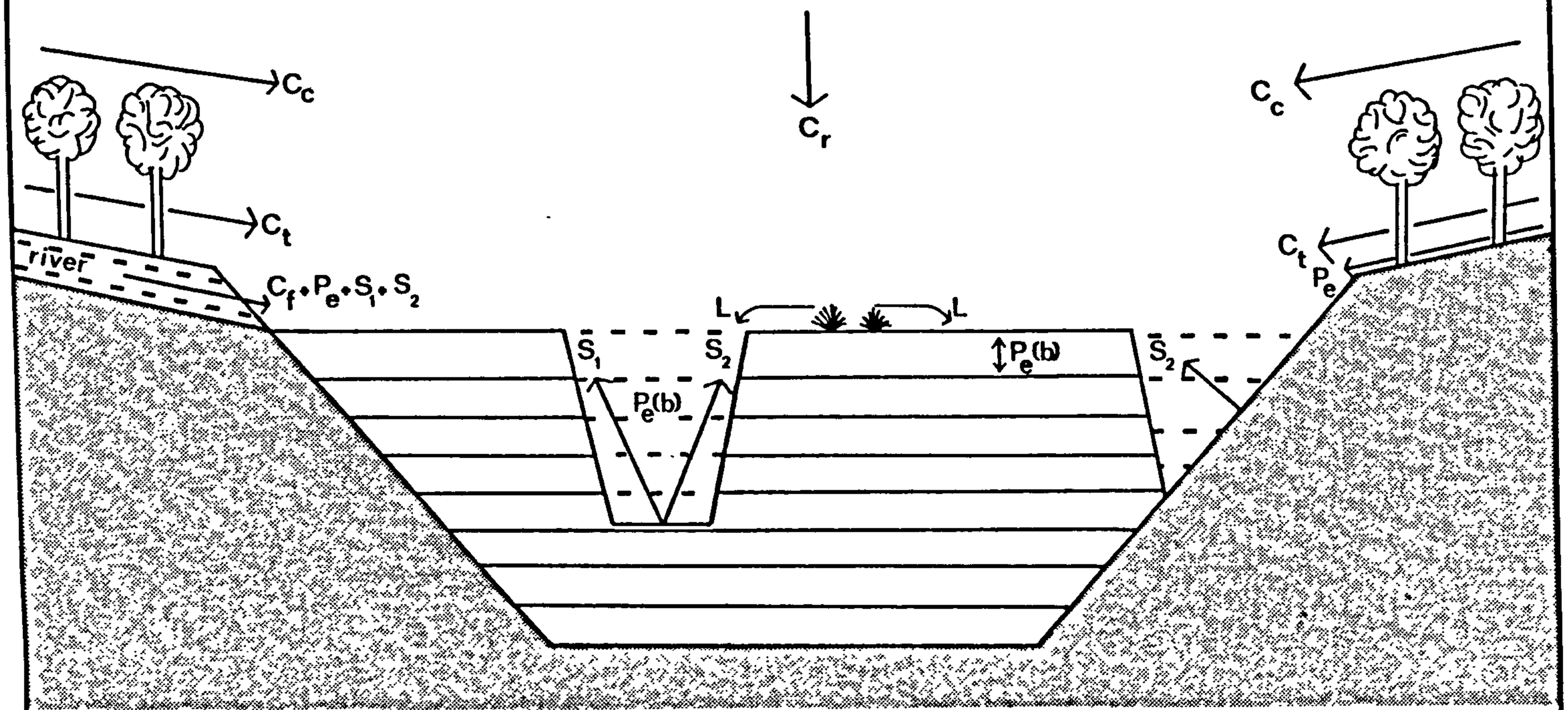
The above discussion illustrates that pollen dispersal and eventual incorporation into sediments may be complex. In order to help clarify the ways by which a pollen assemblage may come to consist of grains originating from a number of sources, a model of pollen dispersal into estuarine silts and clays is presented. Although the model is principally concerned with the minerogenic sediments of the Eastbourne area, it may also be applicable to detrital peat or to peat-rich clay that contains inwashed material.

The transfer of primary pollen follows Tauber's (1965) model. The ideas for the transfer of secondary grains are largely based upon the conclusions reached from the study of the pollen record at Lottbridge Drove and Langney Point. The model is shown by Figure D2. The terminology used is that proposed by Cushing (1964) and by Tauber (1965).

The various pathways illustrated by this model demonstrate possible primary, penecontemporaneous and secondary sources of pollen and spores. Ct., Cc., Cr., Cf. and L. are primary sources differing greatly in the distances covered by the grains from their source. For example, the Cr. component may cover hundreds of kilometres, while the L. component only a few metres. The Cf., Pe., S1. and S2. provenances brought down by rivers may be an important source of pollen and spores. In addition the following points should be considered :-

1). Because the sediments are frequently flooded by tides, the pollen and spores can become waterborne and thereby distributed widely over the estuary. Thus the redeposition of

FIGURE D2. A MODEL FOR POLLEN TRANSFER IN AN ESTUARINE BASIN



CHANNEL BEDROCK (FOSSILIFEROUS) ESTUARINE SILTS AND CLAYS CONTAINING OLDER DEPOSITS

C_t – TRUNK SPACE COMPONENT C_c – CANOPY SPACE COMPONENT C_r – RAIN-OUT COMPONENT
AFTER TAUBER (1965)

C_f FLUVIAL COMPONENT (RIVER TRANSPORT OF PRIMARY POLLEN)
L LOCAL POLLEN FROM VEGETATION GROWING ON THE ESTUARINE SEDIMENTS
S_1 SECONDARY POLLEN FROM REWORKED OLDER UNCONSOLIDATED SEDIMENTS
S_2 SECONDARY POLLEN FROM ERODED FOSSILIFEROUS-BEDROCK
P_e PENECONTEMPORANEOUS POLLEN FROM SLOPE WASH AND/OR RIVERS
$P_e(b)$ PENECONTEMPORANEOUS POLLEN FROM BIOTURBATION AND/OR REWORKING BY WAVES AND TIDAL CURRENTS

secondary grains S2., for example, would not necessarily be confined to the area of their origin. Conversely, the low energy environment of an estuary may also result in very local redistribution of pollen, especially if sedimentation rates are rapid.

2). The release of S1. and S2. grains is likely to decrease with time as the estuarine sediments develop and effectively bury bedrock and unconsolidated deposits from which secondary pollen could be derived. With the formation of an extensive in situ peat, the source of the secondary grains would be sealed off and therefore only primary pollen should be found, unless there was a renewed phase of erosion. However, detrital peat, due to water movement, may contain penecontemporaneous pollen or even secondary grains. A discontinuous organic horizon may still allow non-primary sources to be reworked. The Willingdon Peat is an example of the latter case.

3). The secondary grains may have undergone polycyclic redeposition.

The above model is principally concerned with estuarine environments but there are of course many similarities with the pathways taken by pollen and spores into and within lakes. A model for pollen transfer in lake sediments is provided by Moore and Webb (1978). These types of models illustrate the interrelationship between pollen and sediment transport and deposition. In particular they show that the same processes which result in the deposition of sediments also deposit secondary and penecontemporaneous pollen and spores.

D 4. Pollen deterioration.

The study of the state of preservation of pollen and spores is as much part of palynology as the identification of the grains. Indeed, pollen deterioration may have some very important implications for the recognition of the pollen and for the

interpretation of pollen diagrams. The intention of this section is to explore some of these implications.

In view of the poor preservation apparent in many of the levels on the three pollen diagrams from the Eastbourne area, a study of the amount and type of deterioration was considered to be necessary. Data on pollen deterioration is presented and explanations are offered concerning the cause of the deterioration. Some implications this may have for the interpretation of the pollen diagrams are also discussed. However, it should be established at the outset that the mechanism of deterioration is poorly understood (Lowe, 1982) although some attention has been paid to this problem (Sangster and Dale, 1964; Havinga, 1967).

Previous work on pollen preservation is limited in extent partly because it is by no means certain as to the cause of deterioration or its significance to palaeoenvironmental reconstruction. However, some authors, for example Cushing (1967) and Lowe (1982), have suggested that pollen deterioration should be recorded if for no other reason than as a gauge of the likely problems inherent in identification. In extreme cases it is possible that entire pollen types may be absent or in very low frequencies because they may be particularly susceptible to deterioration. In this context a measure of pollen preservation is as important as allowances for over- and under-representation of taxa on pollen diagrams caused by their pollen production and dispersal mechanisms.

The analysis of pollen deterioration has usually concentrated on one or more of a number of objectives. First, to identify categories of deterioration (Cushing, 1967), secondly, to ascertain the cause of deterioration either by laboratory experiments or by analysing data from fossil pollen assemblages (Sangster and Dale, 1964; Cushing, 1967; Havinga, 1967) and thirdly to review any implications this may have for the interpretation of the pollen diagram. The latter point can itself

take on two different but often related aspects. Pollen deterioration may alter the character of a pollen diagram to the extent that certain trends shown on a diagram may not reflect vegetational history. One example, stressed by Godwin (1975), is the possible over-representation of Tilia - a particularly resistant grain - due to selective pollen preservation. The second aspect involves the use of deterioration as a method for investigating environmental changes. For example, Lowe (1982) in a study of pollen preservation at sites in the Teith Valley, Scotland identified a 'regional' deterioration pattern that appeared to be common to a number of sites and was independent of any lithological changes. He tentatively suggested that such a pattern may have been caused by a drier climate during the 'Late Boreal Period', resulting in the drying out and reworking of sediments close to the pollen sites.

The classification of deterioration used in this study follows the scheme presented by Cushing (1967). Four categories of deterioration are used :-

Corroded - Grain has an etched or 'moth-eaten' appearance. Havinga (1967) provides photographs of this type of deterioration.

Degraded - All or most of the surface features of the grain are fused together. Lowe (1982) describes such deterioration as 'amorphous'.

Crumpled - Grain is badly folded. However, small creases are not classified as deterioration. Because some pollen types, notably Cyperaceae, are especially prone to crumpling, a grain was only recorded as crumpled if it exceeded the extent of damage normally expected on a reference slide of fresh pollen that had been prepared by Acetolysis treatment.

Broken - Grain has a clearly defined split. Small cracks on the surface were not recorded.

When recording grains that have more than one category of deterioration Cushing (1967) and Lowe (1982) adopted a hierarchy of deterioration, with the highest ranked category being recorded. However, such a method will tend to over-represent corrosion, the category highest up the hierarchy and, as a consequence, underestimate broken and crumpled grains (Lowe, 1982). In this study whichever category was considered to be the most extensive on any grain was the type recorded.

In addition, a measure of the number of indeterminate grains is given. This category includes a small number of concealed grains, otherwise an indeterminate grain is one that is so deteriorated it cannot be ascribed with any certainty to a particular pollen type.

D 4.1. Results.

For the three pollen diagrams presented in this work, the total amount of deterioration (i.e. the sum of the four categories) is shown on the main diagrams. This has been calculated as a percentage of all pollen and spores. From an assessment of this data, two factors emerge. First, the state of pollen preservation is generally poor on all three diagrams. Secondly, although variations in the extent of pollen deterioration show some correlation with the lithostratigraphy, importantly there are significant variations within apparently uniform lithostratigraphic units. Often different lithologies show similar amounts of pollen deterioration. These factors are illustrated by an examination of the diagrams from both sites.

At Langney Point (Fig. C1) an improvement in the preservation of the grains occurs within the Lower Minerogenic Sequence and continues through the Crumbles Peat with the best preservation occurring in the lower levels of the Upper Minerogenic Sequence. However, within this lithostratigraphic unit there are zones where deterioration is almost as extensive as in the Lower Minerogenic

Sequence. Therefore, although most deterioration (up to 95% of all grains) occurs within a single lithostratigraphic unit - the Lower Minerogenic Sequence - there is no close correspondence between the extent of deterioration and the type of sediment.

On the Lottbridge A diagram (Fig. C2) the best preservation occurs within the Willingdon Peat. However, the association between the extent of deterioration and the type of sediment is not straight forward. In the upper levels of the Willingdon Peat deterioration reaches similar values to those in the Lower Silty Clay and the Upper Clay. Moreover, the basal layers of the Valley Gravels contain better preserved pollen than some of the peat layers.

A major problem of interpreting the amount of deterioration for each pollen level is the possibility of the figures being distorted by the most frequently occurring pollen type. For both the Langney Point and Lottbridge Drove diagrams, the common occurrence of Cyperaceae pollen may cause an apparently high amount of deterioration. To overcome this bias, diagrams have been constructed showing the extent of deterioration for selected taxa at each site. The taxa shown are the best represented types, but levels in which they are recorded in values of less than three grains are not included. The values on the graphs show the proportion of deteriorated grains at each level as a percentage of the total number of grains counted for each of the taxa illustrated. The graphs do not show the relative importance of each taxa. For this reference should be made to the original pollen diagrams.

<u>Langney Point - deterioration for selected taxa.</u> (Fig. D3).*

The deterioration record for all the pollen types illustrated follows the same trend shown by the diagram of total deterioration

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*Note: In jacket on back cover.

outlined above. However, certain taxa, especially Corylus, Quercus, Ulmus and Chenopodiaceae obtain well above average improvements in their state of preservation throughout most of the Upper Minerogenic Sequence. Their pattern of deterioration follows the general trend as this improvement begins in the upper horizons of the Lower Minerogenic Sequence, continues through the peat and they reach their best state of preservation in the lower section of the Upper Minerogenic Sequence. Therefore three zones of differing degrees of deterioration are marked on the diagram. Zone 1 has very poor preservation of all pollen types. Zone 2 contains the best preservation while Zone 3 shows fluctuations of better and worse pollen preservation.

Lottbridge A - deterioration for selected taxa. (Fig. D4).*

From the graphs the extent of deterioration appears not to be constant. Seven zones of better preservation or greater deterioration can be identified :-

Zones 1, 3, 5 and 7 - poor preservation.
Zones 2, 4 and 6 - better preservation.

These variations are thought not to be the result of laboratory techniques because the zones do not coincide with groups of samples that were prepared together, and, because of the presence of silica throughout, no variations in treatment were applied.

Four conclusions can be drawn from figure D4. First, it is clear that only one zone coincides with a lithostratigraphic unit, namely Zone 1 with the weathered Gault horizon. Secondly, there is no correlation between sediment particle size and the extent of deterioration. Thirdly, no zone, other than Zone 1, corresponds with any pollen assemblage zone. Fourthly, the identification of

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* Note: In jacket on back cover.

these zones suggests there is no evidence for progressive pollen deterioration with depth as suggested by Hall (1981).

Similar to the Langney Point data, certain pollen types, for example Quercus, Betula, Alnus and Chenopodiaceae, have zones of better preservation than the diagram for total deterioration suggests. Thus at Lottbridge Drove the most frequently occurring pollen types (Gramineae, Cyperaceae and Pinus) tend to distort the picture of deterioration in the zones where better preservation can be identified (Zones 2, 4 and 6).

Therefore, it is apparent that some pollen types at both sites have undergone less deterioration than others. In order to investigate this further the type of deterioration has been recorded. Initially this was done for selected levels at both sites to give a general indication of the relative importance of each deterioration category.

Langney Point - types of deterioration. (Fig. D5).

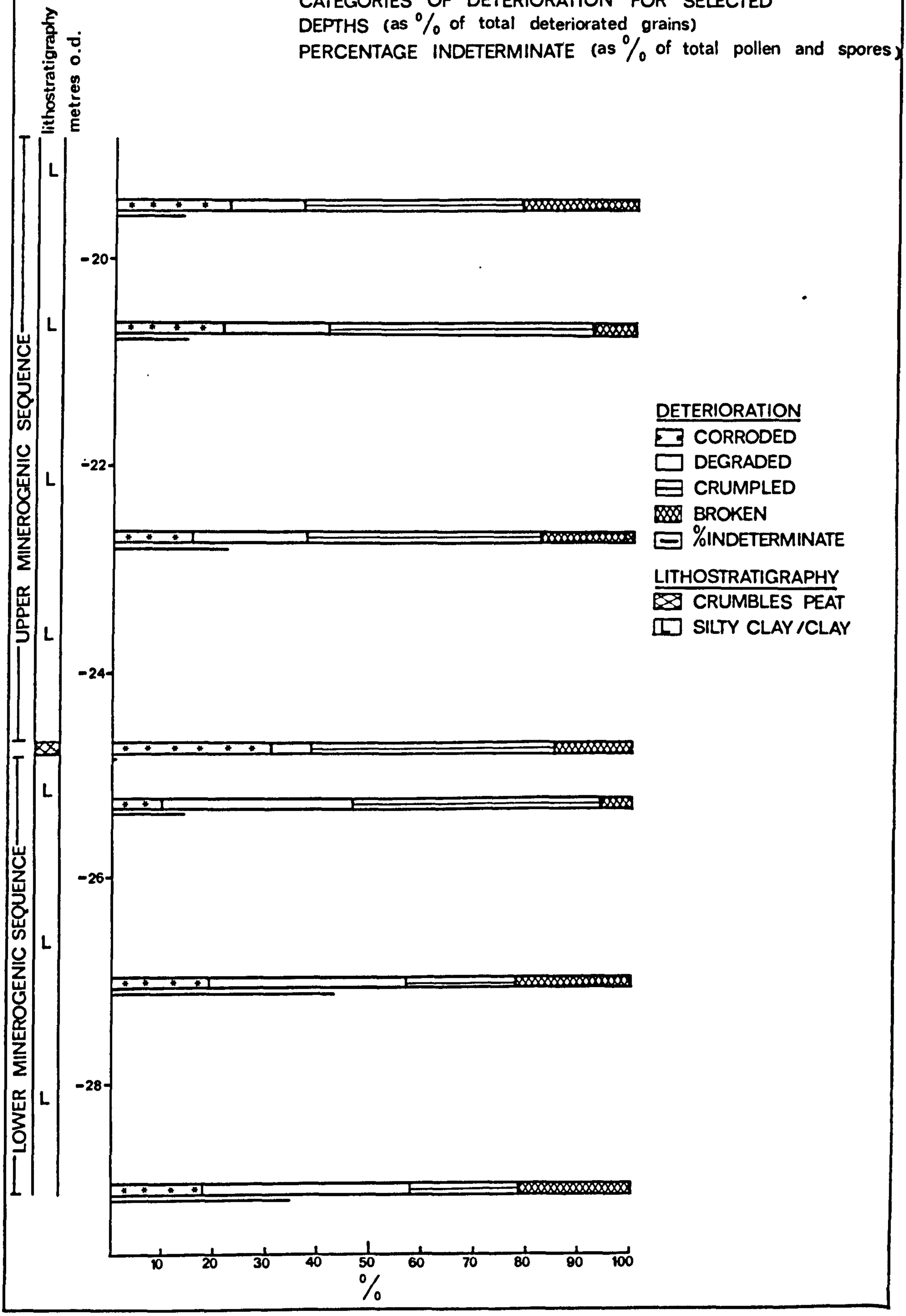
At this site the nature of deterioration is generally uniform throughout the entire sequence even though, as discussed above, the extent of deterioration varies. The only exceptions to this picture are, first in the Crumbles Peat where corrosion increases at the expense of the degraded category, and secondly the proportion of crumpled grains increases up through the sequence as the degraded category decreases.

Attention is also drawn to the percentage of indeterminate grains. The value for this category in the Lower Minerogenic Sequence, where deterioration is extensive, is high (up to 43% of all pollen and spores). As a consequence, it could be suggested that selective pollen preservation and a reduced ability to identify grains may have influenced the pollen diagram. However, this is considered not to be a significant consideration for two

FIGURE D5. LANGNEY POINT. TYPES OF POLLEN DETERIORATION

CATEGORIES OF DETERIORATION FOR SELECTED DEPTHS (as % of total deteriorated grains)

PERCENTAGE INDETERMINATE (as % of total pollen and spores)



reasons. High pine and hazel frequencies in the early Flandrian, a characteristic of this part of the diagram, are also features of other pollen diagrams from southern England (see Section C). Also the trends on the pollen diagram which occur within the Lower Minerogenic Sequence where the percentages of deteriorated and indeterminate grains are high continue unbroken into zones of better preservation with lower amounts of indeterminate grains. Most noticeable of these trends is the start of the decline in Pinus values and the beginning of the Quercus expansion, both of which occur within the zone of extensive deterioration well before the onset of better preservation. In addition, the main juniper peak falls totally within the zone of maximum deterioration. For such a fragile grain to follow this pattern suggests that neither selective pollen preservation nor problems of identification are operating to any great degree.

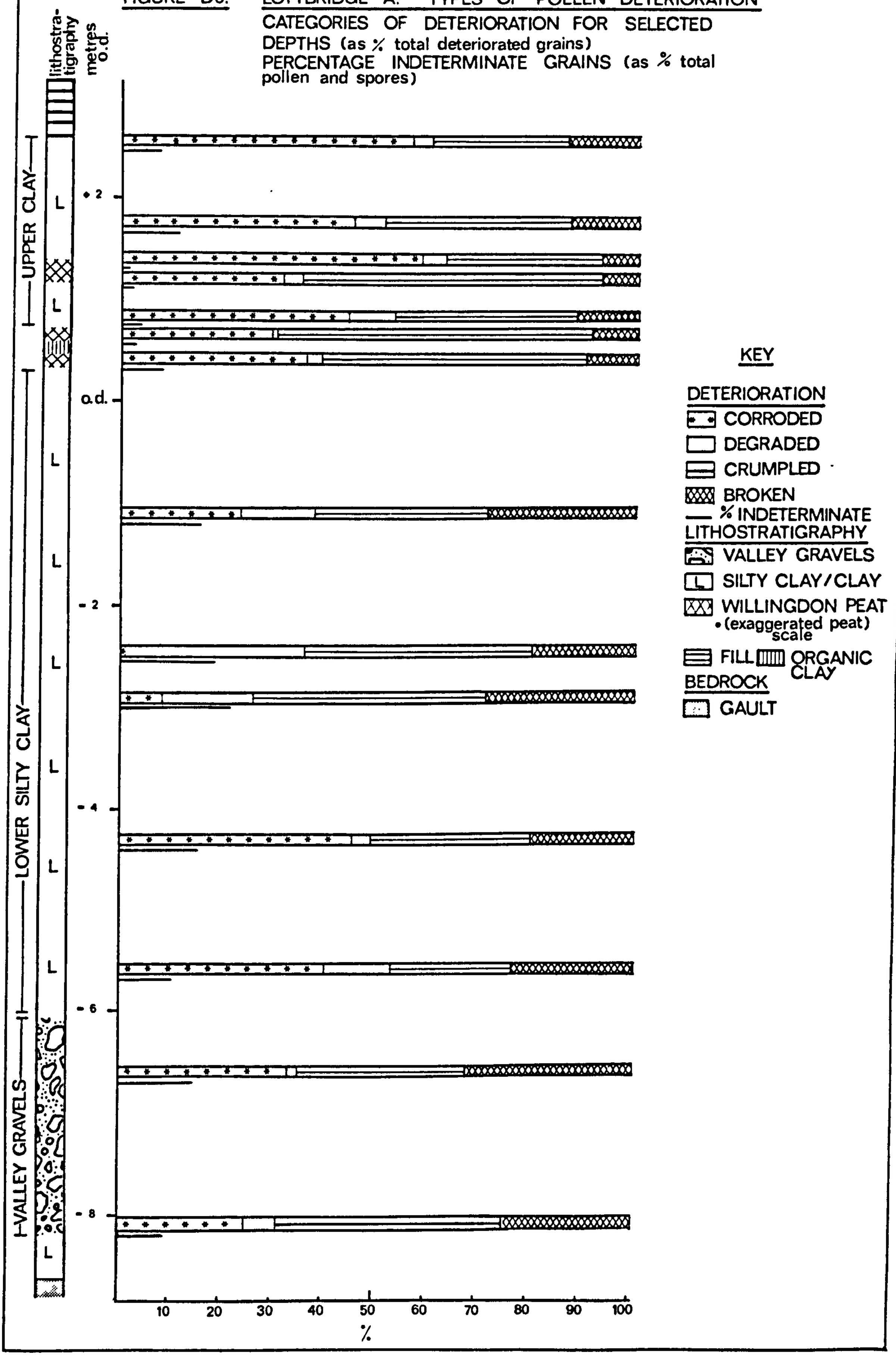
Lottbridge A - types of deterioration. (Fig. D6).

The most noticeable feature is the relative importance of corroded and degraded grains. Corrosion is important in the lower and upper levels of the sequence while the degraded category increases around the -2.45m. O.D. level. The proportion of crumpled and broken grains shows less variation with the former contributing a substantial amount to the total deterioration. In contrast to the Langney Point diagram, the corroded category does not show any significant preference for a particular sediment type. Although corrosion reaches a maximum (58%) within the top levels of the Willingdon Peat, this type of deterioration attains a similar value in the Upper Clay (56%), up to 46% in the Lower Silty Clay and up to 33% in the Valley Gravels.

Therefore this diagram illustrates very clearly a trend apparent at both sites; the nature of deterioration shows no close correspondence with lithology.

FIGURE D6. LOTTBRIDGE A. TYPES OF POLLEN DETERIORATION

CATEGORIES OF DETERIORATION FOR SELECTED DEPTHS (as % total deteriorated grains)
PERCENTAGE INDETERMINATE GRAINS (as % total pollen and spores)



The Langney Point and Lottbridge Drove diagrams reveal general tendencies of the type of deterioration. However, as with the case for the amount of deterioration, these tendencies may be biased in favour of the most frequently occurring pollen types. Therefore a study has been made of the type and amount of deterioration for selected taxa within the Willingdon Peat at both the Lottbridge A and Lottbridge B sites. It has been previously suggested that the peat at Lottbridge A may have to some extent been disturbed during the intercalation of a clay horizon. In addition, the pollen record of these two sites shows significant differences even though they are in close proximity to one another (Section C). This suggests the pollen were deposited under different environmental conditions at each site. This provides a useful opportunity to test the hypothesis that pollen deterioration may reflect these differences and thereby provide an insight as to the cause of the deterioration.

Comparison of pollen deterioration at Lottbridge A and B.

In this section reference is made to figures D7, D8* and D9*. Figure D7 illustrates the general pattern of deterioration at the Lottbridge B site. In contrast to Lottbridge A there is a greater proportion of broken grains in the lower levels of the Willingdon Peat. Otherwise, the relative importance of corroded, crumpled and degraded grains is similar.

The most striking similarity between the two sites is in the amount of deterioration. The general pattern is shown on the original pollen diagrams where it is noticeable how the lower levels of the peat contain better preserved pollen than in the upper parts. This is particularly apparent on the Lottbridge B diagram.

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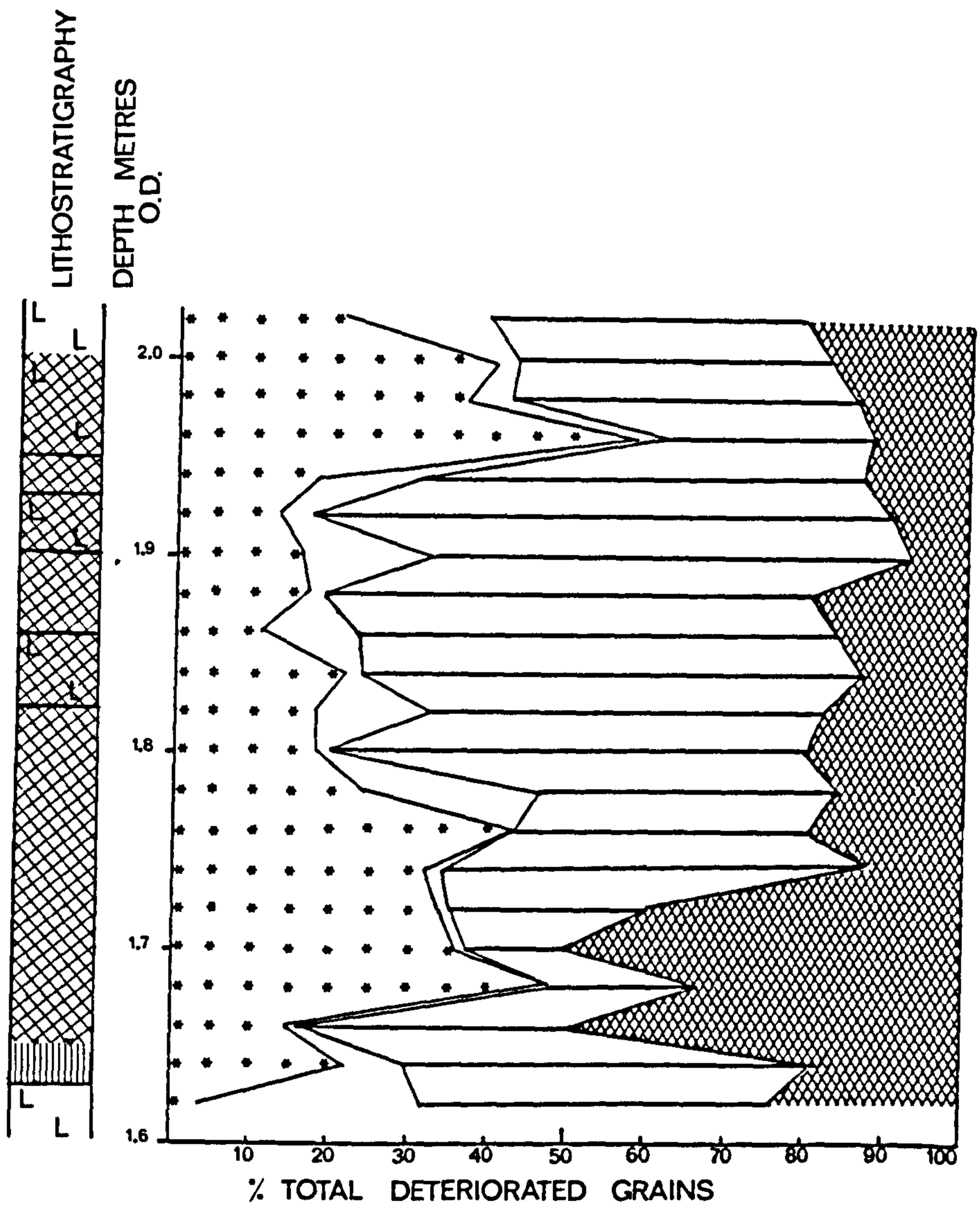
*Note:- Figures D8 and D9 can be found in the jacket on the back cover.

FIGURE D7. LOTTBRIDGE B. TYPES OF POLLEN DETERIORATION



KEY

LITHOSTRATIGRAPHY

PEAT

PEATY-CLAY

ORGANIC CLAY

SILTY-CLAY/CLAY

DETERIORATION

CORRODED

DEGRADED

CRUMPLED

BROKEN

This feature is very well illustrated by figures D8 and D9 which depict the type and extent of deterioration for the best represented taxa. At both sites there is a distinct deterioration 'horizon' which divides the relatively well preserved pollen from the poorly preserved. At Lottbridge A this horizon coincides with the clay layer. However, at Lottbridge B no change in the lithology occurs at the horizon, which is well marked at the +1.78m. O.D. level.

Besides an increase in deterioration at this horizon, there is also a change in the type. At both sites degraded pollen is virtually absent in the peat below the horizon, but increases above it especially at Lottbridge B. At this site Corylus and Alnus particularly follow this pattern. Below the horizon the grains of these taxa are better preserved with corrosion being the predominant type of deterioration. Above the horizon their pollen is more deteriorated with the degraded category often being the most common. Most of the other pollen types illustrated also follow this pattern, but there are exceptions; Filicales and Cyperaceae have a very small degraded component while Quercus' degraded values fall well short of those of Corylus and Alnus.

On the Lottbridge A diagram the increase in degraded pollen is largely confined to the clay layer, the deterioration in the upper peat horizons showing a similar pattern to that in the lower section, although the grains are more deteriorated and corrosion is more important.

From an analysis of this data it appears that with the onset of minerogenic sedimentation at Lottbridge A and at the +1.78m. O.D. level at Lottbridge B, the pollen suddenly becomes more deteriorated. An examination of the type of deterioration that occurs over this horizon reveals a complex picture. At Lottbridge A the degraded element increases in the clay, but the major gain is made by corrosion. At Lottbridge B the increase in the frequency of degraded grains is more pronounced. At both sites crumpled grains are an important category.

Havinga (1967), Birks (1970) and Lowe (1982) reflect the view that corrosion of pollen is usually caused either by oxidation or by microbial attack, while crumpled and broken grains are caused by mechanical processes involving the movement and subsequent attrition of pollen. The cause of degraded pollen is unclear. Cushing (1967) and Birks (1970) believe this type of deterioration to be caused by abrasion and compression. However, Lowe (1982) questions this by suggesting that degraded deterioration is the result of chemical damage.

The Lottbridge A and, to a lesser extent, the Lottbridge B diagrams show corrosion increasing towards the surface. The Upper Clay at Lottbridge Drove is considered to be oxidised because of its orange mottling. It may, therefore, be reasonable to conclude that the corrosion of pollen in the Willingdon Peat and in the Upper Clay is the result of oxidation. Significantly, the severest attack occurs in pollen closest to the present land surface. This suggests that much of the oxidation has taken place comparatively recently, some time after the pollen grains were deposited. Today, during dry summer months much of the peat remains above the water-table. This can be largely attributed to artificial drainage of the fields.

Besides corrosion, mechanical damage, especially crumpling, is very common at both sites. The pollen record, discussed in Section C, indicates that during the formation of the Willingdon Peat water movement along channels took place. Therefore crumpled deterioration may be contemporary with the deposition of the pollen. Because degraded deterioration tends to increase with more minerogenic sedimentation, it is proposed that this type of deterioration is also due to mechanical processes.

D 4.2. General conclusions.

The above discussion suggests that a study of pollen deterioration is of use in the interpretation of the Eastbourne pollen diagrams.

However, conclusions drawn from such a study must be treated with caution because the recording of the type and extent of deterioration contains an element of subjectivity, and because the cause of deterioration is imprecisely known. A greater understanding is required concerning the manner in which changes to the structure of pollen and spores occur. Therefore, the following points are of a general and somewhat tentative nature.

1). Different categories of deterioration of the pollen at Lottbridge Drove may have occurred at different times. The mechanical deterioration of crumpled, broken (and possibly degraded) grains is likely to have taken place at the time of pollen deposition. The corrosion of the same grains may have occurred much more recently when artificial drainage allowed the upper section of the Willingdon Peat and the Upper Clay to remain above the water-table for prolonged periods. However, it is recognised that some corrosion could have taken place during the period of peat formation, for example due to a drought affecting the surface layers of the peat.

2). Pollen within the Valley Gravels is both corroded, crumpled and broken suggesting water movement with periodic desiccation of the sediments. This is in accordance with the ideas proposed in Sections B and C for the environment of deposition for this lithostratigraphic unit.

3). The Langney Point and Lottbridge A pollen diagrams are characterised by high frequencies of deteriorated grains and low pollen concentrations. Hall (1981) suggests that such a pattern indicates a pollen assemblage that has been altered subsequent to its deposition. He maintains that differential pollen preservation may cause these alterations. For example pollen of Pinus, Picea and Tilia resist deterioration more successfully than pollen of Quercus, Gramineae, Cyperaceae and Chenopodiaceae. Therefore an increase in the frequency of Pinus, Picea and Tilia

relative to other types may not be due to palaeobotanical changes but instead be attributed to selective preservation. Reference to this for the Langney Point diagram has already been made on page 153 where it is concluded that selective pollen preservation has not occurred. An analysis of the Lottbridge A diagram suggests this important problem is not influential at Lottbridge Drove for a number of reasons :-

(a) Although Pinus and Picea are consistently present and their combined frequency often forms an important fraction of the assemblage, their frequencies do not fluctuate with zones of different preservation. In fact in Zone 3 (poor preservation) these two taxa are in low numbers and conversely some of their highest frequencies are found between -6.10m. O.D. and -5.45m. O.D. in a zone of better preservation.

(b) Pinus and Picea show some of the most consistently high percentages of deterioration. For example in Zone 4 both are more deteriorated than Juniperus and Quercus. In this context, an examination of the types of deterioration affecting Pinus grains at Langney Point reveals that in the two lower levels illustrated in figure D5, the grains suffer from all types of deterioration. However, above these levels deteriorated Pinus grains are almost exclusively broken. This corresponds well with the onset of estuarine conditions when, as argued in Section C, pine was probably not growing in the area at the time, its grains being transported to the site by the sea. Similarly at Lottbridge Drove within the estuarine silts and clays, deteriorated pine grains are almost entirely broken, but with corrosion increasing in the surface layers probably as a result of later oxidation, as explained above. Picea grains show a greater propensity to corrosion and are generally better preserved than pine grains. This suggests that high percentages of broken pine grains may reflect long distance transportation and thereby substantiate the view that the pine frequencies in p.a.z.s L.P.3 and L.D.3 and 5 do

not reflect the local growth of this genus. Equally, deterioration cannot be used to identify secondary pollen. The Lottbridge A diagram for deterioration (Fig. D4) illustrates how the arguably secondary pollen type of Picea has a similar tendency towards deterioration as most of the other pollen types depicted.

(c) Quercus, Corylus, Juniperus, Chenopodiaceae, Gramineae and Cyperaceae frequencies appear to be independent of their state of preservation. Some of the highest representations of Quercus on the Lottbridge A diagram occur in Zones 6 and 7 which contain respectively some of the best and worst examples of preservation. Peaks and troughs of Corylus , Juniperus, Chenopodiaceae, Gramineae and Cyperaceae show no correlation with zones of different deterioration.

(d) The increase of Tilia pollen in p.a.z. L.D.3b of the Lottbridge A diagram is believed to represent a switch in the provenance of the pollen from secondary to primary sources (Section C). Moreover, this Tilia peak is not considered to be a product of selective pollen preservation because although it occurs in a zone of poorly preserved pollen, figure D4 shows that Tilia pollen is no better preserved than most of the other pollen types. Also Tilia frequencies show no increase in any other zone of extensive deterioration.

Therefore, with the exception of corrosion in the upper layers at Lottbridge Drove, deterioration on any large scale has probably not occurred subsequent to deposition and, therefore, the pollen assemblages at both sites are not seriously affected by selective pollen preservation.

D 5. Summary.

The pollen record from the Eastbourne area analysed in this study no doubt broadly reflects climatic change. The decline of the

thermophilous genera within the Valley Gravels unit at Lottbridge Drove is probably the result of climatic deterioration during the Younger Dryas Stadial of the Lateglacial. The succession from Pinus to Quercus in the early Flandrian of Langney Point may best be explained as the response of thermophilous taxa consequent upon the climatic amelioration at that time.

However, other significant changes in the pollen record are better explained as responses to more local factors. The major Juniperus peak at Langney Point is considered to be a result of local edaphic changes caused by a combination of dune building and rising sea-levels in the early Flandrian, allowing juniper to expand locally free from competition by Corylus and Pinus. The mid-to late-Flandrian pollen record at Lottbridge Drove shows no obvious climatic influence, other than reflecting an interglacial climate. The major changes on the diagram are considered to be the result of variations in the provenance of the pollen (either primary or secondary), the influence of sea-levels and the activities of man (Section E 1).

The occurrence of secondary pollen, particularly at Lottbridge Drove, although not reflecting Flandrian vegetational change, is important in the recognition of pre-Flandrian deposits that contributed to postglacial sedimentation. This emphasises the need to study secondary pollen assemblages, not for biostratigraphic purposes, but for the analysis of the sediments. The incorporation of older sediments into younger sequences is an important process not least because it implies that the sedimentation record of an area may be more complex than it first appears. The Lottbridge Drove site is a good example of this as reworking of sediments has probably been common in the postglacial. The identification of this process has been revealed only by the secondary pollen assemblage which has also given an indication as to the age of these reworked sediments.

Importantly, to conclude that reworking has occurred, it is necessary to be certain that the pollen assemblage contains secondary pollen. Morphologically distinct secondary pollen are no problem to recognise. By a careful analysis of the pollen record, some indication can also be gained of the quantity of secondary pollen that are morphologically indistinct from primary grains. This has been attempted at Lottbridge Drove, and it is proposed that constant ratios between a morphologically distinct secondary grain and other pollen types can act as a measure of secondary pollen content. Unfortunately the extent and type of grain deterioration and staining cannot be relied upon to identify secondary pollen. Also, the problem of polycyclic redeposition remains.

This division into primary and secondary components can never be achieved with absolute certainty, but pollen diagrams that contain both types of assemblages can be of great value to the understanding of past environments and to the processes which helped to form them. It may be wise to examine carefully sudden changes on any pollen diagram that correspond to litho-stratigraphic boundaries. Although the biostratigraphy and lithostratigraphy may be registering a major environmental change at such boundaries, the pollen spectra may in addition reflect a switch in the provenance of the pollen. At its most extreme, this could represent a change from primary to secondary sources. Under such circumstances, pollen analysis is limited in providing a reliable biostratigraphic record over these transition zones and throughout lithostratigraphic units dominated by secondary pollen.

SECTION E.

LATE-QUATERNARY LANDSCAPE EVOLUTION AT EASTBOURNE.

In this section the nature of environmental change at Eastbourne since the Lateglacial is examined. The pattern of vegetational change is presented first. This is followed by a discussion on sea-level change in the study area. These two themes are brought together in Section F through a model of landscape evolution for the Eastbourne area during the Flandrian.

E 1. Late-Quaternary vegetational change at Eastbourne.

In Sections C and D data collected from the study area, principally by pollen analysis were presented, with the objective of elucidating vegetational change. This included a discussion on the secondary as well as the primary pollen record. This is considered to be necessary because the secondary pollen component can provide information on the process of sedimentation. Also no reliable attempt at reconstructing vegetational change can be made until the secondary pollen is identified. In this context, selective pollen deterioration must also be considered.

In Section D it is argued that at Langney Point secondary pollen is not in sufficient quantities to influence the pollen spectra which, as a consequence, is considered to be a true reflection of the early Flandrian vegetation at and around this site. However, the continued presence of Pinus throughout p.a.z. L.P.3 is likely to be the result of either reworking or long distance transportation by sea currents.

At Lottbridge Drove, secondary pollen is significant in p.a.z. L.D.3 and, to a lesser extent, in L.D.4b and 5. A corrected pollen diagram for L.D.3 is presented in Section D which is an

attempt to remove the secondary pollen component from this section of the diagram. The provenance of the secondary pollen is also discussed. In addition it is argued that at neither site is selective pollen preservation an important influence on the pollen assemblages.

E 1.1. The Langney Point vegetation record.

The establishment of Corylus by the opening of the pollen record at Langney Point is evidenced by both macro- and microfossil evidence. Hazelnuts recovered from the sediments in the U.100 sampler together with pollen frequencies of up to 46% during p.a.z. L.P.1 attest to its growth during the early Flandrian at this site. The high pollen frequencies of Juniperus in p.a.z. L.P.2 suggest a local establishment for this genus, an assertion supported by the identification of juniper fruits in the sediments at the same depth. Throughout L.P.1 and 2 Pinus plays an important role on the pollen diagram, but is replaced by members of the 'Mixed-Oak Forest' in L.P.3. It is therefore argued that juniper was growing close to or at the pollen site during L.P.2, but separate from the pine/hazel wood. A system of coastal dunes is proposed on which juniper became established (Section C). Taxa characteristic of freshwater marsh and pools of open water are present throughout the pollen diagram and, with the arrival of estuarine conditions during L.P.3, Chenopodiaceae became established.

Thus the pollen assemblages identified at Langney Point indicate four different communities :-

1). Woodland which presumably colonised drier low-lying areas as well as the slopes of the nearby Gault, Greensands, Weald Clay and, possibly, the Chalk. This community consisted of Corylus, with Pinus giving way to Quercus and Ulmus. Fraxinus and Tilia then became established.

2) Sand dune flora composed of Juniperus with Frankenia, Parnassia and Linum catharticum.

3). A salt marsh community of Chenopodiaceae, Gramineae and Glaux.

4) A freshwater community of Cyperaceae, Typha sp., Potamogeton sp., Nymphaea, Nuphar, Equisetum, Sphagnum, Filicales and other aquatics. Alnus and Salix may also belong to this community.

The role of the herbaceous taxa is difficult to define precisely because such plants are likely to become established wherever competition and edaphic factors allow. Therefore many of these taxa may have grown in any of the four communities identified.

These four communities can be used as the criteria for identifying the type of vegetation present at Langney Point in the early Flandrian. Thus, during L.P.1 woodland and freshwater communities were predominant. The pine/hazel wood of this time also included small amounts of oak, elm and lime. The increase in Pteridium during this p.a.z. corresponds with a decrease in Pinus and Corylus. This suggests a more open canopy in the early stages of this zone which may also have been responsible for the initial expansion of Juniperus. Alnus and Salix probably inhabited the moister parts of the wood and formed an ecotone to the freshwater community dominated by Cyperaceae with Filicales and Sphagnum.

In L.P.2 the woodland community of hazel and pine continued to play an important role in the vegetation of the area, but the freshwater community declined. The expansion of juniper during this zone is interpreted as marking the growth of a dune system, for the reasons given in Section C. An important consideration here is the relationship between juniper and pine and hazel. Importantly, juniper begins to expand before pine and hazel decline. This suggests that juniper was growing separately from the other two taxa. Nonetheless, it should also be recognised that juniper may also have played a transitionary role between the time of the decline of Pinus and the establishment of Quercus.

Therefore the period covered by L.P.2 was probably one in which juniper became established on a developing dune system. Once established in its own niche, a further expansion was encouraged by the opening of the woodland canopy during the succession from pine to oak. This would also have allowed the second but smaller increase in Pteridium to take place at this time.

During L.P.3 all four communities are present. The salt marsh community becomes established during this time, while in the woodland pine has given way to the 'Mixed-Oak Forest'. The low but consistent pine values are probably the result of long distance transport by ocean currents. These changes occurred some time before 8,770 ± 50 B.P.. Just prior to this date and corresponding with the development of the Crumbles Peat, the freshwater taxa, especially Equisetum expand their relative frequency.

The continued presence of Juniperus pollen after the establishment of the 'Mixed-Oak Forest' suggests this genus still inhabited areas unfavourable for the woodland. The existence of sand dunes is suggested by the presence of Frankenia, Parnassia and Linum catharticum.

The pollen record at Langney Point reveals a landscape that was largely wooded by the early Flandrian and remained so into the mid-Flandrian. The location of these woods is difficult to assess. During p.a.z. L.P.1 and 2 woodland may have become established close to the pollen site, the macrofossil evidence indicates Corylus was growing in the vicinity, but it is probably reasonable to assume that with the onset of estuarine conditions this woodland's range was reduced to the surrounding slopes. Therefore, the rising sea-levels of the early Flandrian became an influence upon the type of vegetation that could grow at this site. Woodland and freshwater taxa soon had to compete with a

developing dune system and its associated vegetation which in turn gave ground to a salt marsh.

E 1.2. The Lottbridge Drove vegetation record.

In Section C it is argued that p.a.z. L.D.1 probably represents a cold (glacial) stage with a treeless landscape. This is followed by the Lateglacial flora of L.D.2. Neither of these zones is apparently influenced to any great extent by secondary pollen, selective pollen preservation nor contamination. The Lateglacial assemblage is particularly interesting as it consists of an open landscape with Gramineae, Cyperaceae and Alnus being the most important taxa. A sparse alder woodland with small amounts of other thermophilous arboreal taxa is inferred from the pollen record. In addition the presence of Typha sp., Menyanthes and Potamogeton sp. indicate the proximity of water to the pollen site.

The succeeding p.a.z. L.D.3 is greatly influenced by secondary pollen. As discussed in Sections C and D, this p.a.z. cannot be used to reconstruct reliably detailed vegetational change. However, two general points can be made. First, the peaks of 'Mixed-Oak Forest' pollen in sub-zones 3b and 3d probably reflect an influx of primary or penecontemporaneous pollen and are therefore unlikely to represent vegetational change. Nevertheless, it may be concluded that the pollen types involved in this influx are a reflection of the types of taxa growing in the area. The expansion of Tilia in 3b is therefore noteworthy as it indicates that lime must have formed an important component of the vegetation at that time. This expansion is not due to selective pollen preservation, for the reasons given in Section D 4.

Second, the corrected pollen diagram presented in Section D 2 indicates that when the secondary pollen component is removed from

the pollen assemblage, the vegetation of the surrounding slopes appears to have consisted of some areas which were only lightly forested. In these areas Corylus and Juniperus probably formed important constituents of the vegetation. The Levels at this time supported a developing salt marsh consisting of Chenopodiaceae, Gramineae and Cyperaceae. This section of the pollen diagram is a good illustration of the problems for interpretation posed by different provenances of the primary pollen. As argued in Section D, the A.P. probably originated from the surrounding slopes and are therefore likely to be under-represented due to the more local pollen rain of the Levels.

A more detailed reconstruction of the Flandrian vegetation at and around Lottbridge Drove is possible for the Willingdon Peat phase from 3,750 ± 40 B.P. to 3,390 ± 40 B.P.. This period in the history of the Levels is covered by both Lottbridge pollen diagrams. As discussed in Section C, the two diagrams are constructed from sites only 20m. apart and yet significant differences in the pollen record occur. These differences are attributed to the presence of an estuarine channel at Lottbridge A allowing a salt marsh community to become established locally. In this channel minerogenic sedimentation incorporated secondary and other marine transported pollen.

These two diagrams highlight some important considerations for the analysis of pollen dispersal. The low values of Chenopodiaceae pollen at Lottbridge B indicate very local pollen dispersal from the salt marsh at Lottbridge A. This suggests that in an environment such as that of the Willingdon Peat period where different vegetation communities became established in close proximity, the pollen record will contain significant variations over short distances. Also, any secondary pollen is likely to be confined to minerogenic layers.

Thus at Lottbridge Drove a freshwater marsh co-existed with a salt marsh only 20m. away. The two pollen diagrams can therefore be used to reconstruct a detailed picture of the vegetation of the area during this phase.

At Lottbridge A, salt marsh persisted throughout much of the Willingdon Peat period. However, Typha sp., Potamogeton sp., Filicales and, in sub-zone 4c, Menyanthes undergo significant increases indicating the proximity of freshwater marsh to this site. Importantly Typha sp. and Filicales decrease during sub-zone 4b which corresponds with the intercalation of the minerogenic horizon and the maxima for Chenopodiaceae pollen. Ranwell (1972) observed the spread of Typha latifolia onto the upper limit of a salt marsh at Bridgewater Bay, Somerset. Therefore the co-existence of Typha sp. with Chenopodiaceae in the peat horizons at Lottbridge A may indicate the transition from freshwater to salt marsh, while the decline of Typha sp. and expansion of Chenopodiaceae in the minerogenic layer may be explained by an increase in salinity during this phase. These saline conditions are also indicated by the diatom record (Section B). The family Chenopodiaceae consists of some 500 species and although many can withstand high salinity levels, Ranwell (1972) states that only a few of these can withstand 'tidally-disturbed salt marsh conditions'. Most of them inhabit more stable inland salt marshes. Therefore the major expansion of Chenopodiaceae during L.D.4 suggests these salt marshes formed in a quiet, sheltered environment.

At Lottbridge B the salt marsh component on the diagram is very limited suggesting this site was never directly influenced by saline conditions during this period. Here, freshwater habitats were prevalent in which Filicales were particularly important. Cyperaceae, Gramineae and Typha sp. also formed significant constituents of the vegetation community. The increase in Typha

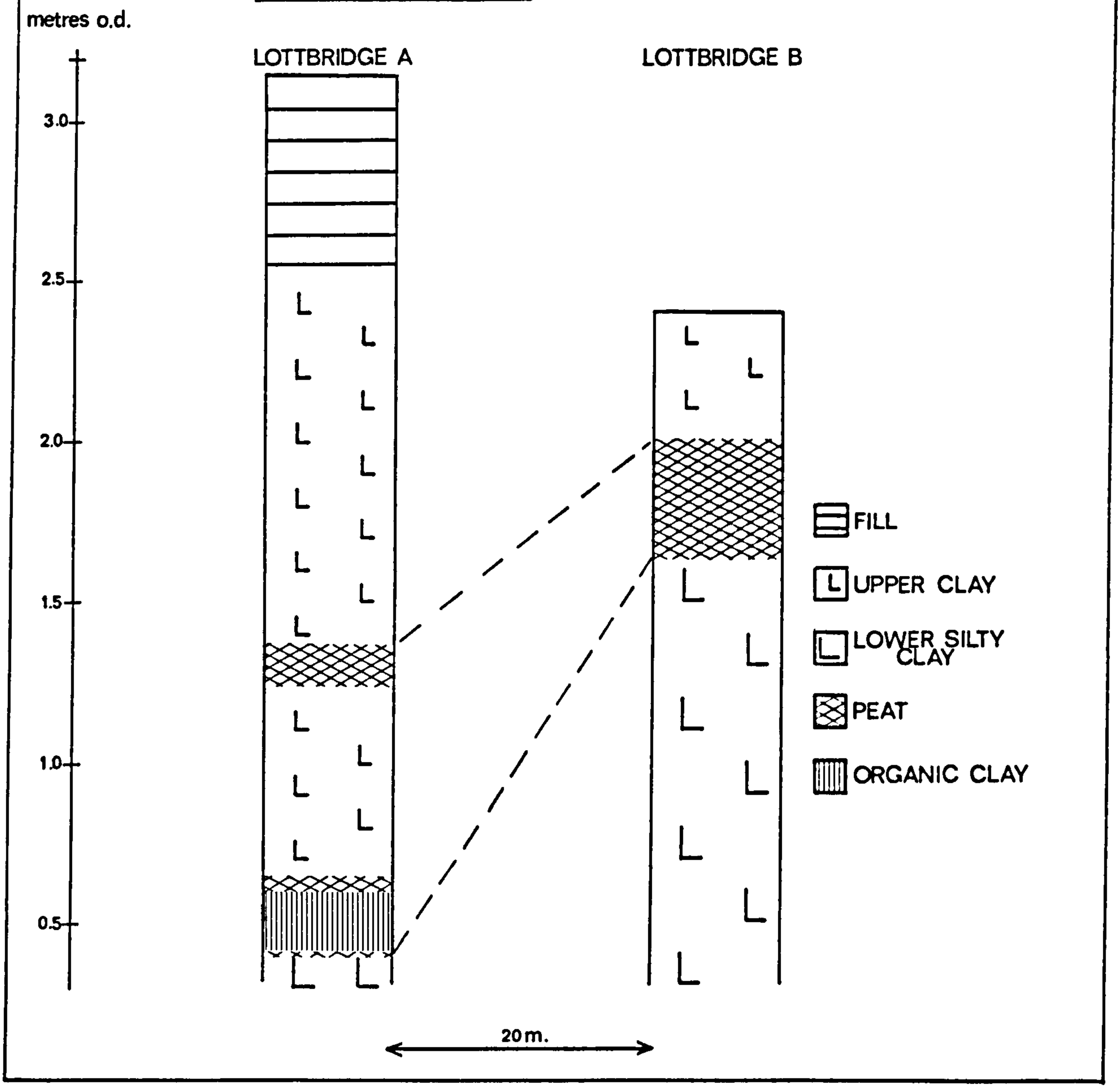
angustifolia and Chenopodiaceae at the +1.90m. O.D. level corresponds with the lowest values for Filicales. Considering that Typha sp. may invade the upper part of a salt marsh, this phase may mark an encroachment of the salt marsh towards the site of Lottbridge B.

The close proximity of freshwater and salt marsh probably reflects the presence of a channel cut into the peat. These channels are likely to have followed existing depressions in the Willingdon Peat/Lower Silty Clay surface. This is shown by figure E1 which places the two sites examined at Lottbridge Drove in their relative stratigraphic positions reduced to O.D.. At the Lottbridge A site the Willingdon Peat formed at a lower level than at Lottbridge B, thereby supporting the opinion that this site lay in or close to an old channel. Differential compaction is unlikely to be the cause of this difference in levels since at both sites the same types of sediment are found. Although figure E1 indicates less overburden at Lottbridge B, this is due to very recent removal of part of the Upper Clay by engineering work.

During p.a.z. L.D.5 the pollen record at Lottbridge A reflects a transition from initially estuarine to freshwater conditions. This is mirrored by the molluscan, Foraminifera and Ostracoda records as discussed in Section B. The succession of the vegetation on the Levels during this phase is illustrated on the pollen diagram by the initial expansion of Chenopodiaceae. This pollen type then declines as Bidens type and Compositae/Liguliflorae increase. These in turn decline as Cyperaceae expand. Typha sp. and other freshwater taxa remain throughout this zone.

From just prior to the formation of the Willingdon Peat to well into the Upper Clay primary A.P. of the 'Mixed-Oak Forest' play a significant role on the pollen diagram. On both the Lottbridge A

FIGURE E1. THE STRATIGRAPHIC RELATIONSHIP OF THE SITES OF LOTTBRIDGE A AND LOTTBRIDGE B



and B diagrams Quercus is the most important of these genera although Corylus, Alnus and Salix also undergo an increase. However, at no time during the hand augering or the drilling were any branches or trunks of trees encountered. This suggests that the A.P. originated from the slopes surrounding Willingdon Levels. It therefore appears that during the period of Willingdon Peat formation from 3,750 ± 40 B.P. to 3,390 ± 40 B.P. the slopes around Willingdon Levels supported a deciduous forest. However, on both diagrams the A.P., especially Quercus, appears to have two phases of expansion separated by a period of low A.P. values. This decline in the A.P., being identifiable on both diagrams and occurring within the peat, is believed to mark a genuine forest clearance phase and is not the result of a change in the provenance of the pollen.

The cause of this clearance is not clear as it occurred at some distance from the pollen sites on the slopes surrounding the Levels. Bronze Age anthropogenic activity may have been the reason as cultivation was probably taking place in the area by then, as suggested by the cereal pollen grains identified at the Lottbridge B site. However, it is uncertain whether this clearance took place on the chalk or on the slopes of Upper Greensand and Gault just to the north of Lottbridge Drove in the area known today as Hampden Park.

The decline in the A.P. during the Upper Clay period may be attributed to the development of agriculture which eventually spread down onto the Levels when freshwater conditions had replaced estuarine. Precise dating of this extension of agriculture down onto the Levels is difficult, but documentary evidence can provide some clues.

At the time of the Domesday Book there were holdings of 60 acres at Willingdon and 25 at Eastbourne (Dulley, 1966) but 11 salt pans

were also recorded at Willingdon (Ballard, 1910). This suggests that although agriculture had been established in the area by then it was not widespread. However, during the reign of Henry III there is documented evidence concerning the Manor at Eastbourne (Ballard, 1910). The bailiff of Ralph Neville, Bishop of Chichester, recorded that it would be impossible to work the Manors of Eastbourne and Bexhill under one administration because of 'the water of Pevensey'. Hodsoll (1982) cites documentary evidence of an estate at Langney in the 12th century owned by the Cluniac Priory of St. Pancras at Lewes. A charter of 1121 by the Archbishop of Canterbury and the Bishop of Chichester confirmed ownership by the Priory of their chapel at Langney, and another charter of circa 1160 - 65 (Dulley, 1966) allowed them to use sea water to run their mill at Langney. It therefore appears that certainly by the 13th century Willingdon Levels had been largely reclaimed for agricultural usage. Indeed, Dulley (1966) uses the charter of circa 1160 - 65 to infer that most of Willingdon Levels were enclosed by the 12th century.

E 1.3. The regional context.

It is difficult to relate the Langney Point data on vegetation change to any detailed regional context. This is due to the absence of previous palynological investigations on sediments of this age in the coastal areas of Sussex. However, reference has already been made in Section C to the work of Scaife (1980) on the Isle of Wight and Haskins (1978) in Dorset. These results suggest that in the early Flandrian members of the 'Mixed-Oak Forest' became established in southern England during the Boreal. These genera replaced a pine or pine/hazel forest. The establishment of *Corylus* by 9,305 $\pm$ 115 B.P. at Holywell Coombe near Folkestone (Kerney *et al.*, 1980) adds further support to the contention that hazel was an important component of the early Flandrian vegetation in southern England, as indicated by the Langney Point diagram.

The Lateglacial sequence at Lottbridge Drove and that examined by Haskins (1978) in the Poole Basin indicate the existence of a light woodland of alder during the period in parts of southern England. On the Isle of Wight, however, the Lateglacial vegetation appears to have consisted of open Tundra with a variety of herbaceous species and only small amounts of Betula (Scaife, 1980, 1982). A similar picture exists at Abingdon, Berkshire (Aalto, Coope and Gibbard, 1984) where pollen from deposits beneath the Floodplain Terrace of the River Thames revealed an open landscape. The fauna from this site confirm generally cooler conditions than at present but the assemblage for the lower level analysed indicates a phase of warm temperate climate similar to that of today.

At Brook in Kent, Kerney et al. (1964) have demonstrated high percentages of Pinus pollen during the Lateglacial. That pine may have become established in southern England during this period is also shown by fossil evidence believed to be of Lateglacial age, from Naseling, Hampshire (Seagrief, 1959) and from Elstead, Surrey (Seagrief and Godwin, 1960). Kerney et al. (1964) suggest that local edaphic conditions favourable to the growth of pine during the Lateglacial may have existed on sandy substrates.

The Lateglacial of southern England may therefore have consisted of a variety of floral communities ranging from open Tundra-like habitats to areas of open pine woodlands. In addition, locally favourable edaphic and climatic factors allowed the growth of more thermophilous taxa as, for example, at Lottbridge Drove.

The extensive p.a.z. L.D.3 cannot be reliably placed into any regional context because of the complex provenance of the pollen. The corrected pollen diagram indicates that Tilia, Quercus, Corylus, Ulmus and Juniperus were present on the slopes surrounding the Levels. However, the extent and age of this community and the importance of individual taxa is not clear.

From 3,750 ± 40 B.P. the pollen assemblage at Lottbridge Drove becomes a reliable record of Flandrian vegetational change, and it indicates the presence around Willingdon Levels of a forest dominated by Quercus. Episodes of forest clearance are apparent, particularly during the Upper Clay period. Anthropogenic factors are the likely cause for these clearances due to Bronze Age and more recent agricultural activity. Forest clearance on the South Downs probably began in the Neolithic but was more extensive in the Bronze Age (Thorley, 1971; Dimbleby and Bradley, 1975; Thomas, 1982; Waton, 1982). However, Scaife and Burrin (1983) have suggested that Mesolithic activity may have been the cause of sediment accumulation in the early Flandrian at Sharpsbridge in the Ouse valley. Smyth (1985) working in the Combe Haven has recognised forest clearance from the pollen record obtained from the extensive Upper Peat and Upper Silty Clay sequences found there. Although no absolute dating has yet been applied to this work, the clearance phases post-date the decline of elm on her diagram. Smyth attributes the first major clearance phases, induced by man, to the Bronze Age. One notable feature of the pollen record is the decline of Tilia from probably being the most common tree in the area during the mid-Flandrian to virtual extinction after the clearances. Further research, including radiocarbon support, is currently being undertaken in this valley.

Therefore the Willingdon Peat and the Upper Clay units at Lottbridge Drove probably record man's interference with the vegetation of the area, and the influence of sea-levels and changing coastal configuration on the Levels. The fossil evidence indicates that during the Upper Clay period agriculture spread down onto the Levels when conditions had changed from estuarine to freshwater. This indicates that important environmental changes have occurred on Willingdon Levels during the Flandrian. It is with this in mind that attention is now turned to postglacial sea-level changes in the Eastbourne area.

E 2. Flandrian sea-level changes in the Eastbourne area.

Data for the reconstruction of sea-level tendencies in the study area are presented in Section B where attention is also drawn to the problems of methodology and terminology involved in sea-level change research. The aim of this current section is to examine the record of sea-level change at Eastbourne by reference to the contacts and overlaps described in sub-section B 4.4. with additional information taken from cartographic and documentary evidence. The cause of these contacts and overlaps is then examined. However, no attempt is made to construct a sea-level curve diagram due to the difficulties and errors involved. A discussion on this subject can be found in Heyworth and Kidson (1982), Kidson (1982) and Section B of this work.

E 2.1. The Langney Point record.

The sediments and fossils recovered from Langney Point by BH.1 allow a study of sea-level tendencies from the early Flandrian to be made.

The deepest sediments appear, from the pollen record, to be freshwater in origin. The molluscan evidence is of little use at this stage due to poor preservation. However, some time before 8,770 $\pm$ 50 B.P. estuarine conditions replaced the earlier freshwater phase. Unfortunately the timing and extent of this early marine incursion is difficult to ascertain. Drilling carried out by Ove Arup and Partners in 1973 in the vicinity of BH.1 located a deep and very compact organic deposit that not only was more extensive than the Crumbles Peat unit recovered by BH.1, but in addition it was found to be resting on bedrock or on a thin layer of gravel. Samples from this investigation by Ove Arup and Partners provided the ^{14}C assays of 8,760 $\pm$ 75 B.P. and 9,510 $\pm$ 75 B.P. for this deeply buried peat (Shephard-Thorn, 1975). As discussed in Section B, it therefore appears that the

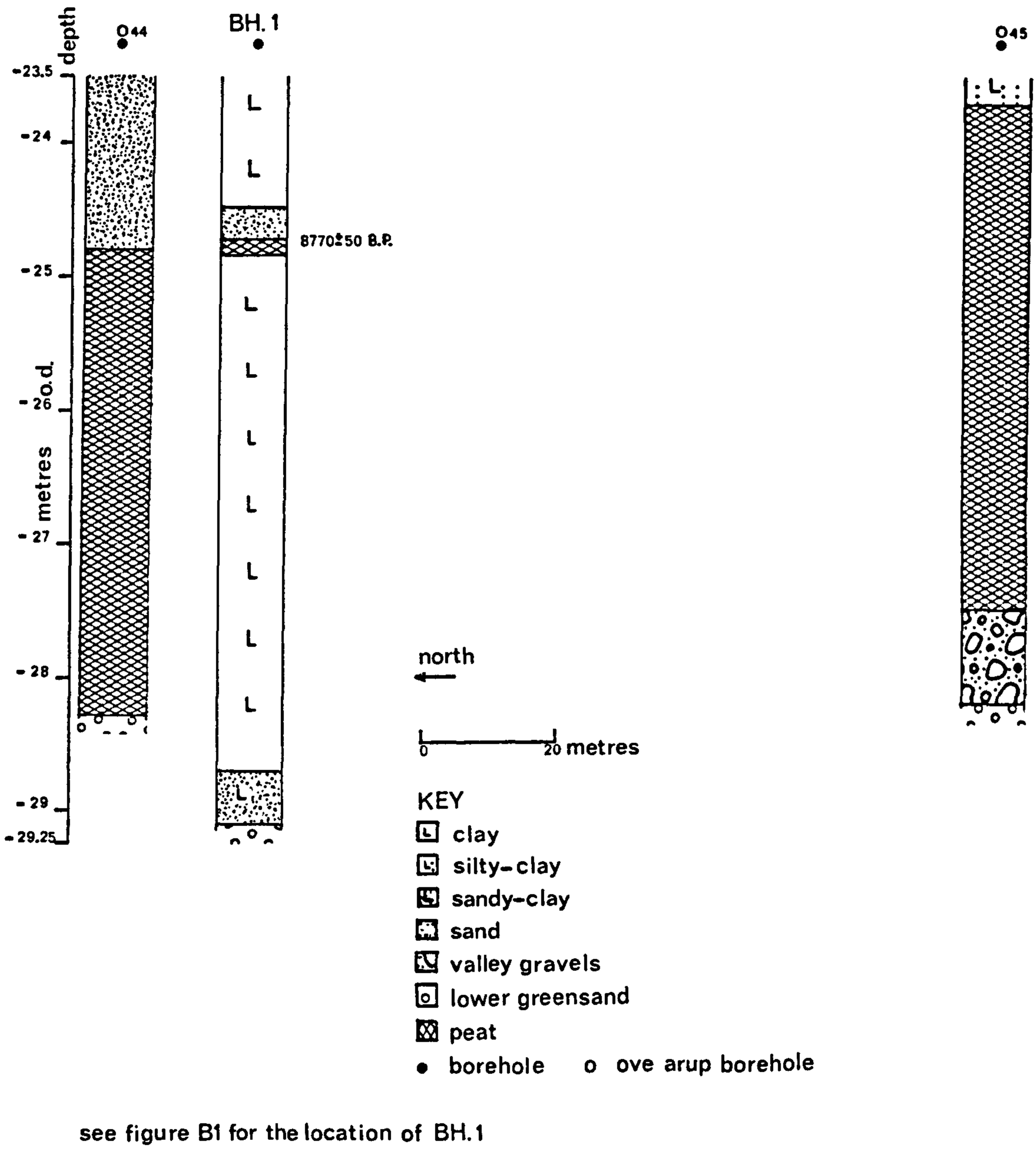
extent of the Crumbles Peat varies locally. That only a single organic horizon is present is shown by the close similarity of the age and depth of the upper levels of this deposit recovered by BH.1 and by the earlier boreholes of Ove Arup and Partners. The implications of this will be further discussed later in this section.

Importantly, the base of the organic sequence recorded by Ove Arup and Partners is at the same depth as the base of the Lower Minerogenic Sequence of BH.1. Therefore the earliest phase of sedimentation at Langney Point is characterised by very marked local variations in sediment type. Figure E2 illustrates these differences.

From the Ove Arup investigations it is clear that freshwater conditions at the site of their boreholes at Langney Point were not interrupted until after 8,760 ± 75 B.P.. Therefore, since the deposition of the Lower Minerogenic Sequence of BH.1 is probably contemporary with the formation of the organic sediments recovered by the Ove Arup boreholes, the early estuarine conditions recorded in BH.1 probably represent a localised channel. This channel may have followed the course of a former stream. This contention is supported by the nature of the Lower Minerogenic Sequence of BH.1 which shows a facies change from freshwater to estuarine. The lower freshwater facies may relate to the course of a stream which flowed through swampy terrain in which organic sedimentation was common. As sea-level rose so the course of this stream was converted into a small tidal inlet. In this way the contrasting borehole records of Ove Arup and Partners and of BH.1 may be explained. At all sites, the initial sedimentation occurred under freshwater conditions which are represented at the site of BH.1 by a minerogenic sequence due to the presence of a stream.

The Lower Minerogenic Sequence recovered by BH.1 consists of clays and coarser material that rest upon bedrock. Under these

FIGURE E2. THE STRATIGRAPHIC RELATIONSHIP OF EARLY FLANDRIAN SEDIMENTS AT LANGNEY POINT



see figure B1 for the location of BH.1

circumstances consolidation has probably been limited. Therefore it appears that sea-level stood close to -26m. O.D. (the depth of the biostratigraphic transgressive contact in BH.1) before 8,770 ± 50 B.P.

This early phase of localised estuarine conditions was then followed by a return to exclusively freshwater conditions at Langney Point with the Crumbles Peat expanding onto the site of BH.1. The onset of this freshwater episode is registered at -24.82m. O.D. in BH.1 with a lithostratigraphic regressive contact. At the neighbouring site (Shephard-Thorn, 1975) the Crumbles Peat sits directly upon the bedrock at a depth of -28.3m. O.D.. These contrasting depths are explained by the site of BH.1 marking first the course of a stream and then an estuarine channel which delayed the formation of the Crumbles Peat at this site.

This freshwater episode ended soon after 8,770 ± 50 B.P.. The very close similarity of this date from BH.1 with that from the earlier borehole by Ove Arup and Partners (8,760 ± 75 B.P. - Shephard-Thorn, 1975) is of note. The depth of this lithostratigraphic transgressive overlap is -24.7m. O.D. in BH.1 and at -24.8m. O.D. in the Ove Arup borehole. Thus the time/depth data from both boreholes records an almost identical pattern for the end of freshwater organic sedimentation. Although this close correspondence between the two sites may be the product of erosion of the upper surface of the peat and although the degree of consolidation of the peat is difficult to quantify accurately, it is tentatively suggested that freshwater conditions at Langney Point ended around 8,770 ± 50 B.P. with sea-level at approximately -24.6m. O.D.. This depth has been calculated by assuming the Crumbles Peat recovered in BH.1 to have been compacted by as much as 90%. This is feasible with a deeply buried peat (Jelgersma, 1966; Bennema et al. in Streif, 1979). That compaction of the Crumbles Peat has occurred is evidenced by its hard and compressed nature. The correspondence between the

timing and the height for this sea-level is in reasonable accordance with published sea-level data for north west Europe (for example Devoy, 1979, 1982; Streif, 1979).

Soon after 8,770 ± 50 B.P. estuarine conditions returned to Langney Point. This is indicated by the lithostratigraphic transgressive overlap discussed above. With the establishment of this second and more extensive phase of estuarine conditions the Upper Minerogenic Sequence was deposited. This lithostratigraphic unit contains two facies, an estuarine period followed by fully marine conditions. This pattern is established by many lines of evidences - particle size, pollen, Mollusca, Foraminifera and Ostracoda analyses (Sections B and C) - and suggests increasing energy within the coastal system at this site over time, culminating in the formation of the Crumbles Shingle.

The formation of the Crumbles Shingle.

The date for the arrival of the shingle in large quantities to this area is difficult to establish. As will be discussed later, this event may be linked to the formation of the Willingdon Peat, but the precise relationship between these two types of sediment is unknown. However, from cartographic evidence it appears that Langney Point itself is of comparatively recent origin.

Carr (1962) and de Boer and Carr (1969) have cautioned the use of cartographic evidence. As well as identifying technical problems, Carr (1962) also warned against "the user of the map attempting to get more out of it than is in fact there in the first place" (page 140). Thus great care is needed when using written and map evidence. As de Boer states, "Cartographic evidence from the earliest periods is rarely good enough to stand by itself, but considered together with other kinds of evidence can be suggestive" (in de Boer and Carr, 1969, page 26).

In the light of de Boer's and Carr's comments and in the absence of other more reliable evidence, the use of old maps, charts and documentary records does provide a useful if sometimes confusing account of the growth of the Crumbles and Langney Point. According to Steers (1964), Langney Point is first mentioned in Budgen's map of 1724. This is consistent with its absence from Richard Mount and Thomas Pages' 1705 chart of the area. However, 'The Beach' which appears to be a precursor of the point is mentioned on Waghenaer's 1588 chart and on some early maps of Sussex, for example John Norden's of 1595. However, these earlier maps make no mention of Langney Point, only the position of the beach, the location of banks offshore from Eastbourne (Collins' map of 1693) and a spit across Pevensey (Dammer's map of 1698). The belief that 'The Beach' of the earlier maps may in fact represent the inception of Langney Point is supported by a map produced from a survey of the coast at Eastbourne made in 1587. This map is reproduced by Bourdillon (1885) and clearly shows 'The Beache' with 'Langney Pointe'. This survey and its associated map also indicates that 'The Beache' is largely composed of shingle. It is therefore tempting to conjecture that 'The Beach(e)' of the earlier maps referred to above represents the full extent of the Crumbles Shingle. If this is true, then Langney Point had formed by the 16th century.

The word 'Crumble' is recorded as early as 1275 (Glover, 1975) and is probably derived from the Old English word 'Crundel' or 'Crumdel' which itself was derived from 'Crumb' meaning crooked (Glover, 1975). The recording of the word 'Crumble' by the 13th century to describe an area close to Eastbourne is significant because some shingle was already present in the area by 1207 as evidenced by a charter of that date allowing the inhabitants of Pevensey to move to a new site on a shingle bank at the mouth of Pevensey Haven (Dulley, 1966).

Therefore by the 13th century much of the Crumbles Shingle was already in place and this correlates neatly with the belief, expressed in Section E 1, that a large part of Willingdon Levels had been reclaimed for agriculture by then. It may be reasonable to assume that the use of the Levels for agriculture would have been more viable with a protective bank of shingle to seaward. However, it is also recognised that the spread of agriculture onto the Levels and the establishment of freshwater conditions may not necessarily have been synchronous events. In this context, the 13th century must be viewed as the latest date for the initial development of the Crumbles.

E 2.2. The Lottbridge Drove record.

The data from Lottbridge Drove provide details on sea-level tendencies for the later Flandrian period and so complement the record from Langney Point.

The Lower Silty Clay unit, which is found throughout Willingdon Levels, reveals an extensive period of estuarine conditions. Unfortunately, due to the absence of appropriate material, no absolute date has been obtained for the onset of these conditions. Also the pollen record cannot provide any detailed relative date or accurately apply the onset of sedimentation to Godwin's pollen zonation scheme. The lithostratigraphic transgressive overlap marking the opening of this estuarine phase occurs at -5.95m. O.D. at Lottbridge Drove (BH.2). This suggests a date of between 5,000 to 6,000 B.P. according to published sea-level data for south east England (Devoy, 1979; Jones, 1981). However, this date is specific to the site of BH.2 at Lottbridge Drove. For most of the Levels, depth to bedrock is unknown and, as a consequence, the timing of the onset of estuarine conditions over the remainder of the Levels is uncertain.

With the formation of the Willingdon Peat from 3,750 ± 40 B.P. to 3,390 ± 40 B.P. there is clear evidence for generally freshwater conditions on the Levels, but with local channels of salt marsh. The lithostratigraphic regressive overlap heralding the onset of this phase is recorded as +1.65m. O.D. at Lottbridge B, although at Lottbridge A probably due to the position of a local channel, it occurs at +0.4m. O.D.. The ensuing lithostratigraphic transgressive overlap dated at 3,390 ± 40 B.P. is recorded at +1.92m. O.D. at Lottbridge B (again deeper, at +1.37m. O.D., at Lottbridge A where disturbance to the peat may also have taken place). The significance of the heights of these overlaps will be discussed later in this section.

Finally, at +2.25m. O.D. a biostratigraphic regressive overlap occurs within the Upper Clay at Lottbridge A. This marks the most recent return of freshwater conditions to the Levels. This event may be tentatively correlated with the documentary evidence for both the expansion of agriculture onto the Levels by the 13th century and the establishment of the Crumbles, also by this date.

E 2.3. The cause of the contacts and overlaps.

The data for sea-level tendencies at Eastbourne as presented above, show alternate periods of freshwater and saline conditions. It is proposed that the main influence on the formation of the contact and overlap sequences described has been local factors, not eustatic oscillations. These local factors resulted in the formation of depositional features such as coastal barriers, spits and bars which, in the earlier Flandrian, were influenced by rising sea-levels. This hypothesis is outlined by Jennings and Smyth (1982) and in this section supporting evidence is presented.

E 2.3.1. Langney Point.

At Langney Point, the Crumbles Peat formation may be intimately linked with the development of coastal sand dunes and sand banks. The evidence for this is largely pollen based but is also supported by lithostratigraphic data (Section C)*. These dunes and banks would have afforded some protection to the early Flandrian coastline at Langney Point which explains why only estuarine conditions prevailed, most notably in the period after the formation of the Crumbles Peat during which the Upper Minerogenic Sequence (clay) was deposited.

The molluscan and pollen evidence suggests that estuarine conditions existed locally for some time during the formation of the Crumbles Peat. It is argued in Section C that the Crumbles Peat at the site of BH.1 did not represent an episode of hydroseral development but rather a colonisation of sediments, mainly by Equisetum, under conditions of high water-table. The picture therefore emerges of an early episode in which a local marine incursion, confined to the courses of streams, gradually gave way to widespread freshwater conditions. Although such a pattern can be produced by a relative fall of sea-level, the shoreward migration of sand bars with sediment accumulation in their lee and the establishment of sand dunes could also result in the above sequence. Given the evidence outlined in Section C, it is probable that sand bars and dunes were an important component of the early Flandrian coastline at Langney Point. The establishment of estuarine conditions at the site of BH.1 just prior to the Crumbles Peat period and for a considerable amount of time after can be attributed to a protected coastline that was also influenced by rising sea-levels. The Crumbles Peat at BH.1 is also probably related to these depositional features. The

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*Note; This data can be found on page 78 of Section C.

establishment of this deposit at this site may represent a phase of dune stabilisation with the blocking of local tidal inlets, rather than a fall of relative sea-level.

It is of note that today this coastline is an exposed, high energy environment and therefore must have undergone major change during the Flandrian which cannot be explained by oscillations of relative sea-level. This increase in the energy of the coastal system can be explained by the establishment of a protective sand bank and dune complex in the early Flandrian and its eventual over-running and shoreward migration. Of note, the initial low energy conditions occurred during the period of rising sea-levels of the early Flandrian. Such a pattern is supported by the lithostratigraphic, pollen, molluscan, Foraminifera and Ostracoda analyses presented in Sections B and C.

One aspect that should be considered when analysing the form of a coastline in the early Flandrian, is the position of headlands and cliffs that may have been eroded significant distances during the postglacial. The chalk cliffs at Beachy Head are retreating at a rate of approximately 1m./year (see page 208). To extrapolate this figure back into the early Flandrian would place this headland some 10km. to seaward of its present position. Such a position, and subsequent retreat, would probably have had a major influence on the environment of the Eastbourne area, possibly determining the energy of the coastal system. As the headland receded, so the exposure and therefore the energy of the coastline would have increased.

However, a number of factors suggest that the location of a major headland, a considerable distance to seaward of its present position, is not a viable consideration for the development of the coastline at Eastbourne during the Flandrian:-

1). The scarp of the chalk in this area is aligned north-south. Thus any former chalk headland could not have

projected eastwards to front the Eastbourne area, the chalk having been removed long before the Flandrian to form the Weald. Any hypothetical headland could only have projected in a southerly and westerly direction.

2). The consequence of 1). is that any extension of the headland at Beachy Head is not an alternative to the development of spits and barriers as an explanation for the changes to the coastal environment at Eastbourne during the Flandrian. Indeed, a more substantial headland, projecting southwards, would have formed a solid foundation for spit development.

3). The extrapolation of current erosion rates at Beachy Head back into the Flandrian is questionable. The shore platforms developed on the chalk of Kent and Sussex attain a maximum width of 300m. (Jones, 1981) and therefore, unless the platforms are being reduced at their seaward end at a known rate, provide no evidence for substantial cliff retreat during the Flandrian. The preservation of an Ipswichian beach at Black Rock, Brighton further suggests that erosion of the chalk cliffs of Sussex has been limited during the Flandrian. Furthermore, the existence of Flandrian submerged forest beds fronting unresistant strata at Bexhill and Fairlight point to restricted cliff retreat even on these rock types.

4). Projecting the 'hanging' dry valleys of the Seven Sisters seaward to establish the former cliff line cannot be undertaken with any certainty because there is no direct evidence that these valleys were ever graded to sea-level during the Devensian/Lateglacial, when it is likely they were last active. The buried channel of the River Ouse at Newhaven lies at approximately -30m. O.D., and this may more accurately reflect adjustment to lower base-levels during the last cold stage.

The extent of cliff retreat during the Flandrian is an important aspect of palaeoenvironmental reconstruction of any coastal area. However, the above discussion suggests that for the Eastbourne area, cliff retreat during the postglacial has been limited, and that present erosion rates may have been achieved only recently and cannot be extrapolated back into the Flandrian with any certainty. As Jones (1981) states; "A number of problems are still to be resolved concerning the origin and evolution of shore platforms in (southern England)". This is a topic in much need of further research.

E 2.3.2. Willingdon Levels.

Willingdon Levels appears to have accommodated estuarine conditions for much of the Flandrian. The sediments at Langney Point are likely to have greatly influenced the environmental conditions on the Levels, and therefore the pattern of sedimentation. As discussed above, the early to mid-Flandrian was a period of sand bar and dune construction in the Langney Point area and this would help to explain the estuarine nature of Willingdon Levels during the Lower Silty Clay period.

The formation of the Willingdon Peat.

The formation of the Willingdon Peat should be viewed against a background of sediment accumulation seaward producing depositional features such as banks, spits and dunes. Also of importance is the topography of the southern part of the Levels. Here two 'islands' of Gault exist which would have been more imposing in the early Flandrian before most of the sediments had accumulated. The position of these 'islands' is shown in figure A3. The influence these had on the pattern of sedimentation on Willingdon Levels is likely to have been considerable. Not only would they have formed a natural breakwater but they would also have provided convenient obstacles to sediment transport, around which and from

which bars and spits could form. Longshore drift would tend to carry material from the chalk cliffs of Beachy Head eastwards - as it does today - and onto the Gault 'islands', thereby producing conditions favourable for the establishment of spits and eventually more substantial barriers. The concurrent sedimentation on Willingdon Levels behind these 'islands' is therefore likely to reflect this development, and indeed this appears to be the case. The estuarine Lower Silty Clay unit gives way to a largely freshwater phase of peat accumulation. Also, the hand augering revealed the Crumbles Shingle on the down-drift side of St. Anthony's Hill but not behind it (Fig. B3). This indicated that St. Anthony's Hill provided the necessary foundations onto which sediment (in this case shingle) could accumulate.

Unfortunately it is not clear whether the Willingdon Peat is contemporaneous with the initial development of the Crumbles Shingle as no contact between these two lithostratigraphic units has been found. Although the base of the Crumbles Shingle lies below the base of the Willingdon Peat (Fig. B3), this may be the consequence of differential compaction of the sediments under-lying the shingle compared to those under the peat. Therefore the stratigraphical positions of the peat and the shingle cannot be used as an indication of their relative age.

However, given the degree of sediment accumulation and the topography of this area it seems reasonable to conclude that the Willingdon Peat is likely to owe its existence to depositional features that formed seawards and against the 'islands' of Gault. In this way a transition from estuarine to freshwater conditions occurred on the Levels. Whether these features were composed of sand or shingle remains open to speculation. The lithostratigraphy of Langney Point (Fig. B2) implies that the earlier depositional features consisted largely of sand, silt and clay with shingle being a more recent addition, a pattern very similar to that proposed for the formation of Dungeness (Green, 1968; Shephard-Thorn, pers. comm.)

Therefore the lithostratigraphic regressive overlap at +1.65m. O.D. at Lottbridge B and dated to 3,750 ± 40 B.P. is considered to be the result of sediment accumulation behind a coastal spit or barrier that was located across the entrance of Willingdon Levels in the vicinity of the 'islands' of Gault. As a consequence, the growth of the Willingdon Peat cannot be used as evidence for eustatic change as it probably owes its formation to local factors.

The formation of Flandrian coastal peat beds in south east England.

The belief that the coastal peat of Willingdon Levels is the product of local factors is at variance with other work on peats found in similar situations on other parts of the Sussex and south east coast of England. It is therefore necessary to examine the factors which have resulted in other coastal peats of south east England in the light of the ideas proposed for the formation of the Willingdon Peat.

In his extensive study of coastal peat beds, Godwin (1943) infers that for two sites in southern England - Southampton and Amberley Wild Brooks - deposition of clay represents a marine 'transgressive' episode and deposition of peat to an end of a 'transgressive' episode. Although not stated specifically for these two sites, Godwin recognises that apparent 'transgressions' and 'regressions' may not necessarily be due to eustatic events but may be the result of changing configuration to the coastline, a process that may even be the consequence of a severe storm. He cites the consequence of the east coast storm of February 1938 as evidence for this.

Thorley (1971), in a discussion on coastal peat beds, refers to shallower organic sediments as 'transgressive peats' formed as a response to a rising sea-level, while also recognising that they are commonly found behind a coastal barrier. Godwin (1962) also equates waterlogging of a site at Wingham with rising sea-levels.

The implication is for peat development along the south coast to have been a consequence of eustatic factors. In this context, Jones (1981) believes that the sea-level data produced by Ters (1973) are likely to represent the most applicable pattern of sea-level tendencies for southern England. Ters' sea-level curve follows an oscillating pattern with the later major phases of eustatic rise ending close to 5,000 B.P., 3,500 B.P. and just before 2,000 B.P. followed by more minor fluctuations. The implication is for the south coast of England to have been affected by variable eustatic movements. However, Jones (1981) has found it difficult to equate the pattern of sedimentation found along the south coast with any detailed theory of sea-level changes. He further states that "relatively little is known regarding the details of coastal evolution" (page 288) in this part of the country. Although this is partly the result of an insufficient number of detailed investigations with absolute dating support, nevertheless, the assertion that Ters' (1973) sea-level curve is applicable to the south coast of England must be questionable, at least until more research has been undertaken.

As discussed in Section B, the imprecise meaning of the terms 'transgression' and 'regression' has often resulted in vague or misleading statements concerning sea-level tendencies, and this has certainly been the case for the Sussex coastline. The implied meanings of these terms as used by Thorley (1971) and Jones (1981) is for eustatic fluctuations to have taken place so that estuarine minerogenic deposits can be used as evidence for a eustatic rise, while organic sediments can be interpreted as a consequence of either a slow rise of sea-level or the ending of a 'transgressive' episode.

However, this implication of sedimentation being the direct consequence of eustatic fluctuations does not adequately explain the pattern of coastal deposition in East Sussex. As previously explained, the Willingdon Peat is probably the result of

freshwater conditions replacing estuarine due to the development of coastal spits and barriers. Even the initial estuarine conditions recorded in the Lower Silty Clay unit of Willingdon Levels are probably the consequence of earlier depositional features creating a protected environment.

A major argument against the hypothesis of coastal peats in East Sussex being essentially 'transgressive' is the diachronous initiation of peat growth along this coastline. From the few radiocarbon dates* available it is clear that significant differences occur. In the Vale of the Brooks peat began to form prior to 6,290 ± 180 B.P. (Jones, 1981), but on Willingdon Levels the inception of peat development began at 3,750 ± 40 B.P.. On the eastern part of Pevensey Levels the base of an organic deposit yielded a date of 3,715 ± 80 B.P. (Moffat, 1984) which suggests that coastal peat formation began significantly earlier in valley situations than it did on the wider expanses of Levels. This is to some extent supported by the pollen evidence from the Combe Haven valley where the Upper Peat unit appears to have started to form prior to the elm decline (Smyth, 1985). The results of the radiocarbon dating for this site are awaited.

The picture is also complex on Pett Levels and Romney Marsh. At the former location peat development occurred around 5,200 and 5,300 B.P. (Shephard-Thorn, 1975) and almost certainly for an unspecified period prior to this as these dates refer to the upper level of the peat. On Romney Marsh peat development is again diachronous ranging from 4,845 ± 100 B.P. at Wittersham Bridge to 2,050 ± 90 B.P. at Lydd (Shephard-Thorn, 1975).

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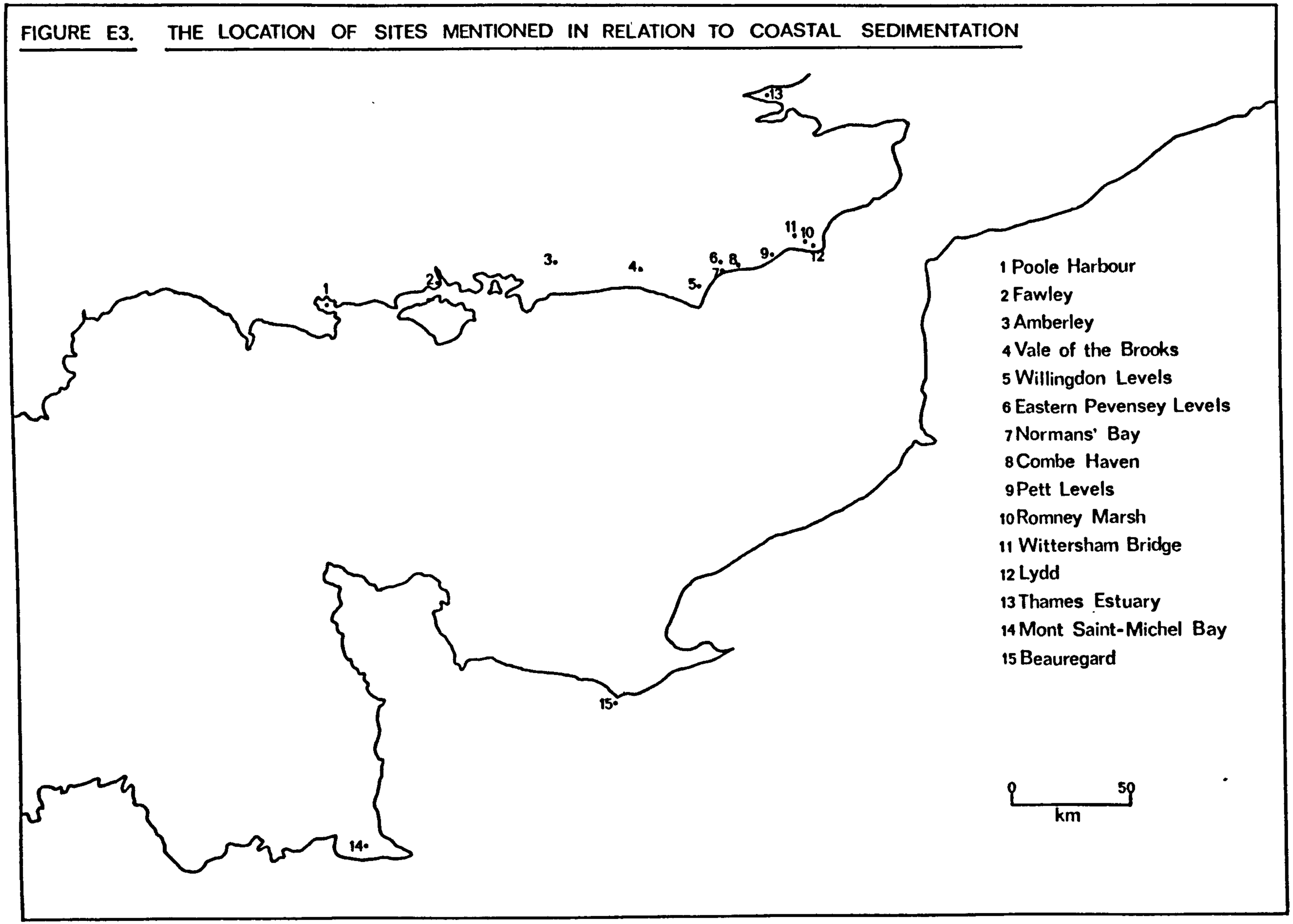
* Note : The location of the sites referred to in the following discussion is shown by figure E3.

FIGURE E3. THE LOCATION OF SITES MENTIONED IN RELATION TO COASTAL SEDIMENTATION



Significantly, Green (1968) suggests that peat development on Romney Marsh should be seen as the result of sedimentation in the lee of offshore spits. The range of dates from the Pett to Romney Marsh area supports this view as the oldest peat occurs in the west and this deposit becomes younger in an easterly and seaward direction, a pattern explicable by the development eastwards of spits and bars as proposed by Lewis (1932), Lewis and Balchin (1940), Green (1968), Eddison (1983a, b) and Shephard-Thorn (pers. comm.).

This diachronous development of the coastal peats of East Sussex suggests they formed due to local factors operating within the low-lying sections of this coastline. The development of spits, bars and barrier beaches is proposed as the principal explanation for organic sedimentation in this area, following the pattern demonstrated for Willingdon Levels (this work) and Romney Marsh (Green, 1968). The nature of these depositional features was probably influenced by their proximity to sediment supplies originating from rivers, areas of cliff erosion or from offshore sources, and by the configuration of the coastline. All of these factors must also be viewed against the background of the main Flandrian transgression which, due to a slower rate of rise from around 5,000 B.P., is likely to have resulted in more stable depositional features from the mid-Flandrian. As a consequence, it is likely that the deeper levels of the peat at the Vale of the Brooks and the Combe Haven register the final phase of more rapid base-level rise.

Return to minerogenic sedimentation.

Although the initial development of coastal peat in East Sussex is diachronous, there is some evidence for a more synchronous return to minerogenic sedimentation. On Willingdon and Pevensey Levels, in the Vale of the Brooks, the Combe Haven, on Pett Levels and Romney Marsh the peat is overlain by such a sediment and which,

although often appearing to be a single lithological unit, contains freshwater and estuarine facies (see the description of the Upper Clay unit in Sections B and C; Jones, 1981; Burrin, 1982; Smyth, 1985).

The extent of the estuarine facies of this unit appears to vary spatially. For example, it is restricted to the more down-valley parts of the Combe Haven (Smyth, 1985) but is more extensive on Willingdon Levels (this work). Where it has been located it always underlies the freshwater facies indicating that a significant environmental change occurred within the period of time this unit formed. This is well illustrated by the Upper Clay at Lottbridge A where at +2.25m. O.D. a biostratigraphic regressive overlap marks the transition from estuarine to freshwater conditions.

Although this return to estuarine conditions in low-lying coastal areas of East Sussex shows a degree of synchronism, in detail the pattern of events does not conform to any single 'transgressive' episode that can be easily correlated between sites. The return is dated on Willingdon Levels to 3,390 ± 40 B.P. and occurs at +1.92m. O.D. at Lottbridge B. In the Vale of the Brooks the contact occurs soon after 3,190 ± 125 B.P. implying a synchronous event between the two sites. However, this date for the Vale of the Brooks should be treated with caution because, as discussed by Jones (1981), while this date was obtained from a sample of peat at -2.3m. O.D., the organic deposits rise to present sea-level at the margins of the Brooks and may originally have been of even greater elevation. Therefore it is possible that erosion of the peat may have resulted in a coincidental similarity of dates.

The problem of peat erosion is also likely to have rendered the Pett Level dates of 5,205 ± 105 B.P. and 5,300 ± 100 B.P. as unreliable indicators for the timing of the return to estuarine conditions. The peats are now in the intertidal zone and have

therefore been subjected to marine processes. On Romney Marsh the youngest date for peat growth is 2,050 ± 90 B.P. at Lydd (Shephard-Thorn, 1975) which is considerably later than for Willingdon Levels. Similarly, on the Eastern Pevensey Levels organic deposition continued until after 2,760 ± 50 B.P. at Normans' Bay (Moffat, 1984). Unfortunately, the transition from this peat to the overlying minerogenic sediment has not been dated, but nonetheless peat was forming at the coast on Pevensey Levels for at least 600 years after the termination of peat development only 8km. away on Willingdon Levels. In fact, this date from Normans' Bay almost corresponds with the end of the 'transgressive' episode at Amberley Wild Brooks in the Arun Valley of West Sussex. Here a freshwater peat began to develop on top of estuarine sediments at an elevation of +1.5m. O.D.. This lithostratigraphic regressive overlap is dated to 2,620 ± 110 B.P. (Thorley, 1971).

It therefore appears that along some sections of the East Sussex coastline a period of estuarine conditions and associated minerogenic sedimentation took place from circa 3,000 B.P.. However, on some parts of Romney Marsh this episode was delayed while at Amberley a negative tendency of relative sea-level movement took place while this episode was in progress in other areas.

Wider correlations.

It is not in the scope of this research to attempt detailed correlations of the coastal sequences of East Sussex with those from other regions of the British Isles and north west Europe. Regional correlations are in any case fraught with difficulties (Heyworth and Kidson, 1982; Kidson, 1982) and an extensive appraisal of sea-level data for south east England is provided by Devoy (1982). Nonetheless, an examination of data from other sites along the coast of the Channel and southern North Sea is instructive for this important period of coastal change centred

around 3,000 B.P.. Such an examination is necessary because of the uncertainties given by the East Sussex data.

In the Solent, peat deposits at Fawley in Southampton Water were overlain by estuarine sediments after 3,689 ± 120 B.P. (Hodson and West, 1972). These sediments formed behind Calshot spit, a feature which may date from Atlantic times or earlier. Thus at Fawley a similar situation exists to that on Willingdon Levels. At both locations estuarine and salt marsh sediments built up behind a coastal barrier culminating in a peat being overlain by further estuarine deposits. Devoy (1982) has used this peat - minerogenic contact at Fawley as a sea-level index point. However it is doubtful whether this date truly reflects a period of widespread marine incursion along the south coast because the timing of this event at Fawley corresponds closely with the initiation of peat development on Willingdon Levels from 3,750 ± 40 B.P.. The reliability of this Fawley date may in any case be questionable because a sample taken from the lower levels of this organic deposit produced a slightly younger date (Godwin and Switzur, 1966).

Gilbertson (in Devoy, 1982, in Jones, 1981) has indentified a phase of marine incursion in Poole Harbour from circa 3,500 B.P. to circa 2,500 B.P. which approximates to the deposition of marine sediments in the Thames estuary from 3,850 B.P. to 2,800 B.P. (Devoy, 1979, 1982). This episode of marine incursion generally correlates with the Dunkerk 'O' lithostratigraphic transgressive overlap sequence form Holland (see Devoy, 1979 pages 390 and 392), but this is of a shorter duration lasting from circa 3,400 B.P. to circa 3,000 B.P. (Jelgersma et al., 1970; Van de Plassche, 1979). Along the north west coast of France a short lived phase of positive tendency occurred just prior to 3,000 B.P. (Morzadec-Kerfourn in Devoy, 1979), the earlier stages of which correspond with the formation of the Willingdon Peat. However, at

Beauregard peat is replaced by minerogenic sedimentation after 3,260 ± 100 B.P. (Clet-Pellerin et al., 1977). In an appraisal of the coastal sequences of north France, Sommé (1979) discusses a 'top' peat formed between 3,500 B.P. and 2,700 B.P. that became increasingly influenced by 'regional conditions'. A widespread return to marine conditions occurs from circa 2,000 to 1,000 B.P.. In addition, Larsonneur (1980) has described a sedimentary sequence in Mont Saint-Michel Bay where peat was overlain by estuarine deposits after 3,700 B.P. and again after 2,300 B.P..

These data indicate that in Poole Harbour, the Thames estuary, Holland and northern France marine sediments were being laid down in many areas during the period of peat formation on Willingdon Levels and, subsequent to estuarine conditions becoming established on Willingdon Levels, these positive tendencies of relative sea-level movement ceased or were interrupted at a number of sites.

The above discussion suggests that the onset and cause of the period of marine incursion that took place along the Channel and southern North Sea coasts sometime between approximately 3,800 to 2,500 B.P. cannot simply be attributed to eustatic movements. Clearly the processes involved during this period resulted in a marked variation of the timing and extent of marine inundation.

The cause of the lithostratigraphic transgressive overlap.

On Willingdon Levels estuarine conditions returned at 3,390 ± 40 B.P. and several possibilities can be proposed for this return which resulted in a renewed phase of minerogenic sedimentation.

1). An increase in the rate of sea-level rise. Although the deposits at Eastbourne do not support a pattern of oscillating sea-levels, an increase in the rate of rise at circa 3,000 B.P. as proposed by Devoy (1982) is a possibility. However, as discussed

above, the wide scatter of dates for this peat/minerogenic contact and the variable duration of this estuarine phase along the Channel and southern North Sea coasts casts doubt upon the validity of this argument.

Another factor to consider is the height of the Willingdon Peat. At Lottbridge B it is found between +1.63m. O.D. and +2.00m. O.D.. The spring tidal range at Eastbourne is 6.5m. (Wilson and Wilson, 1968). An engineering report by Lewis and Duvivier (1968) gives the level of M.H.W.S. at Eastbourne as +11.8' (circa +3.5m.) O.D.. Figures for Newhaven, the nearest port to Eastbourne, give a height of 6.6m. for M.H.W.S. and 0.6m. for M.L.W.S. above L.A.T.* (Adlard Coles, 1982). In addition, Devoy (1982) provides a height of +3.08m. O.D. for M.H.W.S. at Newhaven, a figure based upon Admiralty Tide Tables. Therefore the Willingdon Peat falls within the present day tidal range and, as a consequence, there is no need to infer a rise of relative sea-level subsequent to the period of peat formation in order to explain the deposition of the Upper Clay. Palaeotidal range is difficult to establish, but Devoy (1982) considers present tidal ranges not to have altered to any significant extent for approximately the last 4,500 years. Although the Willingdon Peat has undergone some compaction, the observation by Heyworth and Kidson (1982) that near surface peats are unlikely to have undergone much depression suggests that the original stratigraphical position of the Willingdon Peat fell within the present tidal range.

The pollen record from the Willingdon Peat indicates that freshwater and saline vegetational communities were established in close proximity, the latter along channels cut into the marsh (Section C.)

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*Note: L.A.T. refers to Lowest Astronomical Tide.

Assuming no alteration to sea-level since the Willingdon Peat period, the occurrence of these freshwater taxa below M.H.W.S. is explicable by the modification to the environment produced by coastal barriers. Heyworth and Kidson (1982) have argued that behind such features, freshwater taxa, including trees, can become established at levels below M.H.W.S.. Additional evidence for this comes from the height of the present land surface on Willingdon Levels and in the Combe Haven. In both locations the present surface lies below M.H.W.S.. In the mid-valley section of the Combe Haven the land surface attains an elevation of only circa +1m. O.D. (Smyth, 1985). Without the protection of present shingle barriers and the additional protection provided by the construction of sluice gates, embankments and groynes, many low-lying areas of the coastline of East Sussex would be inundated at high water.

2) The influence of short term events. A period of increased storminess is suggested by Lamb (in Devoy, 1982) to have begun around 2,950 B.P.. Although this post-dates the onset of sedimentation at many of the sites discussed above, including Willingdon Levels, storms and tidal surges could have produced marine inundations of different sites at different times. Drawing upon present day storm events as analogues to measure the likely effect past storms could have had on coastal sedimentation is not a valid approach because today machinery can repair damage and remove the evidence (Godwin, 1943; Kidson, 1982)

It has been suggested by Jennings and Smyth (1982) that one possible cause of estuarine minerogenic sediments intercalating and overlying peat in coastal areas of East Sussex is the breaching of barriers and spits. In the Combe Haven, Smyth (1985) provides evidence that a thin clay lense in the extensive Upper Peat was formed by a short lived episode of marine incursion. As discussed previously in this work, the formation of the coastal

peats in East Sussex is probably linked to the establishment of depositional features at the coast which resulted in an eventual switch from estuarine to freshwater conditions in the near-coastal zone. This was largely independent of any sea-level change, although a decrease in the rate of sea-level rise was a contributory factor. Provided these depositional features were never seriously breached, freshwater conditions would be maintained, especially in river valleys. This extra freshwater input provided by a river is a possible explanation for the more extensive development of peat in the Vale of the Brooks and the Combe Haven compared to Willingdon Levels and Pevensey Levels (Jennings and Smyth, 1982).

If the above hypothesis is accepted then major breaching of barriers must have occurred along sections of the East Sussex coastline, for example on Willingdon Levels, in order that estuarine conditions could return. One possible cause for the breaching would be storms, but the range of dates for the peat/minerogenic contact along the East Sussex coast suggests that no single storm or particular series of storms could be the cause of the breaching. In Holland the development of coastal sand barriers during the Flandrian is well documented (Van Straaten, 1957, 1963, 1965; Jelgersma et al., 1970). Alterations to these barriers have been proposed as an explanation for the transgressive and regressive overlaps recorded along the coast of Holland (Van Straaten, 1957, 1963, 1965; Jelgersma et al., 1970). The cause of these alterations is considered to have been largely the consequence of variations in the quantity of sediments reaching the coast and climatic factors, principally changes in storminess and precipitation, all of which has been superimposed upon the Flandrian rise in sea-level (Van Straaten, 1957, 1965; Jelgersma et al., 1970).

It is worth noting that for the south coast of England, Robinson (1955) discusses the role of breaching in the evolution of spits.

Although some of his arguments are questioned in a later review of the growth of spits by Kidson (1963), both authors provide good examples of breaching of spits over approximately the last 200 years.

Heyworth and Kidson (1982) suggest it is feasible that storm surges produced transgressive overlaps in the past. These authors also discuss the possible influence of longer term cycles of maximum spring tides which recur approximately every 1600 years. One cycle occurred around 4,800 B.P. (well before the formation of the Willingdon Peat) and, by extrapolation, the next cycle - at circa 3,200 B.P. - would have coincided with the end of organic deposition on Willingdon Levels and the return of estuarine conditions. If this latter period of above average spring tides coincided with a period of storms then the consequence to low-lying areas of coastline, such as Willingdon Levels, may have been catastrophic.

3). Variations in the quantity of sediment supplied to the coast. This factor has already been mentioned above in connection with the coast of Holland. The maintenance of coastal barriers would be adversely affected under a regime of variable sediment supply. During periods of lower sediment input the barriers would become weaker and this may have been a contributory cause for the return of estuarine conditions on Willingdon Levels. The possible existence of periods during which variations occurred in the quantity of sediment supplied to the East Sussex coast during the Flandrian is discussed later in this section.

4) Isostatic movements. A period of subsidence to the coastline may also serve as an explanation for the return of estuarine conditions. However, the extent and even direction of more recent land movements in south east England has been the subject of much debate. Flemming (1982) has suggested that during the Flandrian coastal areas of Sussex and Kent have been subjected to uplift

while Kelsey (1972) has not detected any subsidence this century throughout the south east. However, the concensus view is in support for subsidence but the rate of this movement is open to question. Valentin's (1953) and Churchill's (1965) results have been criticised for example by Rossiter (1972), who used data from tidal guages, and by Kidson (1968). No evidence has been presented for a sudden subsidence of the Sussex coast around 3,400 years ago. However, this possibility cannot be dismissed and it should be remembered that the Channel has suffered earth tremors this century. Also of note is a small fault located in the north east section of Willingdon Levels. Features of this size could have resulted in local subsidence in the past. For example, in the Seine estuary Huault et al. (1975) explain a 4m. difference in the level of two Flandrian peats of the same age as being the result of tectonic movements.

5) Anthropogenic factors. Widespread forest clearance from the Bronze Age may have resulted in slope wash and an increase in the discharge and the load carried by rivers. For a valley situation, Smyth (1985) has suggested that such a modification to the load and discharge of the Combe Haven may have been partly responsible for the most recent phase of minerogenic sedimentation. Furthermore, the increased discharge may have widened the mouth of the Combe Haven and thereby allowed a marine incursion into the down stream tract of the valley. Although such a proposition is tentative, Smyth points to the apparent coincidence of a major reduction of A.P. just prior to the formation of the upper minerogenic layer.

Around Willingdon Levels the major episode of forest clearance occurs within the Upper Clay, although earlier, smaller reductions of the A.P. are present within the Willingdon Peat. Although it is perhaps difficult to envisage slope wash as the source of the sediments that compose the Upper Clay on the wider expanse of Levels, as compared to the narrower, enclosed valley situation of

the Combe Haven, nevertheless anthropogenic activity cannot be ignored and may be at least another contributory factor to the return of minerogenic sediments on Willingdon Levels.

In summary, the cause of the lithostratigraphic transgressive overlap on Willingdon Levels dated to 3,390 ± 40 B.P. is uncertain, but is likely to have been the result of a combination of the factors outlined above. However, it is difficult to envisage relative movements of sea-level as the cause, for the reasons given, although local isostatic subsidence cannot be ruled out. The over-running of coastal barriers under conditions of reduced sediment supply corresponding with maximal spring tides and possibly storms must be given at least as much consideration as eustatic and isotatic factors.

The cause of the biostratigraphic regressive overlap.

The biostratigraphic regressive overlap within the Upper Clay at +2.25m. O.D. at Lottbridge A is probably the consequence of sediment accumulation behind the growth of the Crumbles Shingle that fronts Willingdon Levels. The initial development of the shingle is difficult to date, as discussed previously. However, by the use of documentary evidence, it appears that the Crumbles Shingle was largely in place by the 13th century and Langney Point by the 16th century. As this barrier developed so conditions on the Levels changed from estuarine to freshwater, thereby creating this regressive overlap.

A similar situation is proposed by Coles and Funnell (1981) to explain the widespread withdrawal of estuarine conditions in the Broadland at circa 1,500 B.P.. Here the growth of a coastal spit is considered to be one possibility for a decrease of the tidal range and an evacuation of the sea from the area.

The final sealing off of the sea from Willingdon Levels had probably occurred by the 15th century when the harbour at Pevensey

and a lagoon behind the Crumbles had silted up (Dulley, 1966). For at least two centuries preceeding this, much of the Levels was already reclaimed for agriculture, with a link between Hydneye, a minor harbour on the Levels, and the sea being maintained by a channel that ran through the Levels.

E 2.4. Flandrian sedimentation in coastal areas of East Sussex.

From published data (for example Green, 1968; Jones, 1981; Smyth, 1985), borehole records and from this work, it is clear that many parts of the East Sussex coast have been the centres for a massive influx of sediment during the Flandrian. At Langney Point approximately 33m. of sediment has accumulated with similar depths being recorded at Newhaven (Jones, 1981) and Dungeness (Green, 1968), while at the entrance to the Combe Haven circa 20m. has been deposited. This accumulation of sediment has resulted in the infilling of buried channels, the positions of which are shown by Auffret et al. (1980), and ultimately, with the creation of spits and barriers, a straightening of a previously indented coastline.

Initially clays and silts were deposited then sand with perhaps a small quantity of shingle and finally the main body of shingle. This 'coarsening upwards' of the sedimentary sequence, which is well illustrated by the lithostratigraphy at Langney Point (Section B), is probably related to a general increase in the energy of the coastal system. The estuarine facies of the lithostratigraphy are considered to be the consequence of the development of bars, spits and barriers which also produced significant changes to the shape of the coastline. This has been demonstrated for the Dungeness area (Lewis, 1932; Lewis and Balchin, 1940; Green, 1968; Cunliffe, 1980; Eddison 1983a, b) and at Eastbourne (this work), but it awaits further investigation before it can be confirmed that this pattern of events has also occurred at other sites along the East Sussex coastline.

At Eastbourne, the development of these depositional features has probably occurred throughout the Flandrian. As previously argued, at Langney Point the Crumbles Peat may owe its existence to an early Flandrian sand bar and dune system, while the Willingdon Peat probably developed behind sand or shingle barriers that were the ancestors of the present Crumbles Shingle. The peats on Pett Levels and Romney Marsh are probably also the product of protection behind coastal barriers (Green, 1968; Shephard-Thorn, pers. comm.) and bear witness to the initial stages of the formation of Dungeness. The earliest spits and barriers here possibly date to before 5,500 B.P. (Eddison, 1983a, b).

In the recent history of this coastline there is sound documentary evidence for the silting-up, usually behind drifting shingle, of south coast harbours. This had begun by the 14th century and was an episode of sedimentation that resulted in the abandonment of most of the Cinque Ports by the 17th century (Redman, 1851-2; Salzman, 1910; Ward, 1920; Dulley, 1966; Millward and Robinson, 1973).

The above discussion serves to illustrate that the coast of East Sussex may have been influenced by distinct phases of extra sediment influx which produced the more stable versions of coastal spits and barriers. No doubt any stabilisation from the mid-Flandrian was also helped by a slower rate of sea-level rise.

The source of this sediment can be divided into two types; cliff and beach erosion, and offshore. Although Redman (1851-2) presents evidence for the erosion of chalk cliffs as being the chief source of shingle, it is difficult to envisage how Flandrian cliff erosion, currently in the order of between 0.42m./year to 0.91m./year for the exposed Sussex chalk (May, 1971) with an average annual rate of retreat of 1.06m. at Beachy Head* (Thorburn

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*Note: In an engineering report by Lewis and Duvivier (1968) a lower average figure of 1' to 2' per year is given for the erosion of chalk cliffs near Eastbourne over the last century.

in Robinson and Williams, 1983b), can account for the quantity of shingle that has accumulated at the Crumbles and at Dungeness, and it may well be that the growth of these shingle features is the result of extra sediment influx from offshore. In favourable localities, such as down-drift of headlands and at the entrance to rivers and other natural inlets, the extra sediment, in this case shingle, was able to collect. The inception of Dungeness as a spit building progressively eastwards from the cliffs at Fairlight has been proposed by many authors (Lewis, 1932; Lewis and Balchin, 1940; Green, 1968; Eddison, 1983a), and Milner and Bull (1925) envisaged a similar process for the formation of the Crumbles building eastwards from Beachy Head. As discussed in this work, the 'islands' of Gault at the entrance to Willingdon Levels may have acted as catalysts to this development.

Although today the floor of the Channel is surprisingly 'clean' (Jones, 1981) it is likely in the past to have been littered with sediments deposited during the low sea-levels of the Devensian and Lateglacial. These sediments were then re-worked by the rising sea-levels of the Flandrian, supplementing material derived from fresh erosion. In the eastern section of the Channel large banks of shingle, largely composed of flint worked from the chalk of the Weald, were probably progressively moved shorewards. Eventually these banks came ashore and, under the influence of longshore drift, created the shingle complexes at the Crumbles and Dungeness. Such a pattern of movement of offshore banks has been demonstrated by Robinson and Cloet (1953) in their discussion of the blocking of the Wanstum Channel that resulted in the connection of the Isle of Thanet to the Kent mainland, and by Carr and Blackley (1973) for the origin of Chesil Beach. Morey (1983) has argued for the progressive shoreward movement of the shingle at Slapton in Devon, while on the east coast, Orford Ness may have initially developed further seaward of its present position (Carr and Baker, 1968). Although it is uncertain whether this feature is currently being fed shingle from offshore (Carr and Baker,

1968), a system of sediment transfer from offshore banks and onto shorebound 'ness' features along the coast of East Anglia has been identified by Robinson (1966). Similarly, on the south coast the shingle that composes Hurst Castle spit may originate from offshore banks* as well as by longshore drift (Jones, 1981), and Robinson (1955) points to offshore sources of sediment for the spits found at the entrance to Poole, Christchurch and Pagham harbours.

In a study of coastal barrier development in Holland, van Straaten (1965) proposes a model of coastal evolution, based on lithostratigraphic and biostratigraphic evidence, which involves the landward migration of sand barriers, resulting in episodes of rapid coastal accretion. Importantly, van Straaten considers the offshore zone to have been an important source of sediment. He further argues that under conditions of more rapidly rising sea-level the offshore zone maintains a gentle angle because sediment is not so easily transported shorewards. However, when the rise in sea-level slows down the offshore sediments can then reach the shoreline. Then, erosion of the offshore zone occurs due to shoreward transport of sediment which results in a deepening of the offshore zone and concurrent coastal accretion.

Thus, a possible explanation for the large accumulations of shingle at the Crumbles and at Dungeness is for a system of sediment transfer from offshore. Both features may have originally formed due to the shoreward movement of entire shingle banks that became 'beached' against earlier sand banks in areas where coastal configuration was conducive to sediment accumulation. Additionally these structures may have been supplied shingle by a system of sediment transfer similar to that found today in East Anglia (Robinson, 1966). At the Crumbles,

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*Note: Nicholls (pers. comm.) believes this to be minimal.

this system no longer operates because the adjacent sea bed is now clear of shingle with no movement from offshore (report by Lewis and Duvivier, 1968). The Crumbles may therefore be a relict feature which has lost its source of offshore sediment. Its present location marks the area where the transference of offshore shingle to the coast has been completed. Erosion now occurs, indicating that material drifted from Beachy Head is not sufficient to maintain a structure as large as the Crumbles.

This situation is analagous to that described by van Straaten (1965) for a sandy coast. He states:

> "Where accumulation of sand derived from the sea bottom leads to accretion of the shore, the subaqueous profile gradually steepens, both by the deposition on its higher parts and by erosion of its lower parts. The accumulative effects then become more and more counteracted by the (indirect) effects of gravity, and eventually the transverse supply of sand to the shore stops altogether". (Page 73).

One other theory for the formation of the Crumbles and Langney Point that deserves consideration is for the shingle now at Eastbourne to have originally come from the beach at Brighton that was destroyed in the early 18th century (Redman, 1851-2; Steers, 1964). Although this date corresponds with some cartographic evidence that suggests much of the Crumbles together with Langney Point is largely an 18th century development, as discussed by Steers (1964), the documentary and cartographic evidence examined in this work indicates the formation of the Crumbles and Langney Point probably pre-dated the removal of Brighton beach. Therefore, other than providing some extra shingle, the theory cannot be substantiated.

If the Sussex coast has been subjected to temporal variations in sediment supply, an appraisal of the sedimentological history of the Eastourne area indicates three periods of maximum influx:

Circa 9,500 - circa 8,770 B.P. - growth of sand-based features at Langney Point.

Circa 3,800 - circa 3,300 B.P. - development of the Willingdon Peat behind barriers of sand and possibly shingle. This period may have begun earlier along other sections of the East Sussex coast, for example in the valleys of the Ouse and Combe Haven.

Circa 700 - circa 300 B.P. - further growth of the Crumbles with the development of Langney Point and the silting up of the East Sussex harbours behind drifting shingle.

These periods may have been separated by episodes of more minor accretion or even erosion in the low-lying coastal areas. Erosion of the Crumbles Shingle is known to exist today at Langney Point (Steers, 1964) a process which, from cartographic evidence, began in the 18th century (Redman, 1851-2; Milner and Bull, 1925; Steers, 1964). Further east, the power stations at Dungeness require beach filling updrift for their protection due to erosion of the shingle (Eddison, 1983a).

The recognition of alternating episodes of more major and minor accretion and of erosion has important implications for planning in low-lying coastal areas. The siting of the Dungeness power stations illustrates the need to study palaeocoastal processes and to take planning decisions in the light of such studies. Some areas of coastline which appear today to be stable are in fact ephemeral and are likely to undergo significant change in the future, thereby requiring expensive coastal defence works.

These periods of maximum sediment influx at Eastbourne have therefore had a great influence upon the pattern of coastal sedimentation and, in the late Flandrian, upon the use of the coastal zone by man. The formation of the Crumbles Peat and the

early episodes of estuarine conditions at Langney Point probably owe their existence to the first episode of sediment influx. Later, the Willingdon Peat and then the freshwater facies of the Upper Clay were probably the consequence of the development of the Crumbles, although no direct stratigraphic link between the peat and the shingle has been identified. It may be that the Willingdon Peat formed behind earlier sand banks with only a limited amount of shingle being present at that time. This represents the second period of maximum influx and is likely to have been influenced by a diminished rate of sea-level rise.

By the 13th century, shingle stretched as far as Pevensey producing freshwater conditions over much of Willingdon Levels which, as a consequence, were enabled to be used for agriculture. The development of the Crumbles afforded protection to this area against the storms of the Medieval period which produced flooding by the sea over large areas of Pevensey Levels (Salzman, 1910; Dulley, 1966; Brandon, 1972a) but apparently had little affect on Willingdon Levels. Finally, the Crumbles Shingle also modified the drainage network on the levels by cutting off the connection from the Cinque port of Hydneye to the sea and by deflecting the streams eastward. The lithostratigraphic investigations of Willingdon Levels carried out for this work support documentary evidence of drainage deflection by the Crumbles. Figure B3 illustrates the lithostratigraphy of the long-profile and shows the bedrock between St. Anthony's Hill and Langney, where the streams currently flow, to be surprisingly close to the surface. However, just to the west of St. Anthony's Hill bedrock was not encountered and the coarser textured sediments found here suggest this to have been the original estuary. This confirms documentary evidence which records the deflection of streams from the west and to the east of St. Anthony's Hill (Salzman, 1910).

This recent deflection east of the mouths of the East Sussex rivers due to the growth of shingle is well documented and appears

to be common to all the rivers. The River Ouse (Brandon, 1972b), Pevensey Haven (Salzman, 1910; Dulley, 1966) and the streams at Hastings (Ward, 1920) were affected in this manner. The relationship between the mouth of the Rother and the development of Dungeness is examined by Green (1968), Cunliffe (1980) and Eddison (1983a). Redman (1851-2) records this process along the length of coastline from Kent through to Sussex. It is this episode which represents the third of the three proposed influxes of sediment.

SECTION F. CONCLUSIONS.

The development of the study area during the late-Quaternary has been shown to have been influenced by a number of factors which can be categorised as follows; climatic change, rising sea-levels, the development of coastal depositional features and anthropogenic activity.

During the Lateglacial and early Flandrian the major changes to the vegetation were largely the consequence of climatic change. This factor also instigated changes in sedimentation whereby Valley Gravels were replaced by freshwater, estuarine and/or marine deposits, the former being a response to a cooler climate, the latter being partly the result of glacio-eustatic events.

The rising sea-levels of the Flandrian, the availability of sediments and the configuration of the coastline combined to create the conditions suitable for the major sediment influx that has occurred in the area. With rising base-levels, the coastline initially retreated into an indented plan but, because of accretion, then became straightened and ultimately advanced.

Although the pattern of sedimentation suggests that no oscillations of sea-level took place, this may be the consequence of the rapid accumulation of sediments which has not recorded more subtle eustatic movements. Similarly, as argued in Section E, although there is no requirement for any relative movement of sea-level since circa. 3,800 B.P. in order to explain the formation of the Willingdon Peat and the Upper Clay, it is however recognised that a slow rise is probable as a consequence of the subsidence of south east England. Nevertheless, any rise that has occurred is believed to have had no discernible effect on sedimentation in the Eastbourne area over this period. Instead, it is suggested that the pattern of sedimentation, especially since circa. 3,800 B.P., is largely the response to the

development of bars, spits and barriers. Thus the hypothesis proposed by Redman (1851-2) and Milner and Bull (1925) whereby the accumulation of sediments on Willingdon Levels has been intimately linked to the creation and stability of the Crumbles is supported. However, it is further argued that this present day coastal barrier is the most recent manifestation of a process that had begun in the early Flandrian. In addition, it is proposed that the Upper Clay has also been influenced by anthropogenic activity, initially through the release of sediments by forest clearance, and then by land drainage and coastal protection. In this way the nature of this upper minerogenic unit owes as much to anthropogenic factors as it does to other environmental processes.

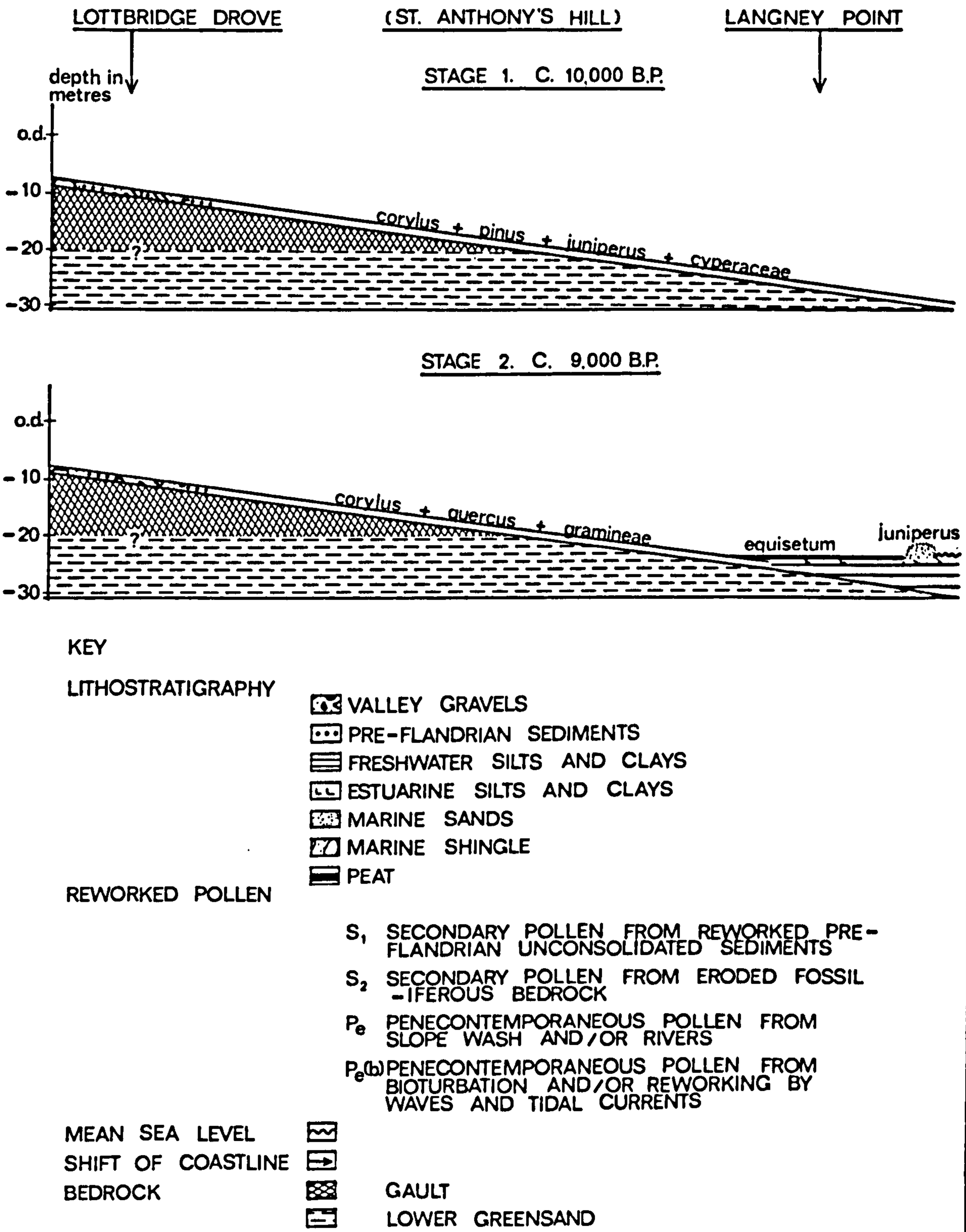
F 1. A model of landscape evolution for the Eastbourne area.

The above discussion is encapsulated in a model of landscape evolution for the Eastbourne area during the Flandrian. Both lithostratigraphic, biostratigraphic and chronostratigraphic information gathered during the course of this work is brought together in order to reconstruct the changing environments of the area. This model is depicted by figure F1.

Holocene sedimentation began at Langney Point with minerogenic deposits at the site of BH.1, but organic material was accumulating close by. On the model, the reconstruction for the Langney Point area relates specifically to the record obtained from BH.1 which is reflected in the depiction of the restricted occurrence of the Crumbles Peat in figure F1.

STAGE 1. Circa 10,000 B.P. Mean sea-level below -29m. O.D.
At Langney Point sedimentation began with organic deposits in low-lying swampy areas and minerogenic sediments along water courses. The pattern of sedimentation at Lottbridge Drove during this stage is uncertain. The Lateglacial Valley Gravels may have been influenced by the final phases of mass movement. This

FIGURE F1a. LATE-QUATERNARY EVOLUTION AT EASTBOURNE



probably soon came to an end with the development of a pine/hazel woodland throughout the region, although this development is not recorded in the biostratigraphy from Lottbridge Drove.

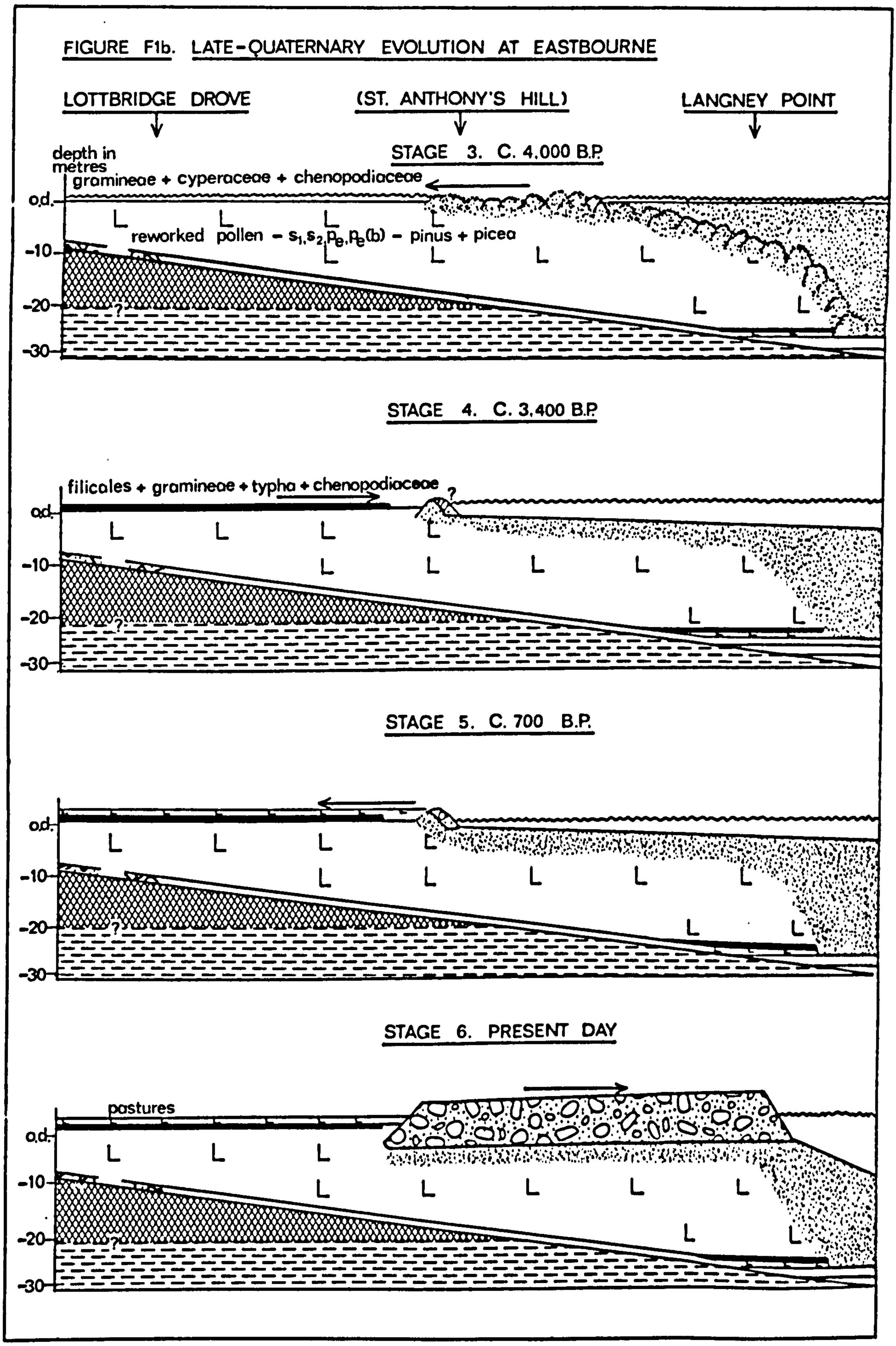
Local stands of juniper may have been common, as were freshwater habitats. However, during this stage the sea began to have an influence upon the environment at Langney Point. Freshwater courses became tidal inlets and a system of sand banks and dunes became established close to Langney Point (see Section C). It was onto these dunes that juniper was able to expand and along the tidal inlets a salt marsh community developed.

STAGE 2. Circa 9,000 B.P. Mean sea-level circa -25m. O.D.
At Langney Point the Crumbles Peat had become fully established, probably as a result of the blocking of the tidal inlets of Stage 1 by the developing sand banks and dunes. Juniper continued to colonise these dunes while *Equisetum* dominated the peat areas. The picture of sedimentation remains unclear at Lottbridge Drove.

During this stage oak and elm replaced pine, while hazel maintained its importance in the vegetation of the area.

STAGE 3. Circa 4,000 B.P.
It was during Stage 3 that the coastline reached its most landward extent, but it is not clear as to the height of mean sea-level. This is because the relationship between the sediments in the upper levels of the Lower Silty Clay and mean sea-level is uncertain, as explained in Section E. During this stage estuarine conditions prevailed at Lottbridge Drove while at Langney Point the seaward limit of estuarine conditions was determined by the position and extent of offshore sand banks. As well as moving landwards, these sand banks also migrated vertically as accretion continued in the coastal zone. Thus the sand banks may have produced a 'flight - of - stairs' pattern in the sedimentary sequence due to this migratory regime. This also resulted in the sudden coarsening of the sediments within the Upper Minerogenic

FIGURE F1b. LATE-QUATERNARY EVOLUTION AT EASTBOURNE



Sequence at Langney Point and the replacement of estuarine Foraminifera and Ostracoda by fully marine species. Behind these sand banks, finer grained sediments accumulated (the Lower Silty Clay) partly due to sediment transfer from offshore but also longshore drift probably carried material eastwards into this area. Re-working of pre-Flandrian sediments within Willingdon Levels was another important process and resulted in the release of secondary pollen. It is possible that such sediments formed a significant component of the material transported within the estuary. From the secondary pollen assemblage, it is tentatively suggested that this sediment is of Ipswichian or early Devensian interstadial age.

Early on in this phase, the estuarine sediments around Lottbridge Drove were not well colonised by vegetation. It may be significant that the major increase of Chenopodiaceae occurs towards the end of this stage which suggests that initially the sediments were low tidal-flat deposits that, probably through natural accretion as much as being a response to rising sea-levels, evolved later into a true salt marsh. Such a pattern of development, with additions of secondary pollen into the sediments, is discussed by Zagwijn (1965) for the coast near the Hague in the Netherlands.

This development of extensive estuarine sediments and offshore sand banks resulted in a shallow offshore zone.

STAGE 4. Circa 3,400 B.P. Mean sea-level circa O.D.
The formation of the Willingdon Peat marks the first major shift of the coastline seawards. On Willingdon Levels a largely freshwater, organic deposit formed that was colonised by Filicales, Gramineae and *Typha* sp., while along localised estuarine channels Chenopodiaceae were important. It is proposed that this stage does not register a fall in relative sea-level but instead marks the establishment of extensive spits and barriers which developed close to, and probably from, St. Anthony's Hill and the other 'island' of Gault. These depositional features were probably mostly composed of sand but it is possible that some shingle may

have been added to them. During this stage the rate of sea-level rise was slow resulting in significant sediment transfer from offshore and the development of stable depositional features.

The streams on Willingdon Levels entered the sea to the west of St. Anthony's Hill. The slopes surrounding the Levels supported a 'Mixed-Oak Forest' that contained some cleared areas.

STAGE 5. Circa 700 B.P. Mean sea-level circa O.D.
This stage marks a second phase of coastal advancement as estuarine conditions once more became established on Willingdon Levels with the deposition of the Upper Clay. A diminution of the sediment supply possibly corresponding with a period of maximum spring tides and storms may have been the cause of this marine incursion. The altitude of the Willingdon Peat falls within the present day tidal range which suggests that no significant movement of relative sea-level took place during the period of Upper Clay formation.

On the slopes surrounding Willingdon Levels more extensive forest clearance took place, a process that may have contributed material to the sediments that formed the Upper Clay.

By the end of this stage shingle had begun to accumulate into spits attached to the 'islands' of Gault and possibly to Beachy Head.

STAGE 6. The present day.
The shingle spits of Stage 5 rapidly developed into an extensive barrier. This resulted in a major episode of coastal accretion with the coastline once more shifting seawards as the Crumbles Shingle became established and Langney Point formed. The source of this shingle may have been mostly offshore with important additions brought along the coast by longshore drift. The effect on the Levels was to bring about a change to freshwater conditions, a process taken advantage of by man through the extension of agriculture down onto the Levels. The 'lost' village and port of Hydneye was abandoned by the sea and, at the same

time, the drainage network was deflected east by the growth of the shingle so that a new outlet to the sea became established to the east of St. Anthony's Hill.

The Crumbles protected Willingdon Levels from the storms of the Medieval Period, a protection now strengthened by the construction of sea defence works and sluice gates. The requirement for sea defences is the result of erosion along the west side of Langney Point. This itself may be the consequence of coastal adjustment to the termination of offshore supplies of sediment with a corresponding deepening of the offshore zone (cf. van Straaten, 1965).

F 2. Final considerations.

The probable dominance of local factors renders the applicability of the above model to other areas tentative. However, it is suggested that all low-lying coastal areas of East Sussex may have been influenced by similar processes (Jennings and Smyth, 1982). Thus, the hypothesis is advanced whereby coastal sedimentation in East Sussex is believed to have been principally the result of the establishment, stabilisation and over-running of bars, spits and barriers rather than being the consequence of variable movements of relative sea-level. Although rising base-levels encouraged accumulation of sediments, the various facies reflect the changing environments associated with coastal barriers.

However, a number of problems are still to be resolved. In particular the precise location of the coastal barriers through the Flandrian is not known. Indeed, reworking prior to burial may have made this task impossible. Furthermore, the processes involved in the formation of the Upper Clay are imprecisely understood. The hypothesis proposed in this study of barrier over-running due to reduced sediment supply, higher than normal spring tides and storms requires further testing.

This examination of palaeoenvironmental change at Eastbourne, although essentially a local study, has nonetheless suggested that the pattern of

coastal sedimentation in East Sussex is probably more complex than previously stated. The 'Tripartite Sequence' of Jones (1981), although a convenient generalised description of these sediments, disguises significant inter- and intra-site variations. This study has attempted to identify and explain the cause of these variations.

It is hoped that this study will be seen as a useful beginning in the reconstruction of the palaeoenvironments and their associated processes that have helped determine the present day landscape of coastal East Sussex. This research work, with that currently being carried out in the Combe Haven, is considered to be valuable for two reasons. First, the comparison of vegetational and sea-level/coastal changes in East Sussex with other regions is not possible until detailed research of this nature has been undertaken. Secondly, studies of palaeoenvironmental changes in present day coastal areas may reveal important trends and events that could have significant implications for planning. This is particularly important in low-lying areas liable to flooding and susceptible to changes in the coastline due to erosion and deposition.

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APPENDIX 1

Zoological nomenclature.

Mollusca.

Cerastoderma edule (Linne).
Hydrobia ventrosa (montagu).
Scrobicularia plana (da Costa).
Hydrobia ulvae (Pennant).
Ostrea edulis (Linne)

Foraminifera.

Ammonia beccarii (Linne).
Jadammina macrescens (Brady)
Trochammina inflata (Montagu).
Ammonia beccarii batavus hofker
Protelphidium germanicum (Ehrenberg)

Ostracoda.

Aurila convexa Brady.
Leptocythere castanea (Sars).
Loxoconcha elliptica (Brady).
Pontocythere elongata Brady.
Cyprideis torosa (Jones).
Leptocythere lacertosa (Hirschmann).
Loxoconcha rhomboidea Brady.

Figure B3. The Willingdon Levels Long-Profile

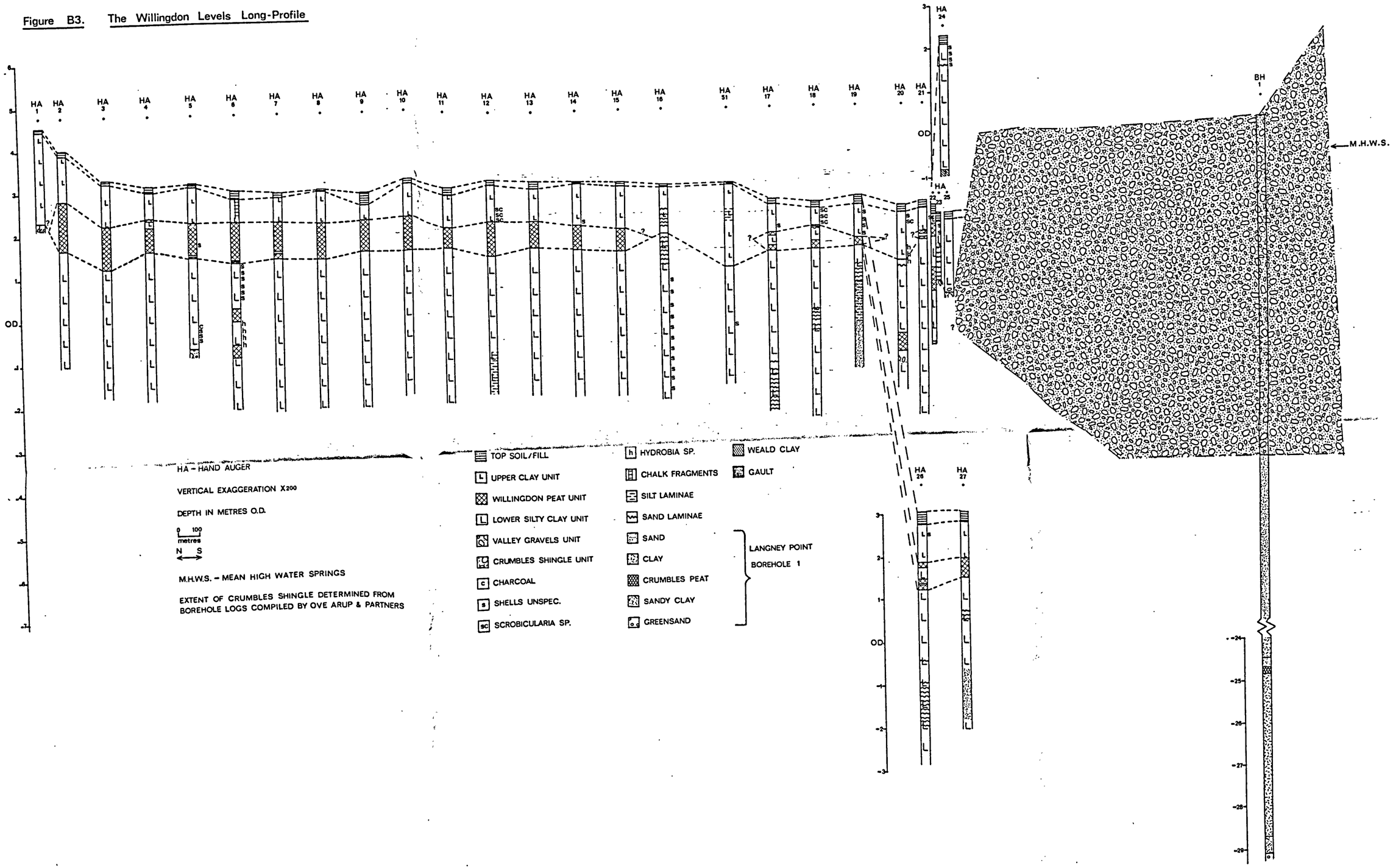
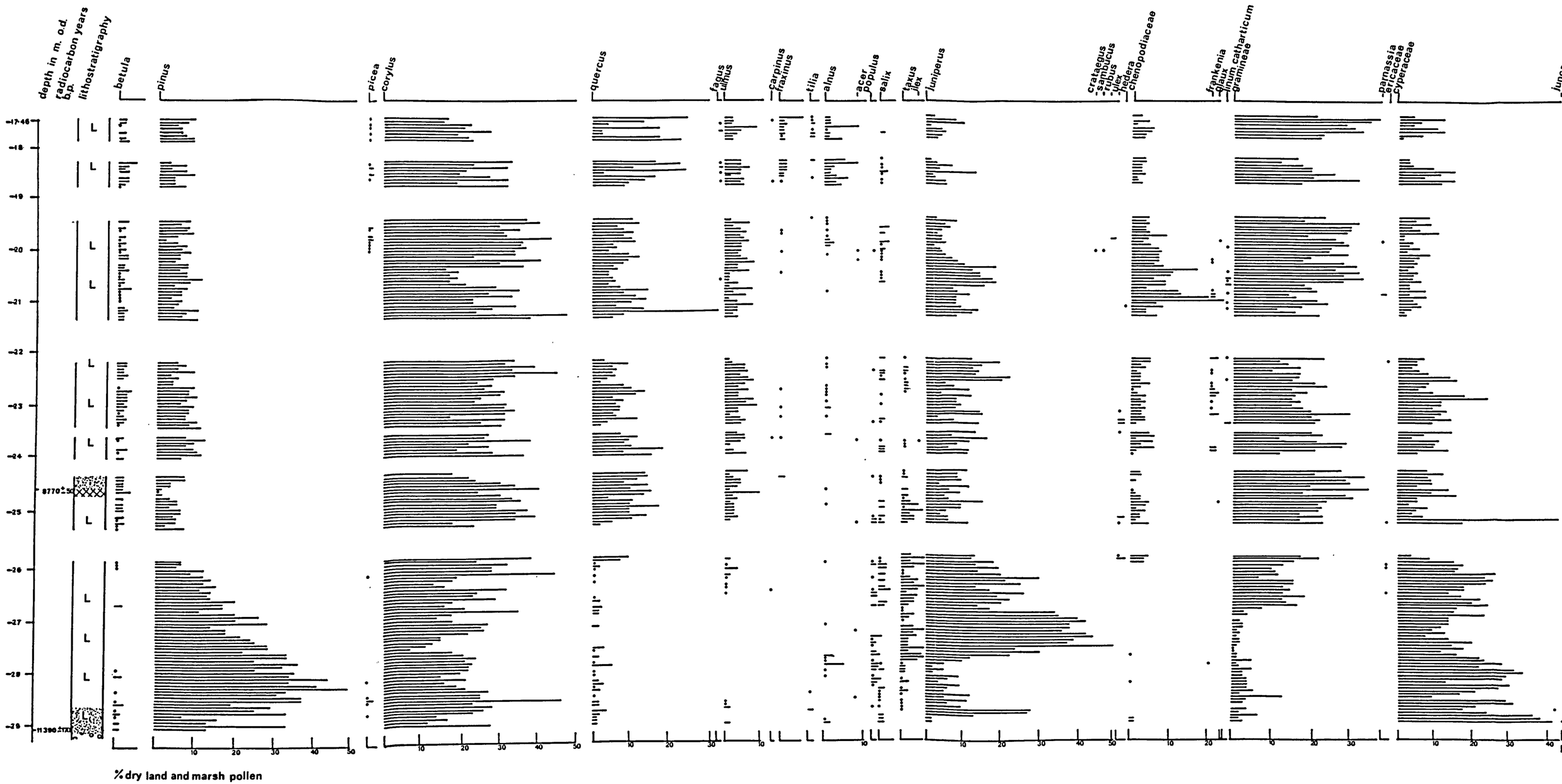


Figure C1a. Langney Point pollen diagram.

Arboreal, shrub and herbaceous pollen.



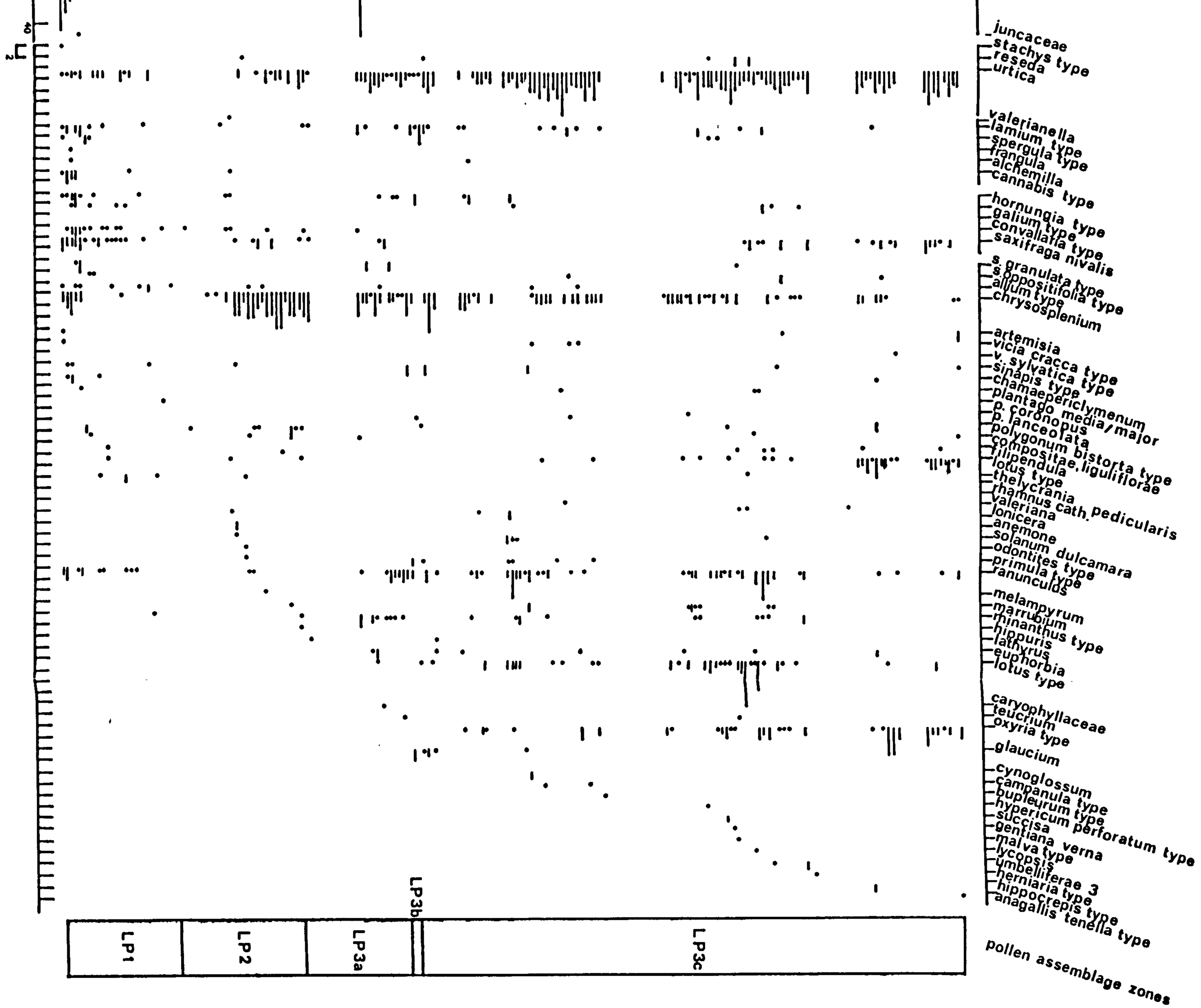
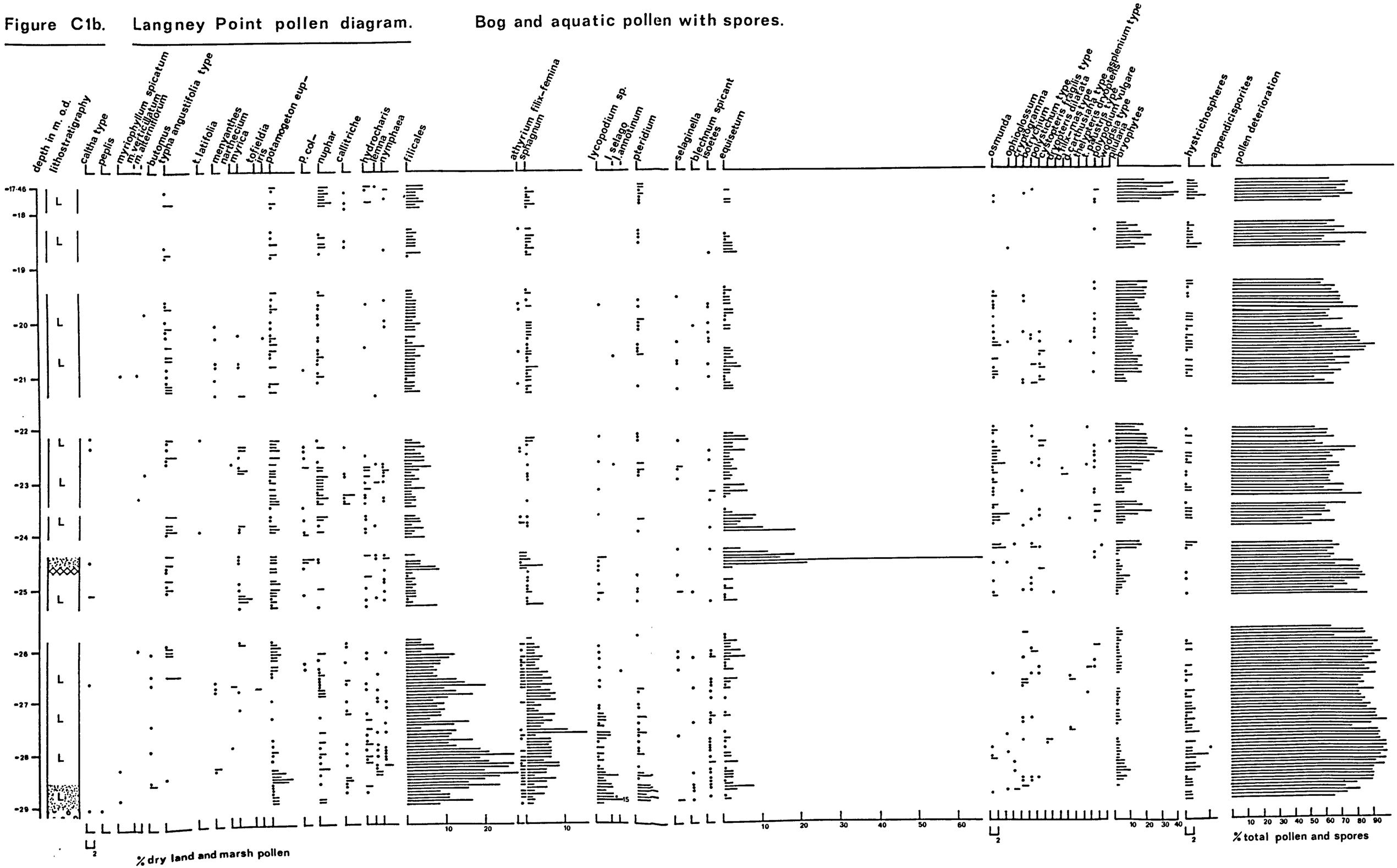
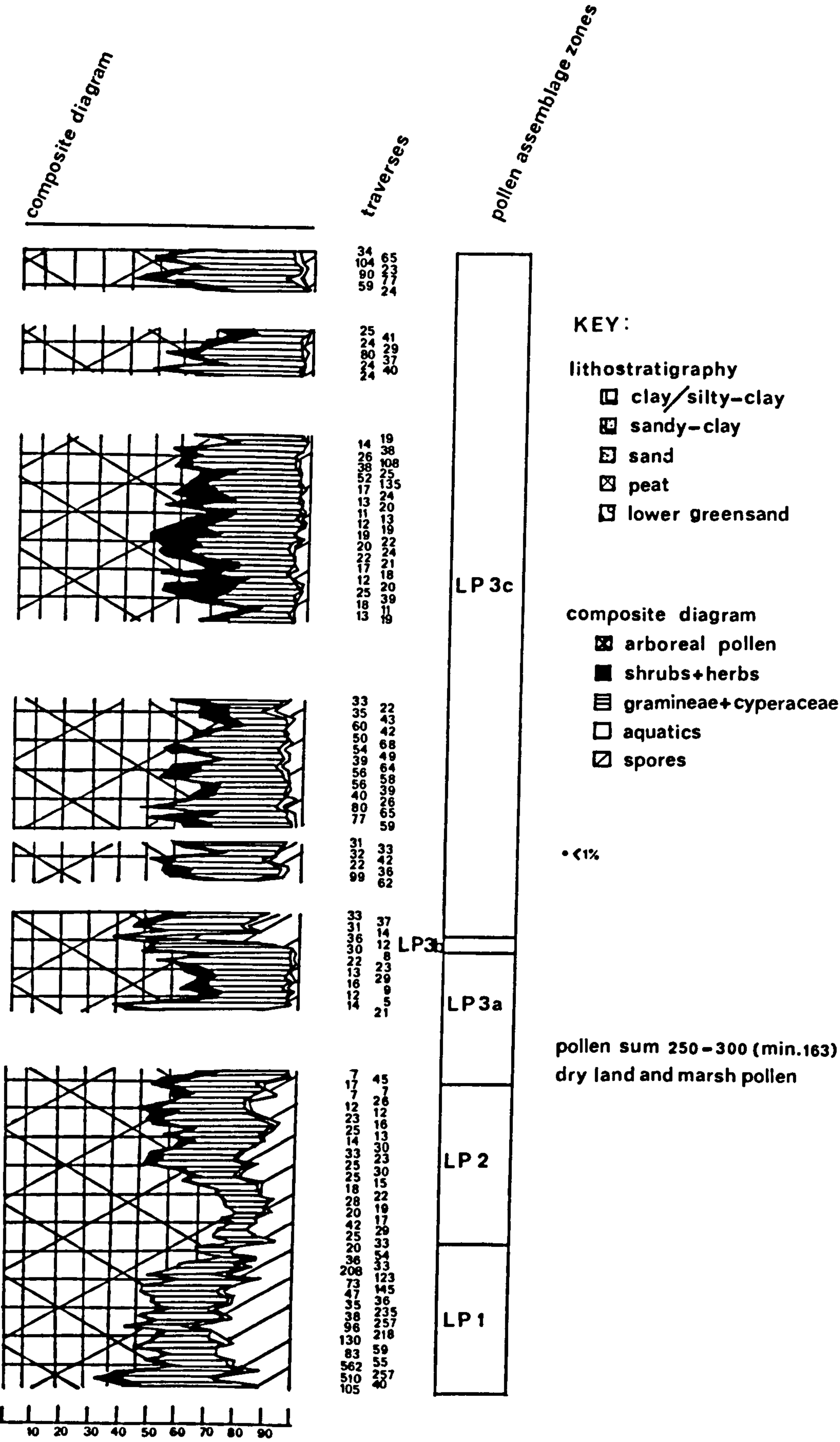
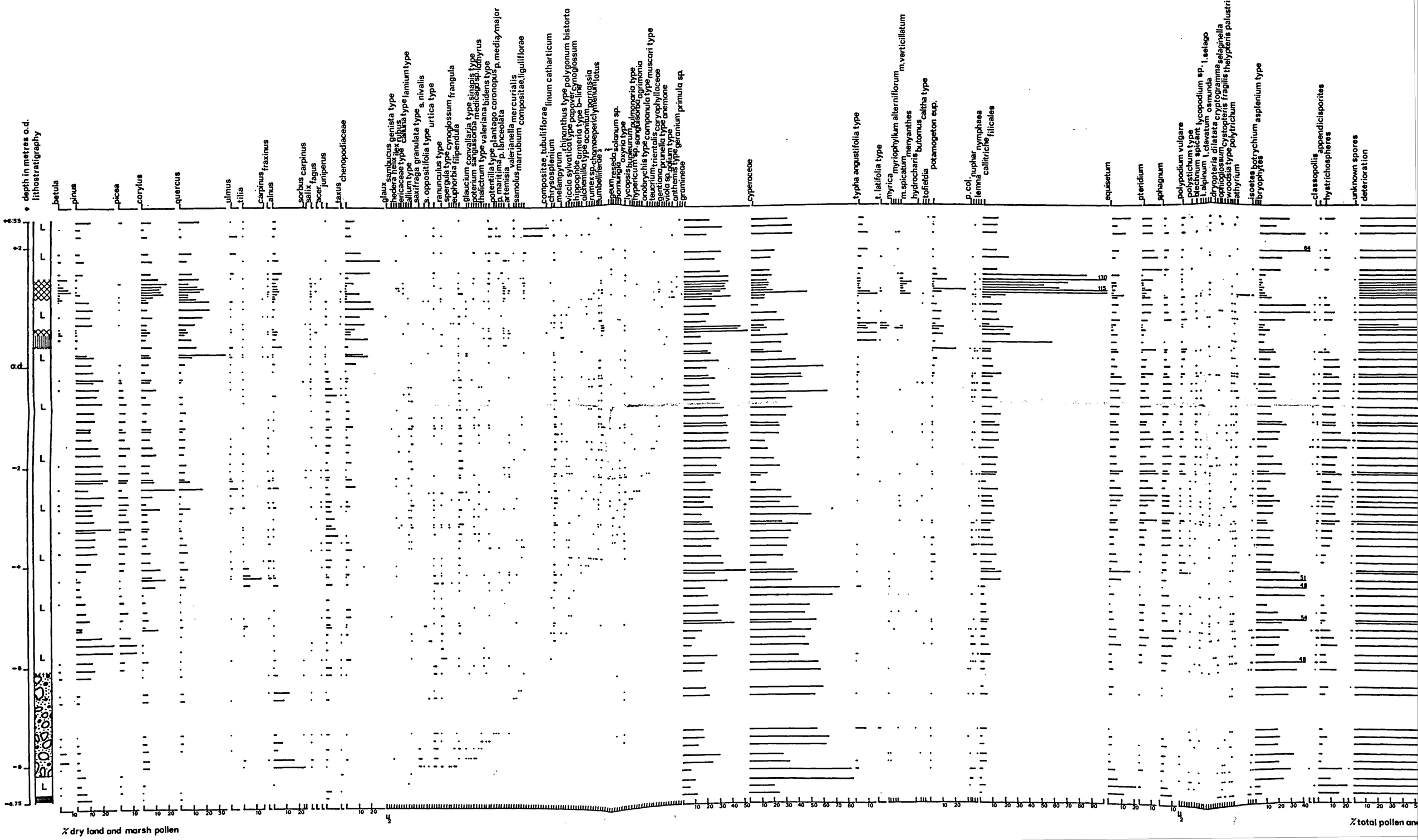

juncaceae
stachys type
reseda
urtica
valerianella
lamium type
spergula type
frangula
alchemilla
cannabis type
hornungia type
galium type
convallaria type
saxifraga nivalis
s. granulata type
s. oppositifolia type
allium type
chrysosplenium
artemisia
vicia cracca type
v. sylvatica type
sinapis type
chamaepericlymenum
plantago media/major
p. coronopus
p. lanceolata
polygonum bistorta type
compositae, liguliflorae
filipendula
lotus type
thelycrania
rhamnus cath.
pedicularis
valeriana
lonicera
anemone
solanum dulcamara
odontites type
primula type
ranunculus
melampyrum
marrubium
rhinanthus type
hippuris
lathyrus
euphorbia
lotus type
caryophyllaceae
teucrium
oxyria type
glaucium
cynoglossum
campanula type
bupleurum type
hypericum perforatum type
succisa
gentiana verna
malva type
lycopsis
umbelliferae 3
herniaria type
hippocrepis type
anagallis tenella type
LP1
LP2
LP3a
LP3b
LP3c
pollen assemblage zones

Figure C1b. Langney Point pollen diagram. Bog and aquatic pollen with spores.




composite diagram
traverses
pollen assemblage zones
LP 3c
LP3b
LP3a
LP 2
LP 1
10 20 30 40 50 60 70 80 90
KEY:
lithostratigraphy
clay/silty-clay
sandy-clay
sand
peat
lower greensand
composite diagram
arboreal pollen
shrubs+herbs
gramineae+cyperaceae
aquatics
spores
• <1%
pollen sum 250-300 (min.163)
dry land and marsh pollen


depth in metres o.d.
lithostratigraphy
betula
pinus
picea
corylus
quercus
ulmus
tilia
carpinus
alnus
fraxinus
sorbus
carpinus
salix
fagus
acer
juniperus
taxus
chenopodiaceae
glaux
sambucus
genista type
hedera helix
ilex
ericaceae type
cuscuta
allium type
lamium type
saxifraga granulata type
s. nivalis
s. oppositifolia type
urtica type
ranunculus type
spergula type
cynoglossum
frangula
euphorbia filipendula
glaucium corniculatum type
sinapis type
poterium sanguisorba
medicago
sp. lathyrus
halictrum type
valeriana
bidens type
potentilla type
plantago coronopus
p. media/major
p. maritima
p. lanceolata
artemisia
valerianella
mercurialis
samolus
marrubium
compositae, tubuliflorae
compositae, liguliflorae
linum catharticum
chrysosplenium
melampyrum
viccia sylvatica type
thinanthus type
polygonum bistorta
hippophaë rhamnoides
armeria type
b-line
cypoglossum
aconitum type
parnassia
cichorium
chamaepericlymenum
lotus
umbelliferae ?
rumex
rosa
solanum sp.
hornungia
oxyria
lycopsis
buglossum type
pulmonaria type
hypericum
sp. sanguisorba
agrimonia
onobrychis type
campanula type
muscari type
teucrium
trientalis
caryophyllaceae
gentiana
prunella type
viola sp.
anemone
anthemis type
geranium
primula sp.
gramineae
cyperaceae
typha angustifolia type
t. latifolia type
myrica
myriophyllum alterniflorum
m. verticillatum
m. spicatum
menyanthes
hydrocharis
butomus
caltha type
fritillaria
potamogeton eup.
p. col.
nuphar
nymphaea
lemna
callitriche
filicales
equisetum
pteridium
sphagnum
polypodium vulgare
polystichum type
blechnum spicant
lycopodium sp.
l. selago
l. alpinum
l. clavatum
osmunda
dryopteris dilatata
cryptogramma
selaginella
ophioglossum
cystopteris fragilis
thelypteris palustris
woodsia type
polytrichum
athyrium
isoetes
botrychium
asplenium type
bryophytes
classopollis
appendicisporites
hystrichospheres
unknown spores
deterioration
% dry land and marsh pollen
% total pollen and

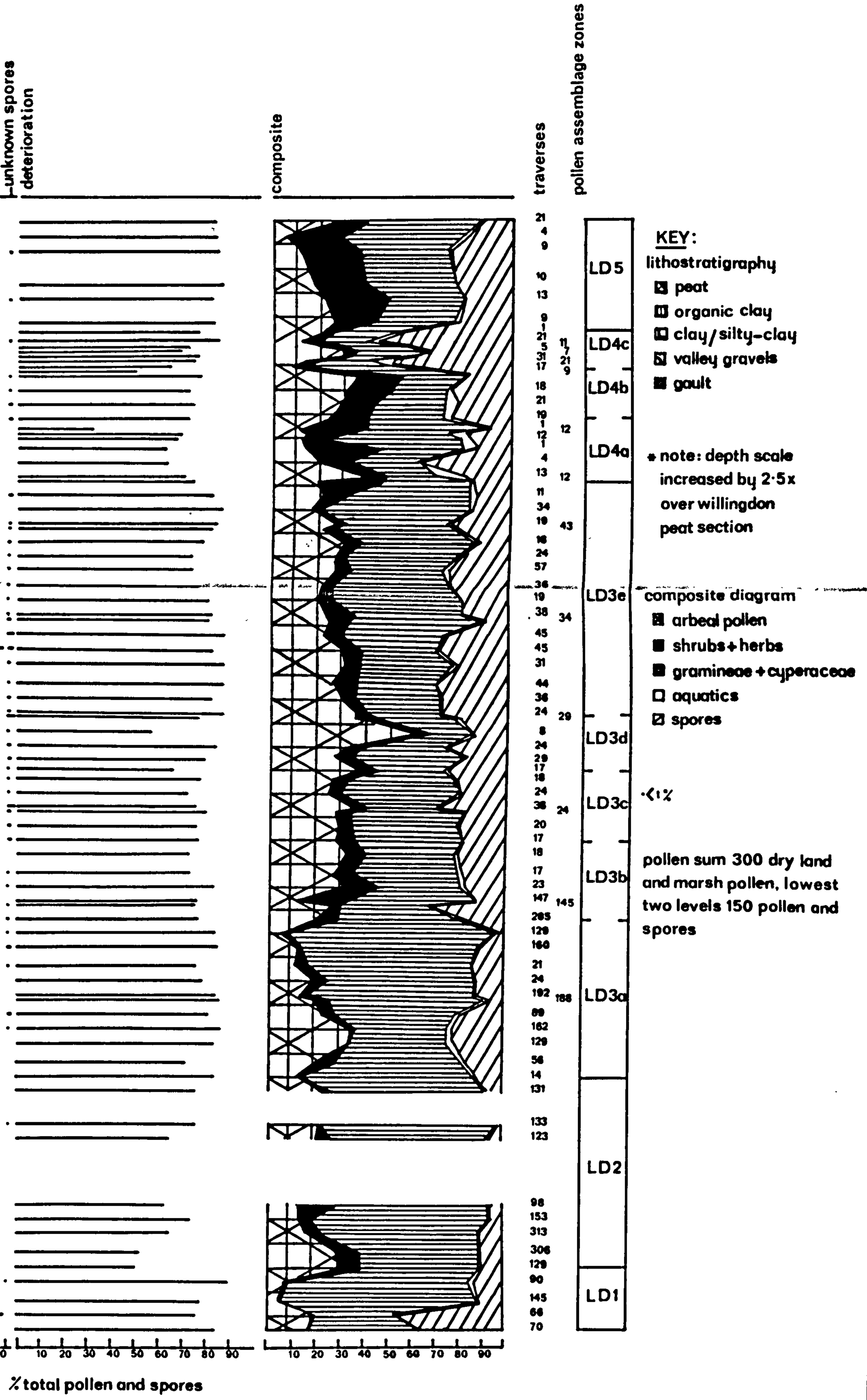
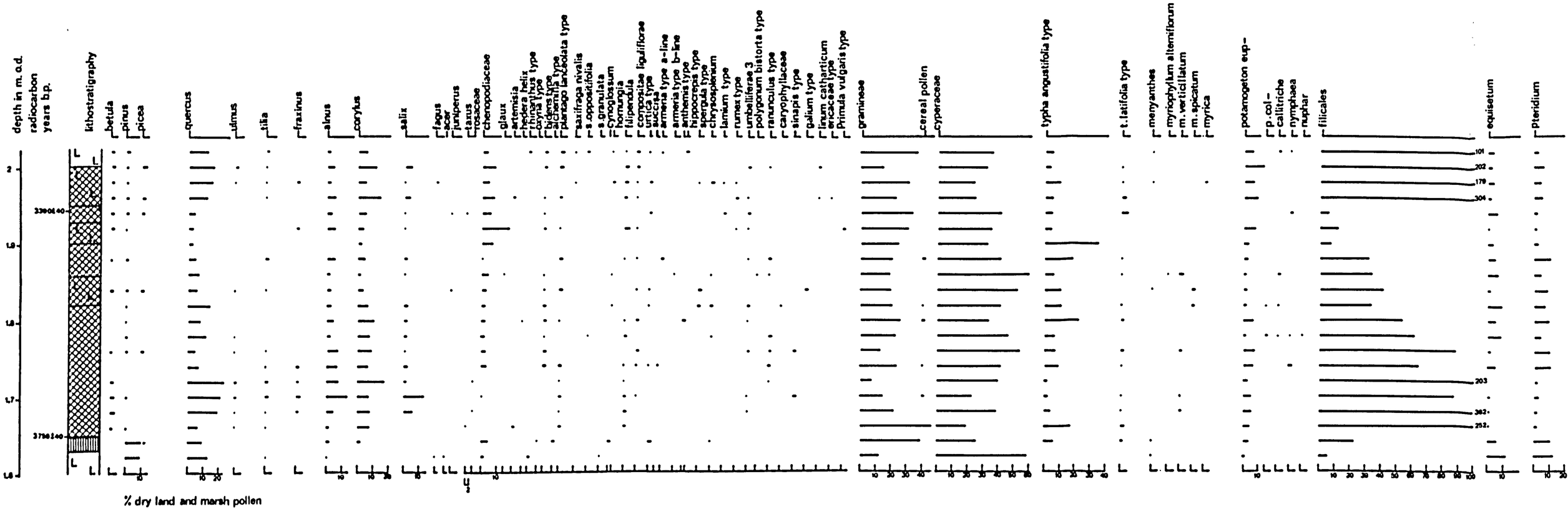

unknown spores
deterioration
composite
traverses
pollen assemblage zones
LD5
LD4c
LD4b
LD4a
LD3e
LD3d
LD3c
LD3b
LD3a
LD2
LD1
KEY:
lithostratigraphy
peat
organic clay
clay/silty-clay
valley gravels
gault
* note: depth scale increased by 2·5x over willingdon peat section
composite diagram
arbeal pollen
shrubs + herbs
gramineae + cyperaceae
aquatics
spores
·<1%
pollen sum 300 dry land and marsh pollen, lowest two levels 150 pollen and spores
10 20 30 40 50 60 70 80 90
% total pollen and spores

FIGURE C3. LOTTBRIDGE B POLLEN DIAGRAM.



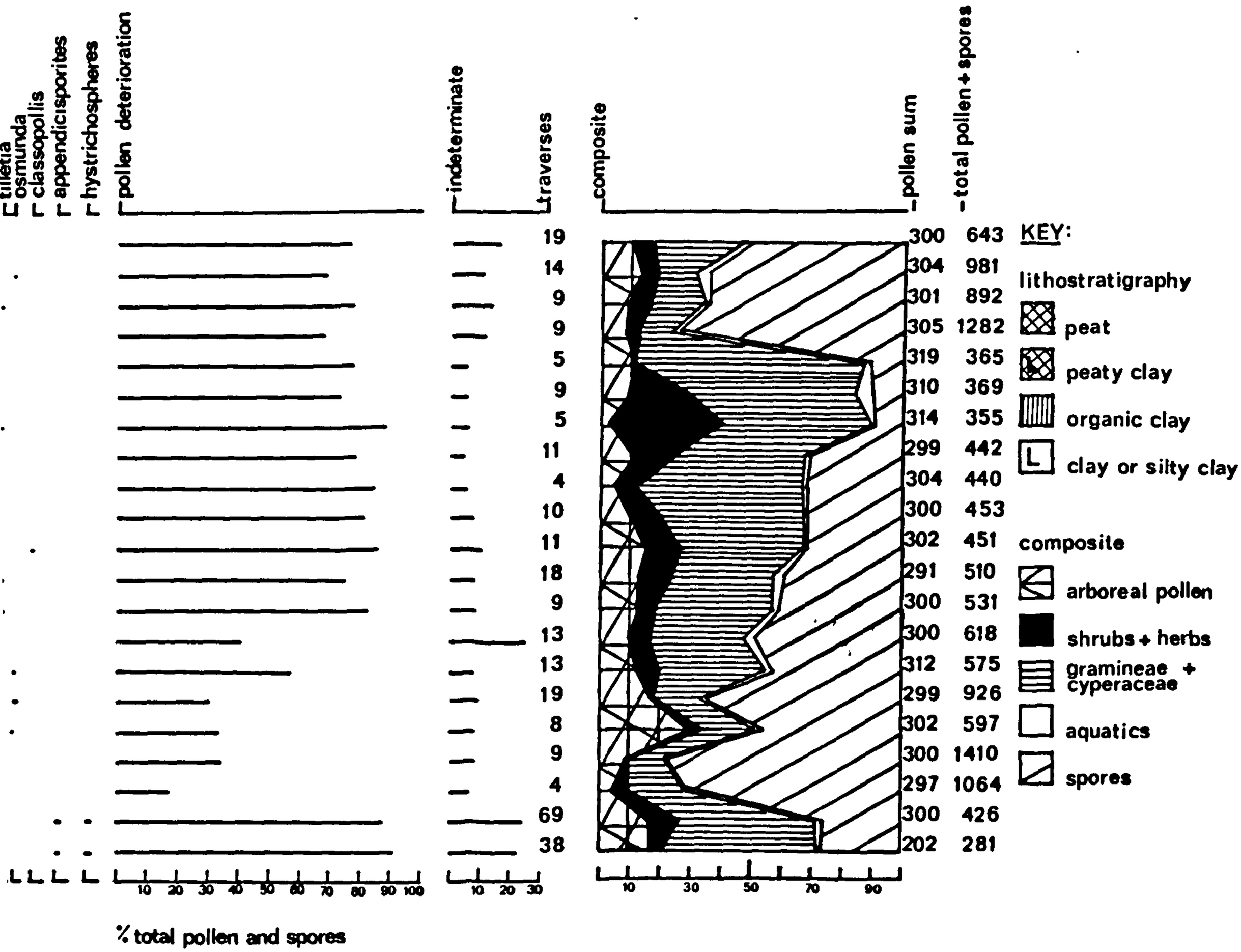

tilletia
osmunda
classopollis
appendicisporites
hystrichospheres
pollen deterioration
indeterminate
traverses
composite
pollen sum
total pollen + spores
19 14 9 9 5 9 5 11 4 10 11 18 9 13 13 19 8 9 4 69 38
300 643
304 981
301 892
305 1282
319 365
310 369
314 355
299 442
304 440
300 453
302 451
291 510
300 531
300 618
312 575
299 926
302 597
300 1410
297 1064
300 426
202 281
10 20 30 40 50 60 70 80 90 100
10 20 30
10 30 50 70 90
% total pollen and spores
KEY:
lithostratigraphy
peat
peaty clay
organic clay
clay or silty clay
composite
arboreal pollen
shrubs + herbs
gramineae + cyperaceae
aquatics
spores

FIGURE D3. LANGNEY POINT - DETERIORATION OF POLLEN FOR SELECTED TAXA

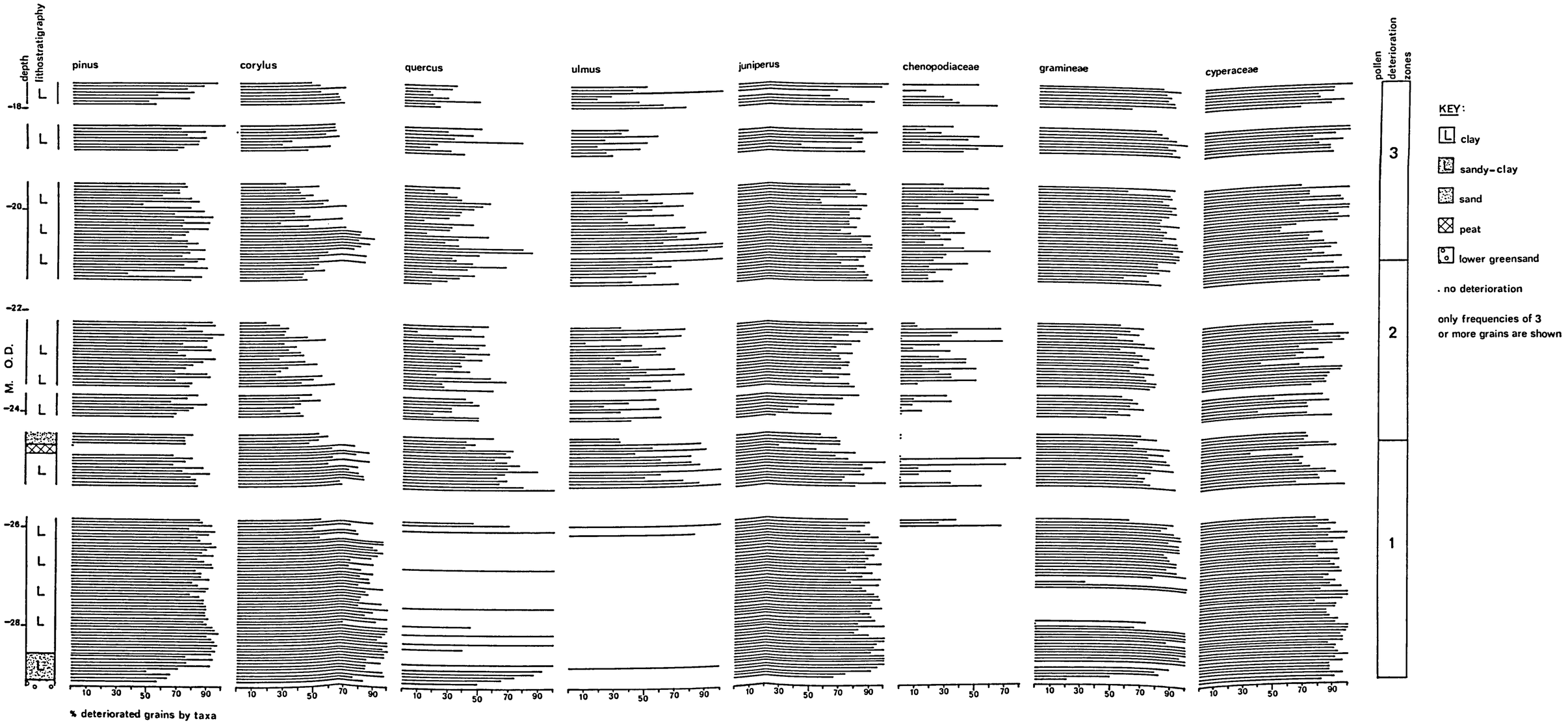
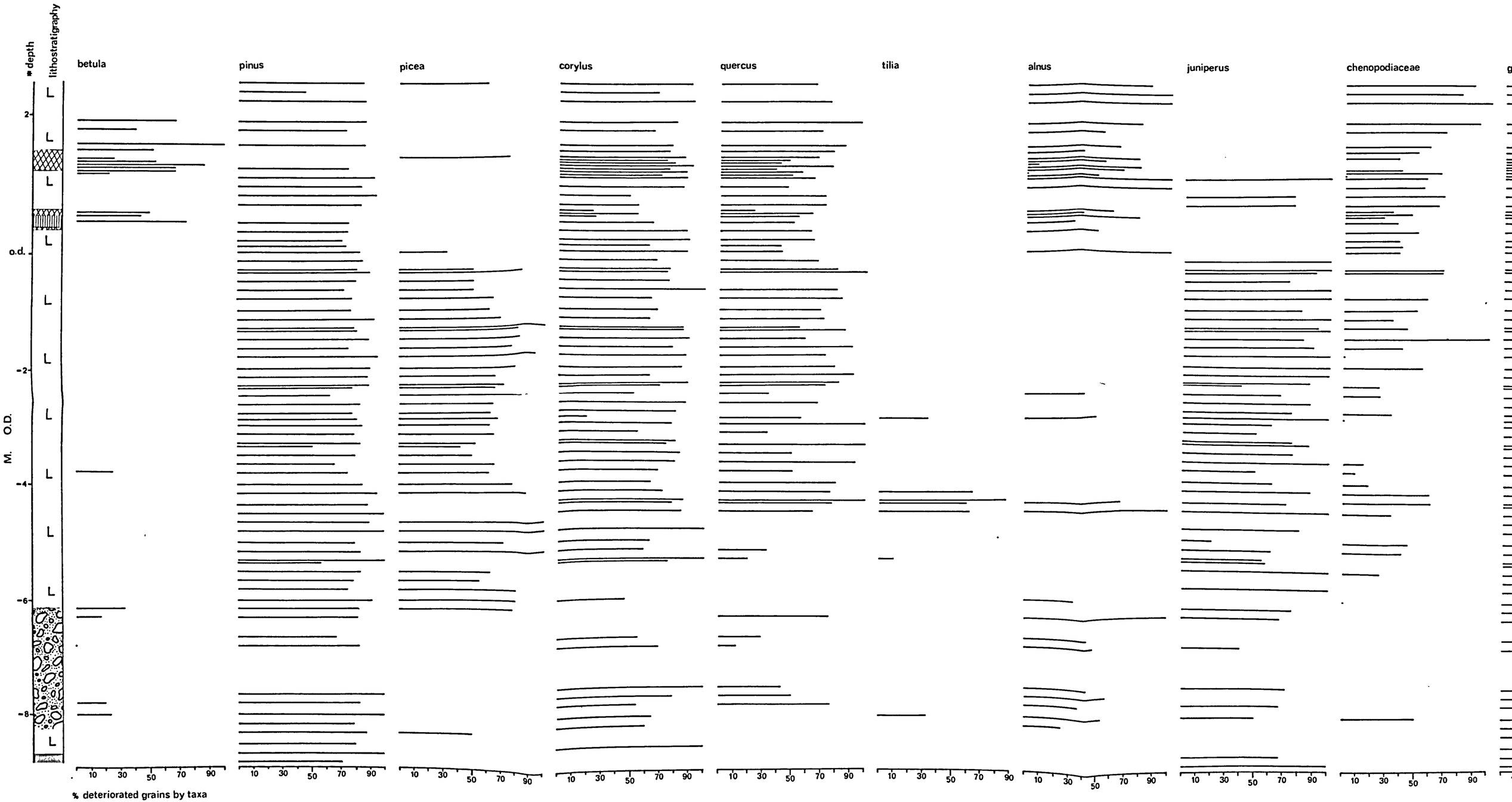


FIGURE D4. LOTTBRIDGE A – DETERIORATION OF POLLEN FOR SELECTED TAXA



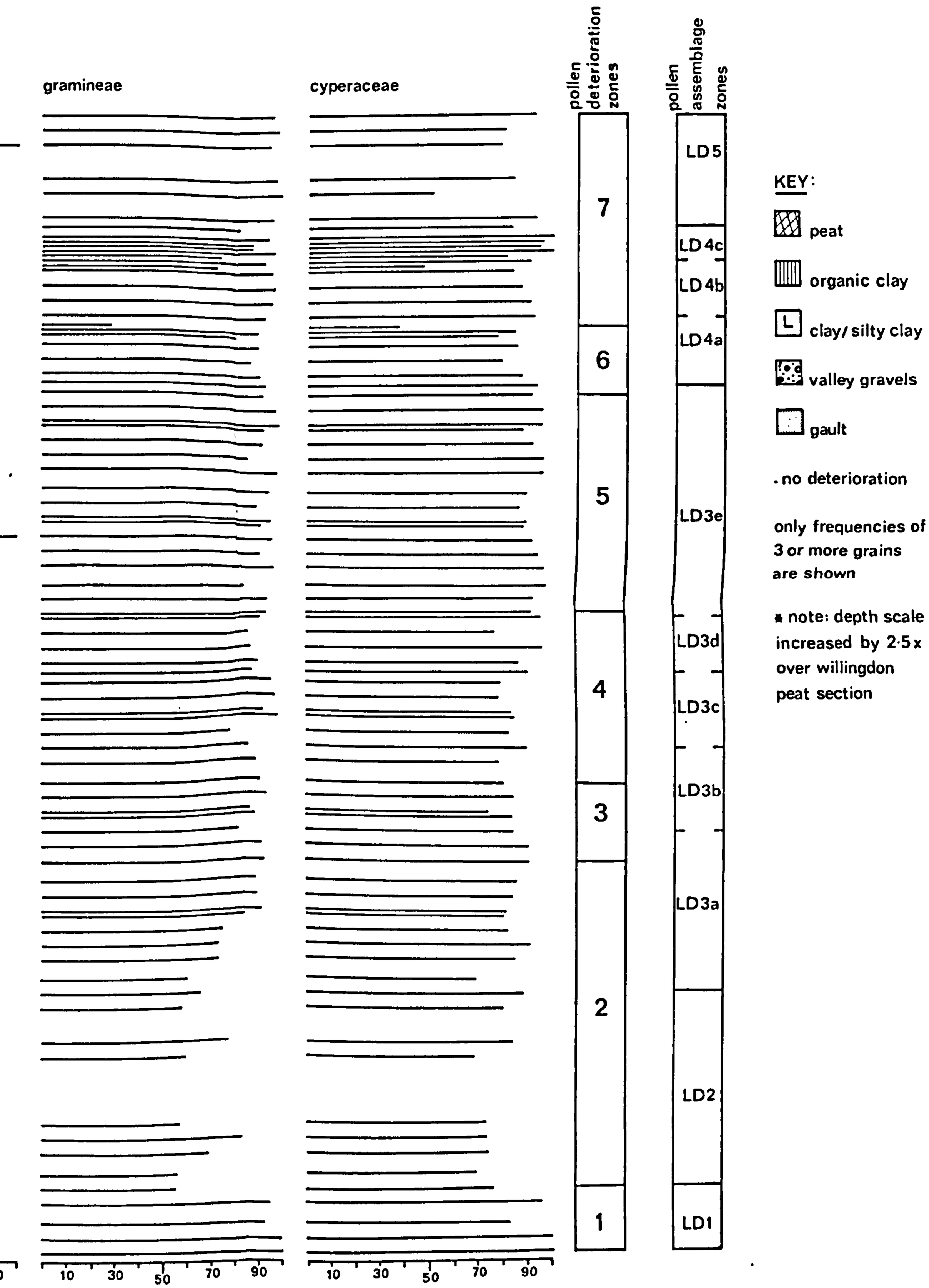

gramineae
cyperaceae
10
30
50
70
90
10
30
50
70
90
pollen deterioration zones
7
6
5
4
3
2
1
pollen assemblage zones
LD5
LD4c
LD4b
LD4a
LD3e
LD3d
LD3c
LD3b
LD3a
LD2
LD1
KEY:
peat
organic clay
L
clay/ silty clay
valley gravels
gault
. no deterioration
only frequencies of 3 or more grains are shown
* note: depth scale increased by 2·5 x over willingdon peat section

FIGURE D8. TYPES OF POLLEN DETERIORATION FOR SELECTED TAXA - LOTTBRIDGE A

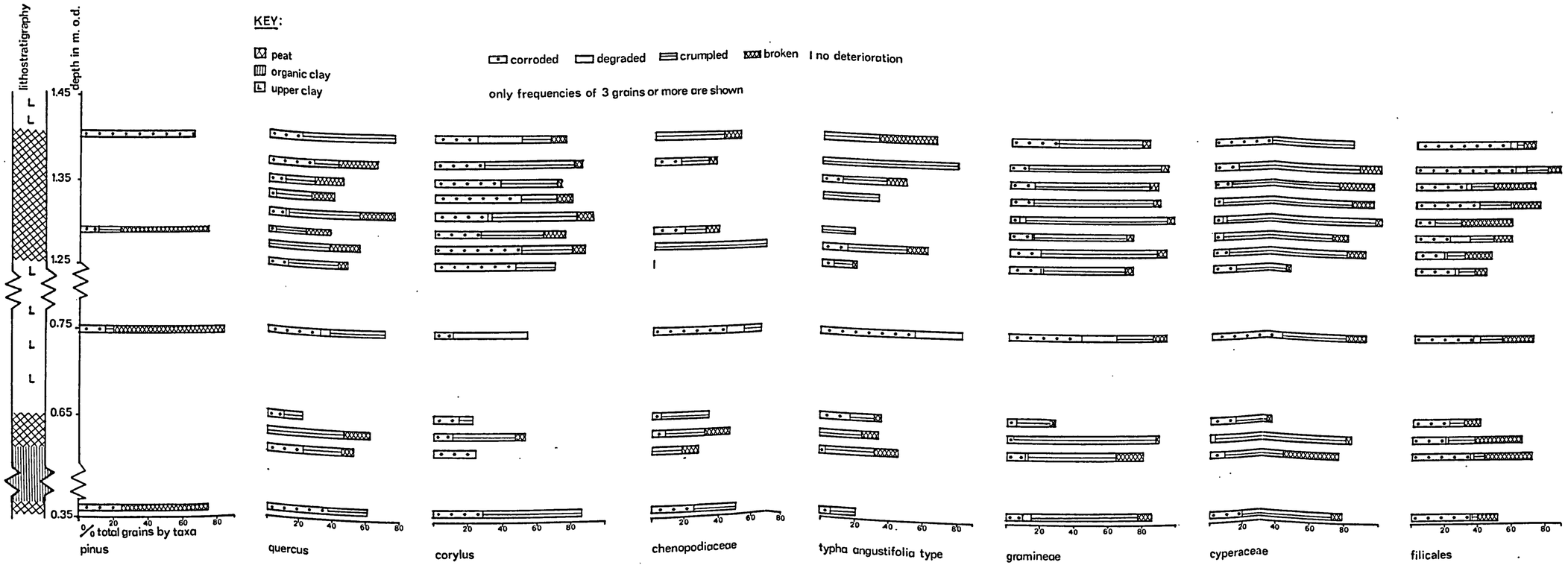
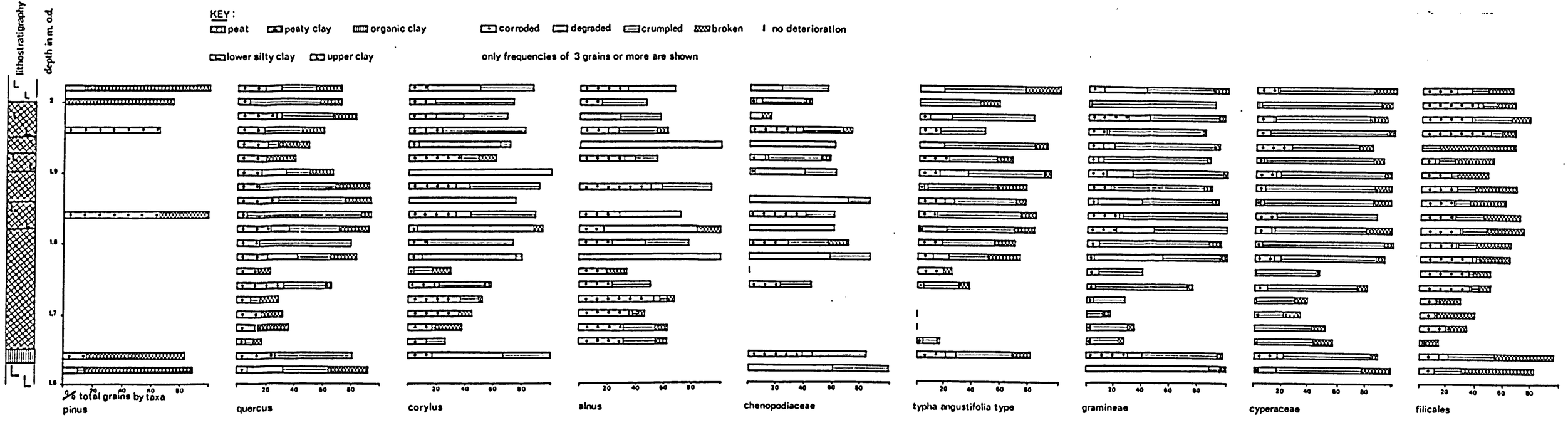



FIGURE D9. TYPES OF POLLEN DETERIORATION FOR SELECTED TAXA – LOTTBRIDGE B